Evaluation of the Hip

What Primary Care needs to know for endoscopic success

Oklahoma State University Health Sciences
Tandy Dedication Celebration
September 29, 2017

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Disclosure Slide

None

Presentation does not reflect policies of Baylor University Medical Center
Dallas, Texas
Did You Know...

**Bone and joint health problems are among the most prevalent and debilitating health challenges that many Americans face.**

Source: American Academy of Orthopaedic Surgeons

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Did You Know...

**More than 1 in 4 Americans has a musculoskeletal impairment**

Bone or joint pain:
- Caused more than one in 10 Americans to miss work in the past year
- Sent one-third of Americans to the doctor in the past year
- Is the reason why 440 million days of work are missed annually
- Causes more than half of all chronic conditions in people over age 50
- Is the leading medical cause of disability claims — 27.5% of new claims in 2015
- Caused 29% of all workplace injuries and illnesses that required time away from work in 2010

Demand for hip replacements will increase by 174% by 2030

Demand for knee replacements will increase by 674% by 2030

Source: American Academy of Orthopaedic Surgeons
Did You Know...

Musculoskeletal disorders cost the United States nearly $850 billion yearly.

Hands that can grasp again
Backs that can lift again
Knees that can walk again
Feet and ankles that can stand again
Shoulders that can work again
Elbows that can earn again
Hips that can move again

Source: American Academy of Orthopaedic Surgeons

Hip pain

— The source of the pain is not always the cause of the pain

— 60% of cases — the hip is not recognized as the source of symptoms

— 7 months — length of time from symptoms to diagnosis
Evolving field dynamics

- Anatomy
- Biomechanics
- Clinical exam
- Diagnostics
- Treatment
- Outcomes

WHERE ARE WE GOING

- ANATOMY
- BIOMECHANICS
- CLINICAL
- DIAGNOSTICS
- SURGICAL TREATMENT
- OUTCOMES
- ECONOMICS
- WHERE ARE WE GOING?
BACKGROUND

• Relative paucity of peer reviewed literature
  — 1st described by Burman in 30’s
  — Few selected case reports in the late 70’s and
    large increase in interest in 90’s

• Reasons for delayed interest
  — Lack of preceding of “equivalent” open
    procedures
    • Knee - open ACL/Shoulder - open Bankart repair
  — Hip - arthrotomy has traditionally been utilized
    for more advanced disease states (DJD)
ANATOMY OF LABRUM

- Acetabulum
  - Deep
  - Concentric

RECENT INTEREST

- Arthroscopic equipment adaptations have led to improved safety & visualization
- Improved surgical techniques
- Better understanding of anatomy and biomechanics of hip joint
- Improved imaging techniques
**Advantages of Hip Arthroscopy**

- Less invasive c/w arthrotomy
- Allows surgeon to address intraarticular derangements that were previously undiagnosed/untreated

**Early 1800s:**
- JC Warren, SD Gross, GA Otis, HJ Bigelow, CF Taylor, LA Sayer

**Late 1800s 85 papers Hip Joint**
- RH Sayer 1893 Treatment of Angular Deformity BMJ, AM Phelps, W Adams, R Davy, EG Brackett
- Amputation, Congenital Dislocation, Angular Deformities, Femoral Osteotomy, Excision of the Hip Joint, Fibrous Ankylosis
Hip Arthroscopic Treatments
Central Compartment

- Teres Debridement / Reconstruction
- Chondroplasty
- Microfracture
- Loose Bodies Removal
- Labral Debridement / Repair
- Mosaicplasty
- Labral Reconstruction
- Psoas Release
- Notchplasty

Hip Arthroscopic Treatments
Peripheral Compartment

- Femoroplasty
- Acetabuloplasty
- Capsulotomy
- Capsular Plication / Shift
- Synovectomy
- Loose Bodies
- Synovial Chondromatosis
- PVNS
- Lavage
- Biopsy
Hip Arthroscopic Treatments
Peritrochanteric Space

- ITB Release
- Gluteus Medius Debridement / Repair
- Gluteus Minimus Debridement / Repair
- Bursectomy
- ITB Repair
- Greater Trochanteric Bone Resection
- Hardware Removal

Hip Arthroscopic Treatments
Deep Gluteal Space

- Sciatic Nerve Decompression / Exploration
- Piriformis Release
- Quadratus Femoris Resection
- Ischium Boney Resection
- Obturator Internus Release
- Hamstring Repair
- Pudendal Nerve
- Lesser trochoplasty
Language of the Hip

- A. Anatomy/ alphabet
- B. Biomechanics / words
- C. Clinical Exam/ Reading words
- D. Diagnostics / Parsing
- T. Treatment/ Interpretation
- O. Outcome/ Communication of the idea(Pathology)
Example of a hip layered diagnosis.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Femoral head cam deformity</td>
</tr>
<tr>
<td>2</td>
<td>Capsular laxity and labral tear</td>
</tr>
<tr>
<td>3</td>
<td>Gluteus medius tear</td>
</tr>
<tr>
<td>4</td>
<td>Deep gluteal syndrome/sciatic nerve entrapment</td>
</tr>
<tr>
<td>5</td>
<td>Lumbar spine arthrodesis</td>
</tr>
</tbody>
</table>

Decision Making

Professor Daniel Kahneman – Princeton
Nobel Prize 2002

• Thinking Fast and Slow
• Thoughts differ in a dimension of accessibility
• Some come to mind much more easily than others
• Distinction between intuitive and deliberate thought processes
## Hip Score Questionnaires

<table>
<thead>
<tr>
<th>Questionnaire</th>
<th>Year</th>
<th>Target Population</th>
<th>Number of questions</th>
<th>Mode of administration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Merle D’Aubigne and Postel (18)</td>
<td>1954</td>
<td>Acrylic Hip Arthroplasty</td>
<td>3</td>
<td>Observer administered</td>
</tr>
<tr>
<td>Paris, France</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Harris Hip Score (11)</td>
<td>1969</td>
<td>Mold Hip Arthroplasty</td>
<td>8 + 2 observer measurements</td>
<td>Observer administered</td>
</tr>
<tr>
<td>Boston, United States</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WOMAC (19)</td>
<td>1988</td>
<td>Hip and Knee Osteoarthritis</td>
<td>24</td>
<td>Self-administered</td>
</tr>
<tr>
<td>London, Canada</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modified Harris Hip Score (12)</td>
<td>2000</td>
<td>Hip Arthroscopy</td>
<td>8</td>
<td>Observer administered</td>
</tr>
<tr>
<td>Nashville, United States</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAHS (20)</td>
<td>2003</td>
<td>Young adults (16 to 45 years) with hip pain more &gt; 6 moths</td>
<td>20</td>
<td>Self-administered</td>
</tr>
<tr>
<td>Bethesda, United States</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>iHOT-33 (14)</td>
<td>2012</td>
<td>Active adults (18 to 60 years) with hip pathology</td>
<td>33</td>
<td>Self-administered</td>
</tr>
<tr>
<td>MAHORN, international</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>iHOT-12 (15)</td>
<td>2012</td>
<td>The same of the iHOT-33</td>
<td>12</td>
<td>Self-administered</td>
</tr>
<tr>
<td>MAHORN, international</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Missing Important Historical Information

- Outcomes are related not just to the layers of the hip
- Cardiovascular Disease and Cancer

Spirit

Body    Mind

Goals of Hip Physical Examination

History Age

- Identify the hip from other sources of regional pain
  lumbar, pelvic, abdominal

  Diagnosis

  Osseous Layer 1
  Capsular/ Labral Diagnosis 2
  Musculotendinous Diagnosis 3
  Neuro vascular Diagnosis 4

- Common language and technique
The Physical Examination of the Hip Continues to Evolve

- What combination of tests
  - Martin 2005: Oper Tech Orthop 15:177-181
  - Test battery
  - Clohisy 2006: JBJS Vol 88-A 7: 1448-57 comprehensive inclusion of physical exam results in a case series
  - Langlotz 2007: CORR 458 117-24
  - ROM in FAI

The Pattern and Technique in the Clinical Evaluation of Adult Hip: The Common Physical Examination Tests of Hip Specialists

MAHORN GROUP
ARHTRO 26: 161-172
Physical Examination

• Standardization improves the physical examination reliability (Cibere, 2008)

• The most efficient order of examination
  – standing tests
  – seated tests
  – supine tests
  – lateral tests
  – prone tests


Most Frequent Tests Performed by
MAHORN Group Hip Specialists

STANDING POSITION
  Gait
  Single Leg Stance Phase Test
  Laxity

LATERAL POSITION
  Palpation
  Passive Adduction Test
  Abductor Strength

PRONE POSITION
  Femoral Anteversion Test

SUPINE POSITION
  Flexion ROM
  Flexion Internal Rotation
  Flexion External Rotation
  FADDIR Test
  DIRI
  DEXRIT
  Straight Leg Raise Against Resistance
  Passive Supine Rotation
  Palpation

Most Frequent Tests Performed by MAHORN Group Hip Specialists

**STANDING POSITION**
- Gait
- Trendelenburg
- Laxity

**SUPINE/SITTING POSITION**
- Flexion ROM
- Flexion Internal Rotation
- Flexion External Rotation

**LATERAL POSITION**
- Palpation
- Ober’s Extension
- ITB Abductor Strength

**PRONE POSITION**
- Craig’s Test

**Structured Physical Examination**
- 32 tests or group of maneuvers
- Assistant recording
The Standing AP Radiograph

1. Leg Length
2. Neck Shaft Angle
3. Trabeculae
4. Acetabular Inclination
5. Center Edge
6. Joint Space
7. Lateralization
8. Head Sphericity
9. Cup Depth
10. Anterior/Posterior Wall

Frog lateral
Nötzli HP et al. 2002.

42 ± 2.2° (33 a 48)
74 ± 5.4° (55 a 95)

Nötzli HP et al. 2002.
CT – Plain Radiography

- Substantial correlations between radiograph and CT were observed

Magnetic resonance

Position | Degrees of Motion Until Impingement
---|---
1. Internal rotation in 85° flexion | 14.4° ± 12.6 (1-45°)
2. Flexion | 101.9° ± 14.9 (78-129°)
3. Abduction | 56.3° ± 5.3 (39-69°)
4. Internal rotation in 85° flexion and 20° adduction | 5.7° ± 15.7 (19-40°)
5. External rotation in 75° flexion | 111.6° ± 25.0 (85-138°)
6. External rotation in 45° flexion abduction | 88.2° ± 37.9 (52-149°)
7. External rotation in neutral | 52.7° ± 15.9 (38-95°)

FADDIR
Lateral Rim Impingement

Deep Gluteal Syndrome (DGS)

Active Piriformis Test
Sensitivity 0.78
Specificity 0.80

Passive Piriformis Stretch Test
Sensitivity 0.91
Specificity 0.90

Ischiofemoral Impingement (IFI)

**Long Stride Walking**
Sensitivity 0.94
Specificity 0.85

**Ischiofemoral Impingement (IFI) Test**
Sensitivity 0.82
Specificity 0.85


Hamstring Avulsion

**Long Stride Heel Strike**
Sensitivity 0.55
Specificity 0.97

**Active 30°**
Sensitivity 0.73
Specificity 0.97

**Active 90°**
Sensitivity 0.70
Specificity 0.97


**COMBINED SN SP**
Why a structured general examination and not regional based examination? Wine / water

When it’s the Hip

- Osseous pain with PROM at end range motion abnormal ROM
- Capsular labral Laxity / Impingement
- Musculotendinous Contractures N/V
Keys to understanding the Hip

• Obtain a Comprehensive History
• Use a structured Physical examination
• Use a structured Radiographic examination
• Utilize specialized test
• Make a four layer diagnosis (OS, CL, MT, NV)
• Recognize multi-layer effect, fifth layer: Kinematic chain

Part II

An introduction to Hip Pathology

• Anterior Hip Pathology
• Lateral Hip Pathology
• Posterior Hip Pathology
Introduction to Anterior Hip Pathology

Treatment

• Cam and Pincer Impingment
• Psoas Impingment

Subspine Hip Impingement

Surgical Technique

Traction
Portal Placement
ARTHROSCOPIC ANATOMY

Central Compartment
Transverse capsulotomy

Outside-In Access
Outside-In Access

Removal of proximal synovium/capsule portion
Debride inner frayed zone

Thermal stabilizing
Release traction

Explore acetabular rim and initiate superior labrum margin release
Acetabuloplasty depending on the cup shape

Labrum repair techniques
Labrum Repair
Femoroplasty

• Depends on:
  – **Acetabular and femoral version**
  – Acetabular morphology and rim Trimming
  – Bone quality
  – Activities
  – Associated Instability

T Capsulotomy and retraction stitch
Fluoroscopic Dynamic Assessment

Pre

Post
Capsular closure

Peritrochanteric Space:
Disorders and Surgical Treatment
Tensor fasciae latae

Peritrochanteric Space

Greater trochanter facets


Bald Spot

Abductor strength
Arthroscopic Anatomy and Surgical Techniques for Peritrochanteric Space Disorders in the Hip
James E. Voos, M.D., Jonas R. Rudzki, M.D., Michael K. Shindle, M.D., Hal Martin, D.O., and Bryan T. Kelly, M.D.

Arthroscopy; vol 23, no 11
Greater Trochanter Bursectomy

Gluteus medius tear
Multiple techniques for Iliotibial band release


Iliotibial band release and GT plasty
GAIT > Posterior Pain?

Extension vs Flexion Hip Pathology

Sub Gluteal Space
FOUR SOURCES OF POST EXTRAARTICULAR HIP PAIN
Intrapelvic Differential Diagnosis
Hamstring Tear

Ischiofemoral Impingement
Hip Extension is Important!
The Endoscopic Treatment of Sciatic Nerve Entrapment/
Deep Gluteal Syndrome

Hal D. Martin, D.O., Shea A. Shears, B.S.N., R.N.
, J. Calvin Johnson, M.D.,
Aaron M. Smathers, M.S., and Ian J. Palmer, Ph.D.

Arthroscopy
Vol 27, No 2
Feb 2011
Differential Diagnostic Considerations

- Pain location and which activity
- Posterior
  Medial to Ischium $\rightarrow$ Pudendial Nerve
  Lateral to Ischium $\rightarrow$ HS vs IFI
  30 degree vs 90 HS active test $\rightarrow$ HS
  Long stride/ short stride, IFI test in ext $\rightarrow$ IFI
- Posterior Superior
  DGS $\rightarrow$ Active/ Passive piriformis test

Part III

- Key to guide the A, B, C, >> D of field development
ACETABULAR LABRAL TEAR AFFECTS ON ILOFEMORAL LIGAMENT LENGTH AND ROTATORY INSTABILITY TEST
MARTIN, PLAKSEYCHUK, PHILIPPON

- TEN CADAVERS EXPOSED LIGAMENTS
- FIXATION POINTS WITH THE MICROSCRIBE RECORDED IN A NORMAL HIP ROM AND ABEER PERFORMED THROUGH A GRID
- AN ACETABULAR LABRAL TEAR WAS CREATED, FOLLOWED BY EXCISION OF 2CM, THE LENGTH WAS RECORDED
- MEDIAL ARM 6.25% INCREASE WITH TEAR
- MEDIAL ARM 12.2% INCREASE WITH EXCISION
- PLICATION DECREASE 8% IN LENGTH

Presented UPMC 2002
The Function of the Hip Capsular Ligaments

- 12 matched pairs of fresh frozen cadaver
- 6 males / 6 females average age 62 yrs
- Motion of the hip was measured in internal and external rotation through a neutral wing path 10 degrees extension to 30 flexion
- Then released the ligaments to determine the contribution of each to the control of internal / external rotation at each flexion/extension angle

Intra-operative Findings

- 2 labrum adhered to ischiofem lig
- 1 thin anterolaterally
- 41 specific tears/locations

Origin and Insertion of the Dominant Anterior Ligaments
Martin et al. Arthroscopy 2008

Orbicular Ligament (Black arrows)
Intertrochanteric Crest, Insertion of Lateral Iliofemoral Ligament
Intertrochanteric Knob, Insertion of Medial Iliofemoral Ligament
Iliopectineal Eminence, Insertion of Pubofemoral Ligament

Oribicular Ligament (Black arrows)
Teres Ligament Function

An Anatomical Model for Function of the Ligamentum Teres

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Assistant Professor
Department of Physical Therapy
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Pittsburgh, PA

Benjamin R. Kivlan PT, OCS, SCL, CSCS
John G. Rangos Sr., School of Health Sciences
Duquesne University
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F. Richard Clemente, Ph.D., PT,
Assistant Professor
Department of Physical Therapy
Duquesne University
Pittsburgh, PA

Hal D. Martin D.O.
The Hip Clinic
Oklahoma Sports Science and Orthopedics
Oklahoma City, OK
THE FUNCTION OF THE LIGAMENTUM TERES AND THE CLINICAL FINDINGS ASSOCIATED WITH COMPLETE LIGAMENTUM TERES TEARS

Hal D Martin, DO; Oklahoma City, OK
RobRoy Martin, PhD, PT, CSCS; Pittsburgh, PA
Kody King, DO; Tulsa, OK
Douglas P Beall, MD; Oklahoma City, OK
Ian J Palmer, PhD; Oklahoma City, OK

The Function of the Ligamentum Teres in Limiting Hip Rotation: A Cadaveric Study

Arthroscopy, 2013

Martin HD, Hatem M, Kivlan BR, Martin RL
FEMORAL NECK VERSION

AVERAGE = 15.97 Degrees
Max = 39 Degrees
Min = 0 Degrees

DOES DECREASED FEMORAL VERSION INFLUENCE PELVIS AND LUMBAR KINEMATICS DURING GAIT?

HD Martin, RG Schroder, IJ Palmer, M Hatem
Baylor University Medical Center

LUMBOPELVIC AND HIP MOTION

Pelvic alignment affecting spinal pathology

- Legaye et al (1998) define pelvic tilt as the angle between the line connecting the midpoint of the sacral plate to the femoral heads axis and the vertical axis.

- According to Herrington (2011), asymptomatic (normal) patients exhibit anterior tilt of about 6-7° while standing.
Treat the hip help the spine??
- Effects of femoral version on dynamic spine mechanics
- Soft tissue contracture effects on IDP
- Osseous blocks to hip extension effects on spinal facet pressure

**Hip-Spine Syndrome**

- Limited hip Extension = Low back pain
  - Decreased Femoral neck version ✔
  - Ischiofemoral Impingement ✔
  - Iliopsoas flexion contracture ?
  - Coxa Profunda ?
  - Hip extensor weakness ?
  - SI joint ?
Hip-Spine Syndrome
Kinematics of the Sciatic Nerve: A Cadaveric Study

Martin HD, Martin RL, Kivlan BR, Palmer IJ, Hatem M.

IN Print Journal of Hip Preservation Surgery
One layer effects all others

Treatment Options

Non-surgical
- Physical therapy
- Steroid injections
- Medication
- Cane/crutch

Surgical
- Open Hip
- Arthroscopic

Diagnostic
Therapeutic

[Images of medical scans showing hip structures]
Advancements in Orthopaedic Surgery

Hips are catching up to knees and shoulders in terms of treatment options

Hip joint is deeper = harder to access

New technology (arthroscopic) allows for more advanced, less invasive procedures

“The Final Frontier”

Body + Mind + Soul = Wellness

Mind

Soul

Body

Wellness
Research in Hip Preservation and Treatment of Hip Pain

15 Book Chapters

ONE BOOK!

72 Papers

109 Lectures Worldwide

Biologics

- Autologous Matrix-Induced Chondrogenesis (AMIC)
- Autologous Chondrocyte Implantation (ACI)
- Microfracture
- Autologous Osteochondral Mosaicplasty (Osteoarticular Transfer System: OATS)

Bedi et al. JBJS [Am], 2010
Hangody et al. JBJS [Am], 2004
Williams 3rd et al. JBJS [Am], 2007
Horas et al. JBJS [Am], 2003
Bodi et al. JBJS [Am], 2010
Humby et al. JBJS [Am], 2004
Computer Navigation

Schnurr et al. Int Ortho, 2009
Kelley & Swank JBJB [Am], 2009
Diagnostics

- EMG
- Comp Nav

Clinical Imaging 32 2008
Summary

1) History and Physical Exam Key to Understanding anatomy and biomechanics critical to successful Endoscopic/Arthroscopic Surgery

2) Introduction to the endoscopic and arthroscopic treatment of anterior, lateral and posterior hip pathology

3) Current research application and advancement from BR1 of hip anatomy, biomechanics and clinical application
**Hip Preservation Center Publications**

**Books**

- **Posterior Hip Disorders: Evaluation and Treatment.** Author and Editors: HD Martin & J Gómez-Hoyos. Springer (In Progress)


**Papers**


- Ischiofemoral Impingement: Defining the Lesser Trochanter-Ischial Space. *KSSTA* 2016. (Accepted, in Press). Kivlan B, Martin RL, Martin HD.

• Accuracy of two clinical tests for ischiofemoral impingement in patients with posterior hip pain and endoscopic-confirmed diagnosis. Arthroscopy 2015. (Accepted, In Proof) Gómez-Hoyos J, Martin RL, PhD; Schröder RG, Palmer UI, Martin HD.

  – Mini Symposium Introduction. Martin HD.
  – Laparoscopic Approach to Intrapelvic Nerve Entrapments. Lemos N, Posover M.
  – Endoscopic Hip Osteotomies: Less invasive approaches to peri-acetabular, proximal femoral, and pubic symphyseal procedures. Matsuda D.
  – Hamstring Injuries. Guanche CA.


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•  *JHPS Comment*: *JHPS* Authors. What the Papers Say. *JHPS* 2015;2(1):84-86. “JHPS has selected six recent and topical articles for those who seek a brief summary of what is taking place in our ever-fascinating world of hip preservation.”
  

  

  

  
  – Comment on two articles:
    
      
    
  – Physical Examination of the Hip
  – Extra-Articular Posterior Hip Pain
  – Hip Arthroscopy and Patient Selection. Who is at risk of a poor outcome?
  – Ligamentum teres
  – Moderator: Groin and Posterior Hip
  – Disorders of the Peritrochanteric and Deep Gluteal Space
  – Extra-Pelvic Posterior Hip Pain and Sciatic Nerve Entrapment
  – Evolving Technique Update: Hip Exam is 4.5 or 15 min? How I Decide
  – Moderator: Mini Debate The Use of Diagnostic Injections
  – Moderator: Q&A with Case Presentations
  – Hip Physical Exam
  – Clinical Cases
  – History/Physical Exam and Diagnosis of Hip Pathology
  – Hip Spine Syndrome

  – Moderator: Posterior Compartment
  – Basic Science of the Ligamentum Teres and its Role in Hip Biomechanics
  – Sciatic Nerve and Deep Gluteal Syndrome
  – Ischiofemoral Decompression – Video with Q&A
• Juan Gomez-Hoyos (Presenter)
  – Iliopsoas tendon insertion footprint with surgical implications in lesser trochanterplasty for treating ischiofemoral impingement: an anatomic study.
  – Accuracy of two clinical tests for ischiofemoral impingement in patients with posterior hip pain.
  – The relationship of femoral neck version and lesser trochanter version with endoscopically confirmed extra-articular hip impingement.
• E-Poster
  – The Effects of Hip Abduction on Sciatic Nerve Biomechanics During the Kicking Motion.
  – Does Decreased Femoral Version Influence Pelvis and Lumber Spine Kinematics During Gait?
  – Arthroscopic acetabuloplasty and labrum repair without traction: outcomes.
• Brazil Hip Congress XVI – Fortaleza, Brazil. September 2-5, 2015.
  – Kinematics Implications for Hip-Spine Syndrome
  – Diagnosis and Treatment of Extra-Articular Posterior Hip Pain
  – Peritrochanteric Space Disorders
• Smith & Nephew Advanced Fellows Course – Austin, TX. May, 2015.
  – Clinical Examination of the Hip
  – Ischiofemoral Impingement
  – Deep Gluteal Syndrome
• Texas A&M Health Sciences Center College of Medicine Research Symposium. April 28, 2015. Dallas, TX
  – Best Podium Presentation - Femoral Neck Anteversion and Lesser Trochanteric Retroversion in Patients with Ischiofemoral Impingement – A Case-Control Study. Reddy MP (Presenter), Gomez-Hoyos I, Schnider HG, Palmer IL, Martin JD.
• OLC AOSSM Surgical Skills Course – Rosemont, IL. April, 2015.
  – Deep Gluteal Space Syndrome
  – Iliopsoas: When and how to release it and when to leave it alone
  – Treatment Algorithm: Static and Dynamic Overload.
• Hughston Society Meeting. Columbus, GA. April, 2015.
  – Posterior Hip, Unusual Pathologies.
  – Poster Presentation. Iliopsoas releasing: Defining the ischial lesser trochanteric space. Martin HD, Martin RL.
  – Moderator: Hot Topics
  – The hip exam
  – Ligamentum teres
  – Deep gluteal pain syndrome.
• OSET Orthopaedic Summit. Las Vegas, NV. December 2014.
  – Diagnostic Tests to Succeed in Hip Arthroscopy
  – Hip patient evaluation and op set up Q&A
  – Mini-Debate: Psoas Snapping. Please no releases. It’s a secondary mechanical problem
  – Subgluteal Space/Sciatic Nerve Entrapment
  – Hip Dilemmas Q&A
  – Hip Arthroscopy without Traction-All my colleagues are completely wrong
  – Sage Advice for Hip Arthroscopy - Faculty’s One Tip!
  – Capsule and Ligaments - how they contribute to Stability
  – Physical Exam - What is Important?
  – Subspinal AIS. Resection with and without Rectus Detachment
  – Gluteal and Iliac Space - Piriformis and hamstrings.
  – Soft tissue causes of hip pain: Gluteus Medius Tears and nerve entrapment syndromes
  – Managing soft tissue pain. 3 cases illustrating GM diagnosis and repair
• ANNA Fall Meeting 2014. Palm Desert, CA. November 6-7, 2014
  – Subgluteal Space Endoscopy
  – Hip Model Lab
  – Moderator: ICL Periarticular Endoscopy The Peritrochanteric Space
  – Instability resulting in extra-articular impingement
  – How I address ili iliofemoral Quadratus approach
  – IFI discussion
• Harvard Medical School. 44th Annual Course: Advances in Arthroplasty. Boston, MA. October 2014.
  – Hip Pain. Pearl to Determine that it is from the Joint
  – Moderator: Open and Arthroscopic Rx of Hip Deformities
  – Physical Examination of the Hip
• American Academy of Orthopaedic Surgeons Annual Meeting, New Orleans, LA. March, 2014
  – Endoscopic Treatment of Iliacofemoral Impingement, Poster Presentation – HD Martin, U Palmer, M Hatem (Presenter)
  – Hip Exam
  – Posterior Hip Endoscopy
  – Role of the Capsule and Ligamentum Teres in Hip Stability.
  – Clinical Evaluation of the Hip, Mini-Battle on portals, Capsular release: Central First – Capsulotomy Better
  – Moderator: Extra-Articular Hip Arthroscopy
  – Nerve Iliacosacue Release: Indication and Technique
  – Gluteus Medius Repair.
• XLVII Congreso Chileno de Ortopedia y Traumatologia. Vina del Mar, Chile. November, 2013.
  – Sciatic Nerve Release: Results
  – Anterior Approach
  – Hip Arthroscopy: My Approach/Vision
  – AVN Options: Vascularized Fibrilar Graft
  – My Worst Case
An Introduction to Research in Hip Preservation

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Anatomic and structural evaluation of the hip: a cross-sectional imaging technique combining anatomic and biomechanical evaluations


Abstract

To describe a technique of cross-sectional imaging of the adult hip designed to evaluate for anatomic anomalies that may predispose to internal derangement in addition to the routine anatomic assessment. Magnetic resonance (MR) imaging, MR arthrography, and multidetector computed tomography (MDCT) scanning protocols utilize high-resolution imaging, and the surrounding anatomy is also assessed using these scanning techniques. Various measurements may be obtained to assess the overarching anatomic configuration including the caput collum diaphysis angle, the femoral angle of torsion, the acetabular angle of torsion, the center edge angle, and the femur length.

Keywords: Magnetic resonance imaging; Computed tomography; Magnetic resonance arthrography; Multidetector computed tomography; Adult hip

1. Introduction

The imaging evaluation of the adult hip has traditionally centered on evaluating such pathologic processes as avascular necrosis, arthritis, acetabular labral tears, trauma, tumors, and unexplained hip pain [1,2]. This evaluation process has been primarily an anatomic assessment in an attempt to search for posttraumatic derangements, arthritic cartilage wear, or infiltrative/destructive processes, and the magnetic resonance (MR) imaging technique is reflective of this assessment [3–6]. While an optimal MR imaging technique is essential in the evaluation for intra-articular and periarticular pathology, there is growing evidence that basic structural or congenital anatomic configurations give rise to or predispose the patient to certain types of pathology such as femoroacetabular impingement (FAI), acetabular labral tears, and articular cartilage damage [7,8].

Our imaging protocols for MR imaging and computed tomography (CT) scanning include mechanisms for the evaluation of the basic structural components likely to produce aberrant biomechanical movements that may cause or predispose the patient to various types of pathology in addition to the routine portions of the protocol designed for anatomic evaluation of intra-articular or periarticular pathology. This dual focus on pathology and the structural designs that are likely to produce biomechanical alterations that produce the pathology may allow for treatment of the...
patients’ underlying cause for their derangements as well as their specific derangement itself.

2. MR Arthrography

Magnetic resonance arthrography is a very useful technique in the evaluation of the hip joint and surrounding anatomy, especially the capsulolabral structures and articular cartilage [3]. The primary indications for MR arthrography are for the evaluation of the capsuloligamentous structures, the acetabular labrum, and for intra-articular loose bodies. Direct arthrography involves the injection of saline mixed with a small amount (0.1–0.2 ml) of gadolinium (i.e., gadopentetate dimeglumine) into the hip joint via a small bore needle. The most significant advantage of direct MR arthrography is the ability to achieve adequate capsular distension which allows the intra-articular anatomy to be optimally delineated by the contrast mixture that is injected into the hip joint. Although most authors advocate the use of direct arthrography when evaluating the hip joint (especially to detect acetabular labral and articular cartilage abnormalities), direct MR arthrography is invasive, is more expensive than routine MR imaging of the hip, and the injection exposes the patient to ionizing radiation during the fluoroscopic placement of the needle. Additionally, the fluoroscopy and MR imaging schedules must be coordinated to allow for an effective transition of the patient to the MR imaging suite after the injection.

Our direct MR arthrography protocol (Table 1) is designed to take advantage of the optimal signal-to-noise ratio produced by the T1-weighted images, and fat saturation is applied to increase the conspicuity of the injected gadolinium. A small field of view (FOV) is used so the resolution of the images produced is sufficient to allow the scrutiny of some of the smaller structures such as the articular cartilage.

Table 1
Protocol for MR arthrography of the hip

<table>
<thead>
<tr>
<th>Primary sequences</th>
<th>Plane</th>
<th>Sequence</th>
<th>Coil</th>
<th>FOV</th>
<th>Slice</th>
<th>Matrix NEX</th>
<th>TR</th>
<th>TE</th>
<th>Flip angle</th>
<th>Band</th>
<th>ETL</th>
<th>Fat suppressed?</th>
<th>Other</th>
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</thead>
<tbody>
<tr>
<td>Localizer</td>
<td>Triplanar GRE Torso 40 7/2 288/128 2 175 Min-full 20 16 – N</td>
<td>2D, GRE, S/I auto</td>
<td>2D, SE, NPW, SAT:S, I, 12 slices, R/I auto</td>
<td>2D, SE, NPWFC, FAS T15 slices, S/I, PC auto freq</td>
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<tr>
<td>2 Axial</td>
<td>Axial T1 SE Torso 20 4/0.5 288/192 2 400 Min-full – 16 – Y</td>
<td>2D, NPW, SAT:S, I, 15 slices, S/I auto</td>
<td>NPW, 14 slices, A/P auto</td>
<td>2D, SE, NPW, SAT:S, I, 12 slices</td>
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<tr>
<td>3 Coronal</td>
<td>Coronal T2 FSE Torso 20 4/0.5 288×256 4 3425 34 – 16 12 Y</td>
<td>2D, NPW, SAT:S, I, 15 slices, S/I auto</td>
<td>NPW, 14 slices, A/P auto</td>
<td>2D, SE, NPW, SAT:S, I, 12 slices</td>
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<td>4 Coronal</td>
<td>Coronal T1 SE Torso 20 4/0.5 288×192 2 400 Min-full – 16 – Y</td>
<td>2D, NPW, SAT:S, I, 15 slices, S/I auto</td>
<td>NPW, 14 slices, A/P auto</td>
<td>2D, SE, NPW, SAT:S, I, 12 slices</td>
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<tr>
<td>5 Sagittal</td>
<td>Sagittal T1 SE Torso 20 4/0.5 288×192 2 400 Min-full – 16 – Y</td>
<td>2D, NPW, SAT:S, I, 15 slices, S/I auto</td>
<td>NPW, 14 slices, A/P auto</td>
<td>2D, SE, NPW, SAT:S, I, 12 slices</td>
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<tr>
<td>6 Oblique axial</td>
<td>Oblique axial T1SE Torso 20 4/0.5 288/192 2 400 Min-full – 16 – Y</td>
<td>2D, NPW, SAT:S, I, 15 slices, S/I auto</td>
<td>NPW, 14 slices, A/P auto</td>
<td>2D, SE, NPW, SAT:S, I, 12 slices</td>
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<tr>
<td>7 Oblique sagittal</td>
<td>Oblique sagittal T1SE Torso 20 4/0.5 288×192 2 400 Min-full – 16 – N</td>
<td>2D, NPW, SAT:S, I, 15 slices, S/I auto</td>
<td>NPW, 14 slices, A/P auto</td>
<td>2D, SE, NPW, SAT:S, I, 12 slices</td>
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<tr>
<td>Knees</td>
<td>Knees Axial or triplanar GRE Body 40 7/2 288/128 2 175 Min-full 70 64 – N</td>
<td>2D, GRE, S/I auto</td>
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</table>

Special instructions
Sequence 1: Both hips and surrounding soft tissues in view.
Sequence 2–7: Small FOV over hip of interest.
Sequence 6: Oblique axial plane oriented parallel to the femoral neck. Coverage is from superior portion of the greater trochanter to the inferior portion of the lesser trochanter.
Sequence 7: Oblique sagittal plane oriented perpendicular to the femoral neck. Coverage is from femoral head to intertrochanteric line.
Localizer 2: Done through the knees using the body coil.
Note: It is important to orient Sequences 6 and 7 parallel and perpendicular to the orientation of the femoral neck it is important to place the patients leg/foot in neutral rotation (toes up).
Employ respiratory compensation if breathing artifact is present.
and acetabular labrum. A T2-weighted coronal sequence (Series 3 in Table 1) is obtained to allow improved conspicuity of nongadolinium fluid-filled structures such as bursae (as is seen in bursitis) and within the tendons (as is seen with gluteus tendon tears). The fat suppression is not applied on the T1-weighted oblique sagittal images (Series 7 in Table 1) so as to allow for the evaluation of the fat containing marrow. The marrow evaluation of nonfat suppressed marrow is optimal for fractures, avascular necrosis, and marrow replacement processes as is seen with infection or tumors [9]. The triplanar localizer (Series 1 in Table 1) is obtained through the pelvis to allow for appropriate prescription of the slice positions for the smaller FOV sequences and to serve as a reference for calculations of the acetabular and femoral anteversion (Figs. 1A, B and 2A, B). One of the coronal imaging sequences (Series number 1, 3, or 4 in Table 1) is used to calculate the center edge angle (Fig. 3). The axial oblique sequence (Series 6 in Table 1) is obtained by prescribing the slices along the center axis of the femoral neck (Fig. 4) and allows calculation of the alpha angle (Fig. 5). This sequence prescription is done from the coronal plane as is the oblique sagittal sequence (Series 7 in Table 1). This series is obtained to evaluate the symmetry of the femoral neck, especially at the femoral head–neck junction (Fig. 6). The coronal portion of the triplane localizer sequence (Series 1 in Table 1) can also be used to calculate a caput collum diaphysis (neck-shaft) angle (Fig. 7). In some cases, calculation of the femoral lengths may be a helpful adjunct to the routine MR imaging protocol. These images are obtained by using the body coil, a large FOV, and by making sure the patient is positioned appropriately so the entire length of the femur can be obtained on a single coronal image.
Fig. 3. Coronal T1-weighted MR image obtained through the center of the left femoral head shows the method of calculating the center edge angle with lines drawn vertically through the center of the femoral head (black arrow) and from the center of the femoral head to the superolateral margin of the osseous acetabulum (white arrow). The resulting angle (white arc) is the center edge angle (normal adult values <26–30°).

(Fig. 8). Radial images through the acetabular labrum have also been used to assess the labrum, but we do not include this as part of our current protocol [10].

3. MR imaging without contrast

Most of the existing literature supports the use of direct arthrography for the evaluation of the acetabular labrum and articular cartilage and has reported sensitivities and specificities of 30% and 36%, respectively, compared to values in the 90% range and higher with direct MR arthrography [11–14]. These studies, however, have not compared optimized noncontrast MR imaging with direct MR arthrography (Table 2). It has been recently demonstrated that noncontrast MR imaging of the hip is diagnostically useful, is noninvasive, and, if optimized for detection of intra-articular pathology, may be diagnostically comparable to direct MR arthrography [4]. This article described a noncontrast MR imaging evaluation of 92 patients and compared it to the pathology detected at hip arthroscopy. Tears of the acetabular labrum were detected 94–95% of the time (as compared to tears detected at hip arthroscopy) and 86–92% of articular cartilage lesions were correctly graded.

Fig. 4. Coronal T1-weighted MR image through the center of the femoral head shows the method of calculating the center edge angle with lines drawn vertically through the center of the femoral head (black arrow) and the orientation of the slices that will produce the oblique axial images (dotted black line).

Fig. 5. Oblique axial T1-weighted MR image with fat suppression shows the method of calculating the alpha angle. The oblique axial images are produced from the prescribed slices shown in Fig. 4. The alpha angle is obtained by drawing a line down the center of the femoral head and neck (white arrow) and a circle around the periphery of the femoral head (black arrowhead). The second line is drawn from the center of the femoral head to where the anterior osseous femur intersects the circle drawn around the femoral head (black arrow). The angle that is produced by the intersection of the lines is the alpha angle (white arc). Normal values of the alpha angle are less than 55°.

Fig. 6. Oblique sagittal T1-weighted MR image. This image is oriented perpendicular to the oblique axial image shown in Fig. 5 and is designed to assess the circularity of the femoral neck. Any deviation from circular (extension of the osseous femoral neck) outside the circle drawn around the femoral neck in the subcapital location is identified (black arrow) and the amount of deviation from circular is measured in millimeters.
This level of accuracy with noncontrast MR imaging of the hip is substantially better than previously reported noncontrast studies [11].

This increased level of accuracy is likely due to imaging sequences that are optimized for evaluation of the acetabular labrum and articular cartilage. These noncontrast MR imaging sequences also use surface coils and a small FOV. An important component of this evaluation is the high resolution that is attained by combining matrices ranging from 512×256 to 512×384 with small FOVs (15 to 17 cm). This produces an in-plane resolution of 330–442 μm. An important feature of this protocol is the use of a fast spin echo proton density sequence that is effective at maximizing the signal difference between the synovial fluid and articular cartilage.

4. Computed tomography imaging protocols

Multidetector CT (MDCT) is also useful for evaluating the osseous structures and surrounding soft tissues of the hip and pelvis (Table 3). The strengths of the MDCT evaluation relate to the isotropic multiplanar reconstruction capability, the ability to optimally display the osseous structures, and its resistance to metallic streak artifacts.

Multidetector CT is capable of producing volumes of data that have the same resolution in the longitudinal axis (z-axis) as in the x- or y-axis. This ability produces voxels that are isotropic and the volume of data may therefore be reconstructed in any plane with the same resolution as the original imaging plane. The hip is scanned from the superior portion of the iliac crest to the tibial tubercles (Fig. 9). This extensive acquisition allows assessment of the femoral and/or acetabular anteversion along with the other measurements described previously (i.e., caput collum diaphysis angle, the center edge angle, and the femoral length). Measurements that allow the calculation of McKibben instability index are also easily obtained. This index is calculated as the sum of the angles of femoral and acetabular anteversion and may be used to estimate the potential for osteoarthritis (low McKibben index grade) or femoroacetabular instability (high McKibben index grade) (Table 4) [15]. Both low and high McKibben indices have been associated with pain [15].

The volume assessment also allows for an overarching view of the anatomy and is effective at demonstrating the pelvic and hip anatomy and their special relationship. The three-dimensional reconstructions that are available with MDCT are easily performed, are of high quality, and may be helpful for evaluation of both routine and complex skeletal diseases (Fig. 10) [16].
Multidetector CT is useful in assessing preoperative and postoperative anatomy in patients who have dysplastic and posttraumatic conditions of the hip and pelvis that require repair with appropriate attention to the acetabular version, femoral version, coverage of the femoral head, and anatomic appearance of the femoral head–neck junction. Conditions such as developmental dysplasia of the hip (DDH), slipped capital femoral epiphysis, and FAI may predispose the patient to long-term functional difficulties due to either a congenital dysplasia or an acquired bony deformity. The multiplanar formatting provides for an effective assessment of alignment of the proximal femur and acetabulum, and the CT assessment of the osseous anatomy is optimal.

In addition to the osseous anatomy, the articular cartilage and acetabular labrum may also be assessed with CT arthrography (Fig. 11). Computed tomographic arthrography is often performed in conjunction with MR arthrography as the iodinated contrast material may be added to the hip joint as part of the mixture (20–50% by volume) in the 1:200 dilute gadolinium mixture. The MDCT examination of the hip, in comparison with the MR imaging examination, is much faster and only requires a few minutes. This allows the examination to be performed in conjunction with an MR arthrogram as the patient may be taken directly from the CT scanner to the MRI machine.

### Table 2

<table>
<thead>
<tr>
<th>Primary sequences</th>
<th>Plane</th>
<th>Sequence</th>
<th>Coil</th>
<th>FOV</th>
<th>Slice</th>
<th>Matrix NEX</th>
<th>TR</th>
<th>TE</th>
<th>Flip angle</th>
<th>Band</th>
<th>ETL</th>
<th>Fat suppressed?</th>
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<tr>
<td>Localizer</td>
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<tr>
<td>1</td>
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<td>Body</td>
<td>48</td>
<td>15/0</td>
<td>256/128 0.75</td>
<td>34</td>
<td>Min-full</td>
<td>30</td>
<td>20.85</td>
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<tr>
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<td>PDFSE</td>
<td>Body</td>
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<td>512/256 2</td>
<td>4000</td>
<td>30</td>
<td>–</td>
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<tr>
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<td>Torso</td>
<td>17</td>
<td>4/0</td>
<td>512×384 3</td>
<td>4000</td>
<td>34</td>
<td>–</td>
<td>31.25</td>
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<td>Coronal</td>
<td>FMPHR</td>
<td>Body</td>
<td>32-40</td>
<td>5/0</td>
<td>256×192 2</td>
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<td>Torso</td>
<td>17</td>
<td>2 - 2.5/0</td>
<td>512×384 3</td>
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<td>512×256 3</td>
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<td>Torso</td>
<td>16</td>
<td>2/0</td>
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<td>Min-full</td>
<td>10</td>
<td>31.25</td>
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</tbody>
</table>

**Special instructions**

Sequence 1: Both hips and surrounding soft tissues in view.
Sequence 3–8: Small FOV over hip of interest.
Sequence 7: Oblique axial plane oriented parallel to the femoral neck. Coverage is from superior portion of the greater trochanter to the inferior portion of the lesser trochanter.
Note: It is important to orient Sequence 7 perpendicular to the orientation of the femoral neck; it is important to place the patient's leg/foot in neutral rotation (toes up).
Sequence 7: Optional sequence.
Sequence 8: Optional sequence.

Employ respiratory compensation if breathing artifact is present.

### Table 3

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Bone algorithm</th>
<th>Soft tissue algorithm</th>
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<tbody>
<tr>
<td>Kilovoltage</td>
<td>140</td>
<td>140</td>
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<tr>
<td>Milliamperes seconds</td>
<td>250</td>
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<tr>
<td>Rotation time (s)</td>
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<td>0.8</td>
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<tr>
<td>Collimation (mm)</td>
<td>1.3</td>
<td>2.5</td>
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<td>Section thickness (mm)</td>
<td>1.3</td>
<td>2.5–3.0</td>
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<tr>
<td>Reconstruction interval (mm)</td>
<td>0.625</td>
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<tr>
<td>Intravenous contrast material</td>
<td>Dilute iodinated contrast (1–2:20) and dilute gadolinium injection (concentration 1:200)</td>
<td>Dilute iodinated contrast (1–2:20) and dilute gadolinium injection (concentration 1:200)</td>
</tr>
</tbody>
</table>

**Special instructions**

Series 1: Scan both hips and surrounding soft tissues from superior iliac crests to tibial tubercles (FOV—36 cm).
Series 2: Small FOV over hip of interest (FOV—20 cm).
Series 3 and 4: Sagittal and coronal reconstructions.
Series 5 (performed at the workstation or the console): Oblique axial reconstruction along the axis of the femoral neck.
Series 6 (performed at the workstation or the console): Oblique sagittal plane oriented perpendicular to the femoral neck.
Note: It is important to orient Series 5 and 6 parallel and perpendicular to the femoral neck, respectively.
examination table to the MR imaging suite while the contrast remains within the hip joint.

The three-dimensional capabilities of MDCT may also be used to facilitate intraoperative mapping to better define the anatomy. This type of mapping may be useful in such procedures as total hip arthroplasty and hip arthroscopy. The surgical goals of conserving bone stock, optimizing implant position, appropriately sizing osteochondroplasties, creating normal biomechanical orientation, and minimizing complications are all facilitated by an optimal preoperative view of the osseous structures and the anatomic relationships. Computed tomography is especially useful when the hip is prominently dysplastic or when the combined femoral neck and external rotation is greater than 15° [17]. Multidetector CT is helpful not only for preoperative repair but for postoperative assessment of the resultant anatomy.

5. Anatomic assessments important for normal biomechanical function

There are five anatomic impairments of the hip joint that are especially important in the imaging evaluation of the hip and pelvis due to the adverse impact that they have on hip function. These five components are the caput caput collum diaphysis (neck-shaft) angle, the femoral angle of torsion,
the acetabular angle of torsion, the center edge angle, and the leg length. There are normal torsional angles and normal caput collum diaphysis angles, and both work in concert with one another to maintain an appropriate biomechanical relationship. The normal caput collum diaphysis (neck-shaft) angle is 120–135°. At birth, however, the neck-shaft angle is approximately 145–150° and slowly decreases over time to the normal adult angle of approximately 125–130°. The position of the greater trochanter influences the extent of contraction of the gluteus medius and minimus muscles and the mechanical stress of the femoral neck [18]. The normal neck-shaft angle has the optimal lever arm for mechanical advantage and produces the lowest stress on the femoral neck and hip joint. The varus hip produces more stress on the femoral neck, and the valgus hip places more stress on the hip joint. As indicated previously, the neck shaft angle is measured by the angle of intersection between lines oriented parallel to the mid-axis of the femoral head and neck and the femoral diaphysis (Fig. 7). One pitfall is that an increase in the anteversion angle results in a projectional foreshortening of the femoral neck on an anteroposterior radiograph. This creates the appearance of a shortened neck-shaft angle [19].

Early in life, the amount of femoral anteversion is increased. This angle decreases from approximately 40° at birth to approximately 32° at 1 year of age to a normal adult value of 8–11°, and the amount of femoral anteversion may vary from 8° to 30° [20,21]. A pathologic increase or decrease is easily detected with cross-sectional imaging examinations and appropriate protocols that not only scan the hip but also image the pelvis and the knees. This type of scanning protocol (Tables 1–3) is requisite for a complete anatomic evaluation. A normal amount of version is necessary to produce an optimal congruence of the hip joint. Increased anteversion or retroversion of the femur can give rise to decreased hip joint congruence and increased femoral anteversion accentuates forces that may displace the femoral heads [22]. The clinician must also be aware of the patient’s femoroacetabular anatomic relationship when directing exercise programs and in preoperative planning.

The center edge angle is obtained by drawing a line that connects the center of the femoral head to the lateral acetabular rim and by drawing a vertical line through the center of the femoral head (Fig. 3). This angle is also called the angle of Wiberg and has normal values ranging from 22° to 42° in an adult, although values less than 26° may be cause for concern [23,24]. A decreased center edge angle can lead to decreased stability of the hip joint with lateral displacement of the femoral head in relation to the acetabulum. This results in decreased congruency of the femoral head with the articular portion of the acetabulum and places the femoral head at increased risk of superior dislocation. The center edge angle normally increases with age as the femoral neck shaft angle decreases and the proximal femur assumes its more varus adult position. A decreased center edge angle is usually obvious in children with DDH but is possibly of more value in patients with subtle forms of DDH or with shallow acetabulae. The patients with subtle forms of acetabular dysplasia may also have thickening of the ligamentum teres femoris and the junction of the ligamentum orbicularis with the iliofemoral ligament (Fig. 12) as this ligament acts to stabilize the femoral head against lateral and superior subluxation.

Leg length discrepancy (LLD) is usually defined as the unilateral difference in the total leg length of one leg as compared with the other. This difference is usually from a structural compromise of the length of the long bones, hemipelvis, or spine. In addition to the structural contribution of these skeletal elements, LLD is also affected by their functional relationship. Pronation and supination of the lower extremity may cause a difference in height of 0.5–1.5 cm and this type of discrepancy is referred to as a functional LLD. The measurement of LLD on imaging examinations is confined to structural LLD. While the measurement of the LLD would not be practical on the routine MR imaging evaluation of the hip, a measurement of the femur may be obtained with a large FOV (Fig. 8) and the proximal femora may be measured on the scout portion of the CT examination (Fig. 9). Although the measurement of the total leg length optimal requires conventional radiography, the anatomy of the pelvis and the length of the femora can be assessed with cross-sectional imaging. Leg length discrepancy has been associated with hip, knee, and
back pain and with lower extremity stress fractures [25,26], and there is evidence that force increases across the hip joint up to 12% in individuals with LLDs of 3.5–6.5 cm and as little as 2.0 cm cause a difference in force across the joint [27,28]. It should be kept in mind that a pelvic tilt is a way of accommodating for a LLD and a pelvic tilt of approximately 6° (in the coronal plane) can accommodate for a LLD of 2.0 cm [29]. Overall, it appears that LLDs of 2.0 cm or more will have an adverse effect on the kinematic functioning of the hip and the measurement of the patient’s leg length should be a consideration when evaluating an individual who presents with hip-related symptoms.

6. Conclusion

The traditional cross-sectional imaging evaluation of the adult hip has been based on finding internal derangements and other anatomic basis for pathology. We present protocols and techniques of cross-sectional imaging that include methods to evaluate the basic structural components that are likely to give rise to aberrant biomechanical movements. These movements may either predispose the patient to or directly cause various types of pathology. The dual focus on detecting anatomic derangements in structural pathology that are likely to produce movements that produce pathology may allow for improved treatment methods that not only repair the primary pathology but also correct the biomechanical movements that predispose that patient to recurrent injury.

Magnetic resonance imaging is an optimal modality for detecting internal derangements and other pathologic processes such as posttraumatic sequelae, arthritic cartilage wear, or infiltrative/destructive processes. Most of the imaging literature supports the use of direct arthrography for the evaluation of the acetabular labrum and articular cartilage, and although most authors advocate direct arthrography, the use of optimized noncontrast MR imaging appears to have the potential to be as effective as direct MR arthrography. Additional investigation will be necessary to determine whether the optimized noncontrast MR imaging technique is as effective as direct MR arthrography and if this technique can be replicated at other institutions.

Radial MR imaging of the acetabular labrum was designed to demonstrate a perpendicular view of the acetabular labrum on all images and some reports have suggested that this type of sequence provides a greater sensitivity in detecting acetabular labral pathology. This claim is controversial, based on a small number of patients, and the value of this imaging sequence remains to be seen. In our institution, we do not find that this sequence provides substantial additional benefit.

The multiplanar capability of MR imaging allows for the measurements of various anatomic parameters that may have an effect on biomechanical function. These parameters include not only the anatomy around the pelvis, proximal femur, and hip joint, but also include the distal femora. These measurements include the caput collum diaphysis (neck-shaft) angle, the center edge angle, the femoral length, the femoral angle of torsion, and the acetabular angle of torsion. The McKibben instability index may also be calculated from the femoral and acetabular angles of torsion.

Multidetector CT is capable of a rapid multiplanar isotropic evaluation of osseous structures and surrounding soft tissues of the hip and pelvis. The volume assessments are effective at demonstrating the special relationships between the pelvis, femora, and around the hip joints, and may also be used with CT arthrography for better demonstration of the articular cartilage and acetabular labrum. The volume acquisition also makes it possible to view the anatomy from the pelvis to the knees and to measure the same anatomic parameters that are evaluated with MR imaging.

The combination of measuring the anatomic parameters that have important biomechanical implications and assessing the anatomy for internal derangement takes longer and adds interpretation time to the typical evaluation for internal derangement alone. We believe, however, this method of assessment has the potential to allow for correction of various underlying anatomic abnormalities that may predispose to recurrent or persistent internal derangement.

References


Technical Note

Arthroscopic Anatomy and Surgical Techniques for Peritrochanteric Space Disorders in the Hip

James E. Voos, M.D., Jonas R. Rudzki, M.D., Michael K. Shindle, M.D., Hal Martin, D.O., and Bryan T. Kelly, M.D.

Abstract: Disorders of the lateral or peritrochanteric space (often grouped into the greater trochanteric pain syndrome), such as recalcitrant trochanteric bursitis, external snapping iliotibial band, and gluteus medius and minimus tears, are now being treated endoscopically. We outline the endoscopic anatomy of the peritrochanteric space of the hip and describe surgical techniques for the treatment of these entities. Proper portal placement is key in understanding the peritrochanteric space and should be first oriented at the gluteus maximus insertion into the linea aspera, as well as the vastus lateralis. When tears of the gluteus medius and minimus are encountered, suture anchors can be placed into the footprint of the abductor tendons in a standard arthroscopic fashion. Our initial experience indicates that recalcitrant trochanteric bursitis, external coxa saltans, and focal, isolated tears of the gluteus medius and minimus tendon may be successfully treated with arthroscopic bursectomy, iliotibial band release, and decompression of the peritrochanteric space and suture anchor tendon repair to the greater trochanter, respectively. Key Words: Hip arthroscopy—Gluteus medius—Peritrochanteric space.

Recent advances in hip arthroscopy have led to a significant evolution in its use for the treatment of athletes and patients in the general public with a broad spectrum of hip pathology. The increasing enthusiasm for minimally invasive surgery combined with technical advances in hip arthroscopic procedures and magnetic resonance imaging of the hip has led to a dramatic increase in the application of hip arthroscopy for the treatment of symptomatic acetabular labral tears, hip capsular laxity and instability, femoroacetabular impingement, chondral lesions, osteochondritis dissecans, ligamentum teres injuries, and loose bodies (e.g., synovial chondromatosis). In addition, Byrd and Jones described treatment of adhesive capsulitis of the hip arthroscopically. In addition, Byrd and Jones described treatment of adhesive capsulitis of the hip arthroscopically.

In addition to arthroscopic techniques, many disorders of the lateral or peritrochanteric space (often grouped into the greater trochanteric pain syndrome), such as recalcitrant trochanteric bursitis, external snapping iliotibial band, and gluteus medius and minimus tears, are now being treated endoscopically. A detailed review of the open and arthroscopic anatomy of the central and peripheral compartments of the hip has been published. Byrd recently published a review of the surgical technique of hip arthroscopy.

In this article we outline the endoscopic anatomy of the lateral compartment, or peritrochanteric space, of the hip and describe surgical techniques for repairs of gluteus medius and minimus tears and release of the
iliotibial band for external coxa saltans. To our knowledge, this is the first report describing endoscopic repair of gluteus minimus and medius tears.

**ENDOSCOPIC ANATOMY AND SURGICAL TECHNIQUE**

Entry into the lateral compartment typically follows routine evaluation and treatment of central and peripheral compartment disorders. The anterior portal offers the best access into the peritrochanteric space, placed 1 cm lateral to the anterior superior iliac spine within the interval between the tensor fascia lata and sartorius (Fig 1, thick arrow). The cannula is directed into the peritrochanteric space with the leg in full extension, held in 0° of adduction, with 10° to 15° of internal rotation. It is directed posteriorly and swept back and forth between the iliotibial band overlying the greater trochanteric bursa and the greater trochanter with free motion in this space. The technique is similar to access to the subacromial space in the shoulder, where the iliotibial band is analogous to the undersurface of the acromion. With appropriate portal and cannula placement, a clear space lying between the iliotibial band and the greater trochanter can be relatively easily identified. If in question, cannula placement can be confirmed under fluoroscopy. A distal posterior portal into the peritrochanteric space is placed midway between the tip of the greater trochanter and the vastus tubercle along the posterior one third of the greater trochanteric midline (Fig 1, thin arrow). This portal placement facilitates access distally and proximally for both diagnostic evaluation and operative intervention (e.g., iliotibial band release). A third portal can be placed proximal to the tip of the greater trochanter in line with the distal posterior portal (Fig 1, open arrow). This portal facilitates more proximal work and can also be used for more distal visualization.

Anatomically, as the 70° arthroscope is placed into the anterior portal, both the light source and camera are positioned proximally and oriented distally. The initial view includes the insertion of the gluteus maximus into the posterior border of the iliotibial band. This insertion can be palpated and the bursa cleaned from this area with a motorized shaver. As the arthrosocist continues to progress proximally, the longitudinal lines of the vastus lateralis are identified and can be traced up to the insertion at the vastus tubercle, looking immediately anterior to the anterior facet (Fig 2). The gluteus minimus tendon and muscle are visualized anteriorly with the arthroscope source and camera placed laterally, looking anterior superior (Fig 3). As the arthroscope is rotated superiorly, the gluteus medius will come into view with its insertion into the greater trochanter (Fig 3). Further cleaning of the fibrinous bands overlying this area may be re-
quired for better access and visualization through the posterior portal. The gluteus maximus tendinous contribution to both the linea aspera and the tensor fascia can be visualized by looking laterally. This peritrochanteric space is typically distended with 50 to 70 mm Hg of pressurization. Hemostasis can be obtained with either radiofrequency ablation or standard coagulation. Sometimes fibrinous bands in this area will require excision. Accessory tendinous structures should also be inspected from across the gluteus minimus muscle, which can cross the gluteus minimus and have an insertion posteriorly as previously described by Ganz and colleagues.19

Proper portal placement is key in understanding the peritrochanteric space and should be first oriented at the gluteus maximus insertion into the linea aspera, as well as the vastus lateralis. Inspection should proceed in a counterclockwise fashion starting distally and posterior at the gluteus maximus insertion and then proceeding proximally and anterior toward the vastus lateralis and continuing proximally to the gluteus minimus. The fiber of the gluteus medius lie posterior to the minimus and should be thoroughly probed and visualized to identify the presence of full-thickness tendon insertion tears (Fig 4). A thorough knowledge of the normal footprint anatomy is critical in adequately assessing the abductors. Finally, the arthroscope should be turned toward the iliotibial band. In particular, the posterior one third of the iliotibial band is implicated in coxa saltans externus (external snapping hip) and may be causing direct abrasive wear to the greater trochanter. In cases in which there is no clinical concern of an external snapping hip and evaluation of the fiber of the posterior one third of the iliotibial band shows no abnormal contact across the greater trochanter, a thorough evaluation for abductor tendon tears is warranted. If no tears are identified debridement of the trochanteric bursae alone may provide an adequate soft-tissue decompression of the lateral compartment.

If coxa saltans externus has been noted or if snapping of the iliotibial band over this area has been refractory to nonoperative treatment, a release may be required; it should be performed along the posterolateral portion of the greater trochanter, beginning at the vastus tubercle insertion, extending to the tip of the greater trochanter in a z-type release of 1 cm anterior, 3 cm distal, and 1 cm posterior with slight variations thereof being required by digital and instrumented palpation in view of the particular fiber under the greatest amount of tension.

The gluteus medius tendon should be examined in a manner similar to subacromial examination of the rotator cuff. Gluteus medius tears can be divided into acute and chronic tears, and some authors advocate an analogy to the shoulder in considering indications for debridement versus repair. All tears should have fibrinous, scarred bands released over the maximus or the medius. When a repairable tear is identified the

![Figure 3](image1.png)

**Figure 3.** Arthroscopic image of a left hip displaying gluteus medius (G med) and minimus (G min) muscle and tendon with insertion into greater trochanter (arrow).

![Figure 4](image2.png)

**Figure 4.** Arthroscopic image of a left hip identifying presence of a full-thickness gluteus medius and minimus tendon insertion tear (arrow). The exposed footprint of the tendon on the greater trochanter is easily visualized (asterisk).
edges are debrided with a full-radius shaver and prepared for repair. The attachment site of the tendon at the greater trochanter is prepared with a full-radius shaver similar to preparation of the footprint for rotator cuff tears. Suture anchors can be placed into the footprint of the abductor tendons in a standard arthroscopic fashion. We have used both metal and bioabsorbable sutures depending on the bone quality. Fluoroscopic guidance may be helpful in directing the anchors in the appropriate direction and location. Once the anchors are placed, the sutures are retrieved and passed sequentially through the edges of the prepared gluteus medius tendon with a suture-passing device and tied under arthroscopic visualization with an arthroscopic knot pusher (Fig 5).

**DISCUSSION**

Several authors have reported the endoscopic treatment of recalcitrant trochanteric bursitis, internal and external coxa saltans, and calcific tendinitis of the gluteus minimus and medius tendons. To our knowledge, this is the first report describing the endoscopic repair of gluteus minimus and medius tendon tears.

**CONCLUSIONS**

Our initial experience indicates that recalcitrant trochanteric bursitis, external coxa saltans, and focal, isolated tears of the gluteus medius and minimus tendon may be successfully treated with arthroscopic bursectomy, iliotibial band release, and decompression of the peritrochanteric space and suture anchor tendon repair to the greater trochanter, respectively. As the open and arthroscopic anatomy of the hip becomes more clearly defined and surgical indications clarified the range of available treatment options for disease entities of the lateral peritrochanteric space of the hip will increase and be used to effectively treat disease entities that have classically required open surgical treatment.

**REFERENCES**


COMPLICATION RATE OF ONE STAGE BILATERAL VERSUS SINGLE SIDED HIP ARTHROSCOPY: A COMPARATIVE STUDY

ABSTRACT

Introduction. Hip arthroscopy is a safe procedure. Some patients could obtain benefits from a same day bilateral hip arthroscopy. However, there is a concern about a presumable increase in complications rate.

Purpose. To compare the complication rate of same day bilateral hip arthroscopies with single sided procedures.

Methods. We retrospectively compared 82 patients who had single stage bilateral hip arthroscopies with a matched group of 82 patients. A binominal logistic regression was performed to adjust the relationship between the type of procedure and complications by age, sex, race and BMI.

Results. The complication rate was 11% (n=9) in the unilateral group and 8.5% (n=6) in the bilateral group (crude OR 1.56 IC95% 0.52-4.60, p=0.41) after adjusting for age, race, gender and BMI (adjusted OR 1.63 IC95% 0.51-5.1, p=0.40).

Conclusion. The results suggest that simultaneous bilateral hip arthroscopy for FAI is as safe as the unilateral procedure.
INTRODUCTION

Hip arthroscopy is a developing surgical procedure. Improvement in portal standardization, fluid management, traction control and patient setup in the operating room have all decreased the complications.(1)

In the 1990’s complication rate of hip arthroscopy was reported between 6.4% and 15%; however, in the last 10 years, this procedure has become even more safe, with complication rates around 1.5%. (2,3)

Kowalz kzuc et al, in 2012, performed a meta-analysis with a total of 66 papers (6.962 hip arthroscopies) and they found an overall complication rate of 4% (95%IC 2.9-4.0). (4) It is important to consider that the expertise of the surgeon is essential to decrease the complications rate. In 2005 Sampson reported 38 complications in 1.000 hip arthroscopies performed over 20 years. The complication rate declined from 15% in the first 60 cases (5) to 6.2% up to the first 500 cases (3) and 0.5% in the last 500 cases.(1)

Performing a hip arthroscopy is mainly indicated for femoroacetabular impingement, a diagnosis that is very common to be present as a bilateral pathology. There are two ways to address these cases: treating each hip individually or simultaneously. In the last case there is a concern about a presumable increase in complications rate, since most of them have been associated with the use of traction (e.g. neuropraxias) and fluid extravasation.(1)

The purpose of this study was to compare the complication rate of one stage bilateral hip arthroscopies with single sided procedures.
METHODS

Between August 2006 and January 2013, 816 patients underwent hip arthroscopy for femoroacetabular impingement and related pathologies. Clinical records were eligible if the patients underwent one stage bilateral hip arthroscopy due to femoroacetabular impingement (Fig. 1). We retrospectively compared two cohorts: 82 patients who had single stage (same day) bilateral hip arthroscopies with a matched group of 82 patients who had unilateral hip arthroscopy to assess the incidence of complications, all patients who underwent unilateral procedure were computer-based randomly selected.

Hip pain not responsive to non-operative treatment in patients with pain and clinical signs of femoroacetabular impingement (FAI), decreased range of motion and imaging studies suggestive of FAI were indications for surgery. Patients with previous history of lower limbs peripheral nerve damage, venous deep thrombosis and heterotopic ossification around the hips were excluded, since these conditions might affect the analysis. Exclusion criteria for controls were identical to those described for bilateral group.

All hip arthroscopies were performed by a single orthopedic surgeon who was engaged in a full-time hip arthroscopy practice. All surgeries were performed through lateral approach described in 1986 by Glick J and Sampson T., et al.(6) We used general anesthesia and antibiotic prophylaxis was warranted with the use of one of the cephalosporin. Deep venous thrombosis prophylaxis was performed with the use of compression stockings and a sequential pump on the down-side leg. Hip arthroscopies were performed in lateral decubitus position with a lateral table attachment with peroneal post pad by Smith and Nephew®. Preoperative x-
rays were performed to check positioning and hip anatomy. The portals used were
nearly identical to the supine approach, except the anterior portal was located
approximately 2 cm lateral to the anterior superior iliac spine. When the anterior
portal was created, especial attention was taken to only incise the skin superficially
to avoid the laceration of a branch of the lateral femoral cutaneous nerve.
Adequate view of the joint was achieved with use of a 30-degree arthroscope. We
used an Outflow-dependent System by Conmed® with a pressure slightly above
diastolic pressure. We initiated the operative distraction after the case was entirely
set up and after all of the equipment had been turned on and was functioning. We
applied traction until observe at least 1 cm to 2 cm of separation between the head
and the acetabulum on the fluoroscopic view. After the arthroscope and the
instruments were in place, the central compartment was inspected and a methodic
fashion to plan the necessary treatment was done. For patients with bilateral
procedure, the same set-up and procedure was done in identical fashion. The
assistant or the circulating nurse announces the distraction time at 15-minute
intervals. After the intra-articular portion of the surgery was finished, all of the
distraction forces were released.
Postoperatively, the rehab protocol was for all patients started the first week with
gentle stretching of lower extremities, stationary bicycling with no resistance twenty
to thirty minutes a day. The next three weeks, all patients continued bicycling with
increasing resistance and progressing of full weight bearing with one crutch or a
cane until the patient was comfortable. Impact activity and falling were avoided in
this phase. After one month all patients returned gradually to work or normal
physical activity.
Demographic data were collected preoperatively, including surgery time, anesthesia time, traction time, pudendal and foot compression, and amount of fluid used. The primary outcome measure in the present study was the complications rate including traction injuries (femoral, sciatic and lateral femoral cutaneous neuropraxia), compression injuries (pudendal neuropraxia), fluid injuries (fluid extravasation), infections, instrument breakage, late complications (heterotopic ossification), anesthesia complications (respiratory, cardiovascular) and others.

The Kolmogorov-Smirnov and Shapiro-Wilk test were used to assess if variables came from a normally distributed population. For the description of quantitative variables, the mean and standard deviation were used, and for the description of nominal variables, frequencies and proportions.

For categoric variables the comparison between groups was performed using Chi square, and for quantitative variables the comparison was performed using the t Student or Mann-Whitney U, depending on whether it came from a normally distributed population or not. Furthermore, a binominal logistic regression was performed to adjust the relationship between the type of procedure (unilateral or bilateral) and complications by age, sex, race and BMI (variables with p value <2.5 in bivariate analysis). The OR and CI95% were calculated. For data analysis we used SPSS, version 21.0 and an alpha error of 5% was considered.
RESULTS

In total, there were one hundred and sixty four hip arthroscopies. The mean age of the patients was 37.52 years ±12.36, BMI 24.2 ±3.79, white was the predominant race (n=156), and 8 subjects were mixed race. In the unilateral group, the mean age (and standard deviation) was 41.28 ±12.52 years, the mean body max index (BMI) was 24.49 ±4.04, and the sex distribution was 46 females and 36 males. In the bilateral group, the mean age (and standard deviation) was 33.77 ±11.04 years, the mean body max index (BMI) was 23.91 ±3.54, and the sex distribution was 42 females and 40 males.

No significant difference was found in demographic data, except age, between both groups. There was an obvious difference in time of surgery (159.8 ±38.6 min vs. 283.6 ±57.8 min), time of anesthesia (207.3 ±39.7 min vs. 333.3 ±64 min), time of traction (28.1 ±20.6 min vs. 49.3 ±28.8 min) and amount of fluid used (44.3 ±20.1 liters vs. 73.4 ±25.1) (Table 1). The time of follow up was 30.7 months ±12.3 in the unilateral group and 35.5 months ±21.7 in the bilateral group.

The complication rate was similar between groups (11% in the unilateral group vs. 8.5% in the bilateral group) with no statistic differences (crude OR 1.56 IC95% 0.52-4.60, p=0.41). No difference was found even after adjusting for age, race, gender and BMI (adjusted OR 1.63 IC95% 0.51-5.1, p=0.40). Most complications were transient neuropraxias. One patient presented two complications also transient neuropraxias. There was one patient with HIV infection in the unilateral group and one case of pneumonia in the same group, but in a different patient, that complication was considered in the anesthesia complication group. One instrument breakage was reported as a complication in the bilateral group (Table 2).
DISCUSSION

To perform single stage bilateral hip surgeries is not a new issue. There are some reports about simultaneous bilateral hip replacement with similar or even fewer complications than two-staged procedures.(7-9)

In 2012, at the International Society for Hip Arthroscopy Annual Meeting (Boston, USA), Klingenstein et al presented a study about the prevalence of bilateral arthroscopic treatment for FAI and correlated patient demographics, and radiographic factors. Over a 2-years period, they included 514 unilateral patients. Twenty percent of them needed a new hip arthroscopy on the other hip. They indicated that male gender, younger age, higher alpha angles and reduced acetabular anteversion are good clinical markers to identify patients who may require bilateral surgery.(10) According with the percentage of a new hip arthroscopy on the other side, as the last paper reported, perhaps an important number of patients could have symptomatic bilateral FAI, but usually most of the hip surgeons treat the most painful side first due to concerns about the safety of a bilateral single stage procedure.

Currently, there is only one clinical study comparing unilateral hip arthroscopy and simultaneous bilateral hip arthroscopy. Mei-Dan et al performed the first retrospective comparative study. In this interesting paper they reported 76 patients in three groups: in group 1 all hips were treated simultaneously, in group 2 both all hips were treated in staged fashion, and in group 3 a single hip was addressed. They noted that simultaneous bilateral femoroacetabular impingement surgery through arthroscopy does not lead to higher rates of complications, postoperative pain, analgesic use, or side effects.(11) Nevertheless, in comparison with our
report, their outcomes were focused mainly in efficacious and adverse effects. They did not report the complications in detail.

This study is the first specific comparative report about complications rate between unilateral hip arthroscopy and one stage bilateral hip arthroscopy for treating FAI. Our outcomes suggest that the bilateral hip arthroscopy in FAI in the same day is as safe as the unilateral procedure. These outcome could benefit all patients with symptomatic bilateral FAI in a number of ways, including lesser length of stay in the hospital, faster return to work, and a total shorter postoperative pain, as other authors have reported.(11)

Our study has limitations that need to be considered when interpreting the results. We studied main outcome parameters such as adverse effects and complications rate. Obviously there are other outcomes variables such as efficacy, however these parameters have been reported by other authors recently, suggesting that simultaneous bilateral hip arthroscopy is as efficacious as unilateral procedure. Nonetheless, further studies with the assessment of those variables are necessary for a more comprehensive comparison of the different possible operative approaches. This study represents a retrospective analysis of prospectively, systematically and consecutively collected data. Despite this setup, the large sample and time of follow-up carry with them the potential for selection bias.

On another hand, although all complications could not be adequately related to a specific cause, observed outcomes were rather amplified than diminished (e.g. a case of pneumonia which was not clearly due to the anesthesia as seen in table 2).
CONCLUSION

From the point of view of possible intra- or postoperative complications, in patients with bilateral FAI, simultaneous bilateral hip arthroscopy must be seen as safe as the unilateral procedure.
REFERENCES


8. Haverkamp D, van den Bekerom MPJ, Harmse I, Schafroth MU. One stage


Figure 1. Flow diagram showing patient selection process.
TABLE 1. Demographic and surgery related data.

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<td>Time of surgery (min)</td>
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### TABLE 2. Incidence of complications.

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* Pneumonia. **All were transient neuropraxia. ***One patient presented two transient neuropraxies.
CAM FEMOROACETABULAR IMPINGEMENT AND LABRAL TEARS:
PHYSICAL EXAM AND RELATED INTRA-OPERATIVE FINDINGS

Hal D Martin, DO; BA Braly, MD; DP Beall, MD; SA Shears, RN BSN; IJ Palmer, PhD

Purpose: The purpose of this study was to determine which clinical tests were most useful in a physical examination in patients with a labral tear and cam femoral acetabular impingement (FAI).

Methods: 44 patients with cam FAI and a labral tear had undergone a full physical examination of the hip. Sensitivity, specificity, accuracy, and positive predictive value (PPV) were determined for range of motion (ROM) tests and FAI tests.

Results: The most frequent positive physical exam tests were decreased internal (IR) and external rotation (ER), dynamic internal rotatory impingement (DIRI), dynamic external rotatory impingement (DERI), flexion/adduction/internal rotation (FADDIR), and the lateral flexion/abduction/external rotation (FABER) tests. The loss of ROM in IR and ER had good sensitivity to each labral tear location (anterior, superior, and posterior), however specificity was low. Accuracy and PPV for superior tears were highest at 63%. Sensitivity of the four impingement tests for anterior tears was similar to superior tears. Sensitivity and PPV improved (to 95% and 85%, respectively) when at least three of the six tests were positive.

Conclusions: We have identified and described the clinically important tests associated with cam FAI and labral tears to be reduced IR and ER, DERI, DIRI, FADDIR, and Lateral FABER tests. These tests were found to have high sensitivity, good accuracy, and PPV for labral tear location in cam FAI patients. This battery of impingement tests for preoperative hip evaluation can be easily replicated in the operating theater as well as postoperatively. Within a comprehensive physical examination of the hip, the inclusion of this battery of impingement tests will improve sensitivity of cam FAI and associated labral tears.

Clinical Relevance: A greater understanding of the tests associated with FAI and labral pathology will aid in a timely diagnosis, which will be of great benefit to our patient.

Keywords: Hip Arthroscopy; Physical Examination; Cam Femoroacetabular Impingement; Labral Tear
Introduction

Physical examination tests are used to evaluate patients with hip pain. Labral tears and cam impingement have been diagnosed clinically by the flexion/adduction/internal rotation test (FADDIR)\(^1\), McCarthy’s test\(^2,3\), log roll\(^4\), the loss of internal rotation (IR)\(^5\) and with other less frequently utilized examinations\(^2,3,6-9\). Restricted internal rotation is a classic physical examination finding related to FAI\(^10-13\). Although some studies have shown that external versus internal rotation does not correlate well with location of labral tears\(^14\), it has been accepted that ROM assessment, especially with pain, is an important physical test associated with labral tears\(^14,15\).

The diagnostic value of the clinical tests of the hip joint must be evaluated as it has in other joints such as the knee\(^16-18\) and shoulder\(^19\). Little published information exists on the sensitivity, specificity, accuracy, and positive predictive value of physical examination of the hip joint in relation to labral tears and cam FAI and no single test or test protocol has been accepted to be the best diagnostic tool. Therefore, this study was a retrospective analysis to determine which clinical tests were most useful in labral tears and cam FAI.

Materials and Methods:

Arthroscopic findings and physical exam data of 150 consecutive patients were reviewed. Forty-four patients (24 females and 20 males), between the ages of 13 and 69 years (mean age = 41 ± 14 years) were selected for analysis. Inclusion criteria were patients who had: 1) cam impingement and labral tear confirmed by arthroscopic evaluation, 2) MRA and X-Ray analyses, 3) MRA detected cam impingement and labral tear, and 4) a normal McKibbin’s index\(^20-22\). Patients were selected on the basis of normal osseous parameters\(^22\) to eliminate concomitant rotatory issues.

Following a thorough history, each patient underwent a structured physical examination (Table 1) based upon the previously described 20-point clinical examination of the hip\(^7\). A single surgeon performed each physical examination. For universal clarification among practitioners, each test was given a descriptive title. A test was scored positive when restriction of normal motion occurred and/or when the reproduction of the complaint pain was achieved. A trained medical assistant recorded the results of the physical exam in real time. Radiographic review included a supine or standing AP\(^23\) and a frog-leg lateral\(^24\). MRA was performed preoperatively and reviewed by a single radiologist\(^20,21\).

Clinical Tests of Interest: A Description of Technique

Internal and External Rotation ROM – The patient is seated to mid-thigh with the hip at 90° of flexion and the knee flexed at 90° off of the exam table. The leg is then slowly brought into passive internal and external rotation until a firm endpoint is encountered. ROM is performed bilaterally for side to side comparisons.
Dynamic External Rotatory Impingement (DERI) – DERI is similar to the traditional McCarthy’s test, in which a positive test is associated with the detection of a pop during this maneuver. With the patient in the supine position and holding the non-affected leg in flexion beyond 90°, the examiner passively brings the affected hip through a wide arc of abduction and external rotation. The arcing maneuver is performed at 90, 60, 45, and 30° of flexion. A positive is noted with recreation of the complaint pain.

Dynamic Internal Rotatory Impingement (DIRI) – DIRI is similar to the traditional McCarthy’s test, in which a positive test is associated with the detection of a pop during this maneuver. As with the dynamic external impingement maneuver, the patient is in the supine position and holding the non-affected leg in flexion beyond 90°, while the examiner passively brings the affected hip through a wide arc of adduction and internal rotation. The arcing maneuver is performed at 90, 60, 45, and 30° of flexion. A positive is noted with recreation of the complaint pain.

Flexion/Adduction/Internal Rotation (FADDIR) – FADDIR traditionally is performed in the supine position with passive movement of the thigh into full flexion, adduction, and internal rotation. With the patient in the lateral position, the examiner cradles the patient’s lower leg with one arm and monitors the superior aspect of the hip with the opposing hand. The hip is passively brought into 90° flexion, adduction and internal rotation. Reproduction of the patient’s complaint pain is scored positive and the degree of flexion and internal rotation is noted.

Lateral FABER Test – Traditionally known as the Patrick test (flexion/abduction/external rotation), which is performed with the patient in the supine position. The Patrick test is designed to differentiate between hip and back pain. The Lateral FABER test, or lateral rim impingement test, is performed with the patient in the lateral position and the examiner cradles the patient’s lower leg with one arm and monitors the hip joint with the opposing hand. The examiner passively brings the affected hip through a wide arc from flexion to extension in continuous abduction. Reproduction of the patient’s pain is scored positive.

Arthroscopic Procedure

Utilizing a supine technique as described by Byrd, the hip was examined in a sequential 23-step central compartment assessment. An intra-articular arthroscopic analysis was performed through the anterior and anterolateral portals using a 70-degree arthroscope. A dynamic peripheral compartment assessment was performed at 30, 45, 60, and 90° of flexion with adduction/internal rotation and abduction/external rotation to assess the dynamic component of femoral head/neck junction and acetabular congruence mimicking the clinical examination (DERI and DIRI), shown in Figures 1 and 2. Dynamic examination confirmed the location of impingement. Impingement was noted with a flattening of the acetabular labrum or superolateralization redirecting the acetabular labrum away from its downward orientation. The intraoperative findings of the labral tear and the location of lesions were described in a standard operative report, which were utilized for review in all cases. Location of the labral tears were classified according
to a “clock face” orientation with anterior tears in the 9-11 O’clock position, superior tears in the 11-1 O’clock position, and posterior tears in the 12-3 O’clock position.\footnote{28}

\textit{Statistical Analyses}

Statistical analyses were performed using SPSS v. 14.0. Sensitivity, specificity, accuracy, and positive predictive value (PPV) were determined by using 2 X 2 tables.

\textbf{Results:}

The clinical tests performed and percent positives are shown in Table 2. The loss of range of motion (ROM) was found to have the most frequent positive scores with decreased external (80\%) and internal (73\%) ROM. Decreased internal ROM was scored positive when ROM was less than 20\°, and decreased external ROM was scored positive when ROM was less than 30\°. Four other tests revealed high frequencies of positive scores, which included the DERI test (70\%), FADDIR test (66\%), DIRI test (61\%), and the Lateral FABER test (59\%). These tests resulted in a positive score when reproduction of the complaint pain occurred.

The sensitivity, specificity, accuracy and PPV for the DIRI, DERI, FADDIR, and Lateral FABER tests to the location of the labral tear are shown in Table 3. For anterior tears (n= 26), the four impingement tests revealed greater than 67\% sensitivity, with the most sensitive tests being the Lateral FABER (75\%) and DIRI (71\%). For superior tears (n= 27), the four impingement tests revealed greater than 73\% sensitivity, with the most sensitive tests being DIRI (79\%) and DERI (78\%). For posterior tears (n= 10), the four impingement tests revealed greater than 70\% sensitivity, with the most sensitive tests being DERI (100\%) and FADDIR (80\%). Specificity for the location of a tear was low for the four impingement tests (less than 50\%). All four impingement tests revealed greater than 63\% accuracy for superior tears, with the Lateral FABER having the highest accuracy (68.6\%). Accuracy for anterior tears was highest with the FADDIR (52.2\%). Accuracy for posterior tears was low for the impingement tests (less than 29\%). Positive predictive value (PPV) was highest for superior tears, with DIRI (73.1\%) and DERI (70\%). For anterior tears, PPV was highest for DIRI (50\%). PPV for posterior tears was less than 34\% for the four impingement tests.

The sensitivity, specificity, accuracy, and PPV for the loss of IR and ER are shown in Table 4. Sensitivity to the location of a labral tear was similar for losses of both IR and ER. Sensitivity of the loss of ER was highest with anterior tears (87\%) and superior tears (81.5\%), while loss of IR was highest with posterior tears (88.9\%). Specificity of the loss of IR and ER for detecting the location of tears was low, less than 30\% at each tear location. Accuracy was highest for superior tears (ER = 62.8\%, IR = 60.5\%), while accuracy was low for anterior tears (less than 54\%) and posterior tears (less than 24\%). PPV was highest for superior tears (ER = 62.9\%, IR = 62.5\%) and anterior tears (ER = 57.1\%, IR = 56.3\%). PPV was low for posterior tears (less than 25\%).

\textbf{Discussion:}
The physical examination of the hip is an important step for the differential diagnosis of hip pain as it is the opportunity for the surgeon to clinically assess the hip joint utilizing static and dynamic techniques. Critical to the hip assessment, and to avoid a misdiagnosis of the back, is the understanding of the ligamentous, osseous, and musculotendinous balance of the hip joint. The current study evaluated the diagnostic values of physical examination tests in patients with radiographically and arthroscopically confirmed cam FAI and labral tears.

The most frequent positive physical exam tests were decreased IR and ER, DIRI, DERI, FADDIR, and the Lateral FABER tests. The loss of ROM in IR and ER had good sensitivity to each labral tear location (anterior, superior, and posterior), however specificity was low. Accuracy and PPV for superior tears were highest at 63%. Sensitivity of the four impingement tests for anterior tears was similar to superior tears; however specificity, accuracy, and PPV were lower. Posterior tear location revealed high sensitivity and low accuracy and PPV, however it is likely due to the low number of posterior tears (n=10). Accuracy and PPV for posterior tears may improve with the inclusion of a posterior rim impingement test. These findings are similar to the diagnostic values for clinical tests of the shoulder, which have shown that tests with high sensitivity lack specificity. Sensitivity and PPV increased (to 95% and 85%, respectively) when at least three of the six tests were positive. Specificity, however decreased, therefore the results of the individual exams remain important. These results provide evidence for including this battery of tests (IR ROM, ER ROM, DERI, DIRI, FADDIR, and Lateral FABER) within a comprehensive physical examination protocol.

Our data is in agreement with the previous concept that a loss of IR ROM is one of the first signs of internal hip pathology, however decreased IR and/or ER could be related to a variety of diagnoses other than FAI such as arthritis, effusion, internal derangements, muscular contracture, or femoral acetabular anteversion. It is well recognized that the FADDIR test is a clinically important impingement test and our data agree. The Patrick test, or supine flexion/abduction/external rotation, is another well recognized clinical test which is useful for differentiating hip and back pain. However the Patrick test has not been shown to be specific for FAI. In our cam FAI patients, 11% (5 patients) resulted in a positive supine Faber test, whereas 59% (26 patients) resulted in a positive Lateral FABER test. The DERI and DIRI offer a more thorough assessment of impingement than the traditional McCarthy test. The traditional McCarthy test was designed to elicit a pop, also known as the McCarthy Sign, while the rotatory impingement tests were designed to reproduce the patient’s complaint pain. The log roll has been suggested to be a specific test for hip pain, but does not identify the specific pathology. Among our patients only two patients (4.5%) revealed a positive log roll. Also of interest was the high frequency of positives in the single leg stance phase test (traditionally known as the Trendelenburg test) which was positive in 72% of the patients and gait abnormalities present in 82% of the patients. It is speculative on whether the labral tear resulted in proprioceptive guarding or secondary muscle weakness.
In order to minimize variability in the outcome of these tests, it is imperative that they are performed as a standardized protocol as described here. Many provocative physical examination tests can cause discomfort or pain resulting in a false positive in non-affected hip joints if performed incorrectly. The physical examination of the hip must be performed with careful attention to patient positioning. As defined within the current protocol IR and ER were performed in the seated position, which ensures that the ischium is square to the table, thus providing a consistent and reproducible platform for rotational measurement. Pelvic positioning in the supine and lateral positions utilizes two set-points of the pelvis, thus regulating the anterior and posterior column. In the supine position a static zero set-point is achieved by contralateral hip flexion which eliminates lumbar lordosis, while the lateral position allows for dynamic individualized lumbar lordosis. In this manner a full appreciation of the osseous, ligamentous, and musculotendous contributions to the hip joint can be obtained.

In conclusion, we have identified and described the clinically important tests associated with cam FAI and labral tears to be reduced IR and ER, DERI, DIRI, FADDIR, and Lateral FABER tests. These tests were found to have high sensitivity, good accuracy, and PPV for labral tear location in cam FAI patients. This battery of impingement tests for preoperative hip evaluation can be easily replicated in the operating theater as well as postoperatively. Within a comprehensive physical examination of the hip, the inclusion of this battery of impingement tests will improve sensitivity of cam FAI and associated labral tears. Through this framework, a greater understanding of the physical examination as it relates to cam FAI, labral tears, and varying hip pathology will help guide successful treatment.

REFERENCES


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<td>Prone</td>
<td>Femoral anteversion test, rectus femoris contracture test</td>
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Single leg stance phase test is also known as the Trendelenburg test. ROM, range of motion. Hip flexion contracture test is also known as the Thomas Test. FABER, flexion/abduction external rotation is also known as the Patrick/Faber Test. DIRI, Dynamic Internal Rotatory Impingement. DERI, Dynamic External Rotatory Impingement. SLRAR, Straight Leg Raise Against Resistance is also known as the Stitchfield Test. Passive Rotation Internal/External is also known as the Log Roll. Tests of Passive Adduction have been previously known as Ober’s test with the Tensor Fascia Lata test performed in extension, the gluteus medius test performed in neutral, and the gluteus maximus test performed in flexion.
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Table 3. Sensitivity and Specificity Values of FAI Clinical Tests in Patients with FAI and Labral Tear

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<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Accuracy (%)</th>
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Table 4. Sensitivity and Specificity Values of ROM Clinical Tests in Patients with FAI and Labral Tear

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<th>Specificity (%)</th>
<th>Accuracy (%)</th>
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<td>80.0</td>
<td>18.2</td>
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FIGURE LEGENDS

Figure 1. Dynamic Peripheral Compartment Assessment with Abduction.

Within the operating theater, the dynamic component of the femoral head/neck junction and acetabular congruence is assessed in abduction to confirm adequate decompression.
Within the operating theater, the dynamic component of the femoral head/neck junction and acetabular congruence is assessed in abduction with internal rotation to confirm adequate decompression.
Capsulotomy Size Affects Hip Joint Kinematic Stability


**Purpose:** To evaluate the effect of capsulotomy size and subsequent repair on the biomechanical stability of hip joint kinematics through external rotation of a cadaveric hip in neutral flexion. **Methods:** Eight fresh-frozen cadaveric hip specimens were used in this study. Each hip was tested under torsional loads of 6 N·m applied by a servohydraulic frame and transmitted by a pulley system. The test conditions were (1) neutral flexion with the capsule intact, (2) neutral flexion with a 4-cm interportal capsulotomy, (3) neutral flexion with a 6-cm capsulotomy, and (4) neutral flexion with capsulotomy repair. Soft tissue was retained during all interventions. Measures indicating joint kinematics (range of motion [ROM], hysteresis area [HA], and neutral zone [NZ]) were obtained for each condition. **Results:** For all hip specimens, the average ROM, HA, and NZ were calculated relative to the intact capsular state (100%) and expressed in terms of percentage (± SD). The findings for ROM were as follows: intact, 100%; 4 cm, 107.42% ± 5.69%; 6 cm, 113.40% ± 7.92%; and repair, 99.78% ± 3.77%. The findings for HA were as follows: intact, 100%; 4 cm, 108.30% ± 9.30%; 6 cm, 115.30% ± 13.92%; and repair, 99.47% ± 4.12%. The findings for NZ were as follows: intact, 100%; 4 cm, 139.61% ± 62.35%; 6 cm, 169.25% ± 78.19%; and repair, 132.03% ± 64.38%. Statistically significant differences in ROM existed between the intact and 4-cm conditions ($P = .039$), the intact and 6-cm conditions ($P < .0001$), the 4-cm and repair conditions ($P = .033$), and the 6-cm and repair conditions ($P < .0001$). There was no statistically significant difference between the intact and repair conditions ($P > .99$) or between the 4- and 6-cm conditions ($P = .126$). **Conclusions:** Under laboratory-based conditions, larger-sized capsulotomies were accompanied by increases in all 3 measures of joint mobility: ROM, HA, and NZ at time zero. Complete capsular closure effectively restored these measures when compared with the intact condition. **Clinical Relevance:** Cadaveric models consisting of the hip joint with surrounding soft tissue were used under laboratory testing conditions to investigate potential iatrogenic joint instability resulting from expansive capsulotomies, showing that complete capsular closure leads to reconstitution of original joint stability properties at time zero.

In recent years arthroscopy, as part of the rapidly expanding field of hip preservation, has been increasingly used to address nonarthritic hip pathology. Unlike in knee and shoulder arthroscopy, a capsulotomy is required for adequate visualization of the joint space to proceed with diagnostic and application submitted to Arthroscopy Association of North America (AANA). Current grant under way with Stryker. Current grant under way with AANA. 2014 OREF Resident Grant awarded. Allsource, Arthrex, Athletic, DJ Orthopaedics, Linvatec, Miomed, Smith & Nephew, and Stryker.

A preliminary version of this study was presented at the Orthopaedic Research Society 2015 Annual Meeting, Las Vegas, NV, March 2015. The contents reflecting this study were presented at the 2015 Annual Meeting of the Arthroscopy Association of North America, Los Angeles, CA, April 2015, and awarded the AANA Basic Science Award.

Received April 17, 2015; accepted January 21, 2016.

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0749-8063/15350/$36.00

http://dx.doi.org/10.1016/j.arthro.2016.01.049

therapeutic procedures. Bony anatomy and articulation of the femoral head and acetabulum confer a large amount of static hip stability. This is complemented by static and dynamic soft-tissue stabilizers. Independent of capsular plication and closure in the setting of hip dysplasia with resulting instability, there is increasing evidence on the benefits of capsular repair minimizing potential iatrogenic instability. However, clinical practice is still variable, with some surgeons rarely repairing the capsule but other surgeons performing repairs routinely. Furthermore, there is variation regarding the size and type of capsulotomy being used.

Commonly, an interportal capsulotomy is performed, and increasing the size of the capsulotomy may enhance visualization of the peripheral compartment for the treatment of cam deformities in femoroacetabular impingement (FAI). A more extensile capsulotomy may better allow the surgeon to correct an osseous defect. However, concerns also exist regarding destabilization of the hip joint. Although little research exists to assess outcomes after extensile interportal capsulotomies, Frank et al. found improved patient-reported outcome scores in a cohort of patients undergoing hip arthroscopy for FAI with T-capsulotomy when they were treated with repair of both the vertical and interportal limbs when compared with patients treated with repair of only the vertical capsulotomy limb, thus leaving the interportal capsulotomy unrepaired. In addition, 13% of the patients in the partial repair group underwent revision surgery, whereas no patients in the complete capsular repair group required revision surgery. Iatrogenic hip instability is a rare but serious complication after hip arthroscopy, and numerous case reports have been published. Regardless, macroscopic hip dislocation was not specifically tested in our following study, and the importance of potential iatrogenic microinstability from hip arthroscopy resulting in possible long-term clinically relevant instability is not well understood at this point. Minimizing the risk of this potential complication is one of the utmost priorities of the hip arthroscopist.

In general, hip instability is uncommon because of the substantial osseous stability conferred by the conformity of the femoral head and acetabulum. This is complemented by static and dynamic soft-tissue stabilizers. Pathologic joint configurations such as protrusio acetabuli, coxa profunda, or FAI should provide different kinematic results. The literature is still in its infancy when it comes to these topics, and work like this aims to contribute to this body of knowledge. However, hip joint stability is complex and under the influence of a number of factors, of which are often directly addressed in arthroscopic procedures: the labrum and the iliofemoral ligament (IFL). Myers et al. performed a study on 15 cadaveric hips that showed the significant role of the IFL in limiting external rotation and anterior translation of the femur. The acetabular labrum was determined to have a secondary stabilizing role in these motions. This finding suggested that both the acetabular labrum and IFL should be surgically repaired to restore native hip rotation and translation. Our study is specifically aimed at investigating hip kinematics while maintaining soft tissue surrounding the joint, which to our knowledge has not been performed previously. We propose defining biomechanical stability as a construct composed of 3 joint kinematic measures: range of motion (ROM), neutral zone, and hysteresis area. These parameters have been previously measured in other orthopaedic joint research.

The purpose of the study was to evaluate the effect of capsulotomy size and subsequent repair on the biomechanical stability of hip joint kinematics through external rotation of a cadaveric hip in neutral flexion. We hypothesized that joint kinematic measures (ROM, hysteresis area, and neutral zone) would increase with an increasing size of interportal capsulotomy and exhibit restored stability measurements after repair of the anterior capsulotomy.

**Methods**

Eight fresh-frozen cadaveric hip specimens consisting of the hemipelvis, femur, and overlying soft tissues were obtained from Science Care (Phoenix, AZ). Specimens were selected and screened by computed tomography: those with a Tönnis grade greater than 1 or a lateral center-edge angle of less than 25° were excluded. The labrum of each specimen was circumferentially inspected at the conclusion of testing with complete opening of the capsule, and all labra were confirmed to be intact.

After thawing for 24 hours, the femur was transected at the junction of the proximal and middle thirds for potting in polymethyl methacrylate cement within a cylindrical polyvinylchloride mold. Each specimen was then placed into a custom-built hip-loading apparatus that allowed for axial rotation of the femur around a static acetabulum. This study used a previously verified method recently published. The iliac wing of the hemipelvis was bolted to a rigid plate (stationary) while the femur (potted in the polyvinylchloride mold) was secured in a larger cylindrical container that was mobile by virtue of a universal joint attached to a shaft concentric to the axis of the cylinder (Fig 1). This fixture was set in motion by a set of pulleys and wires connected to the piston of an Instron 8874 servohydraulic frame (Instron, Norwood, MA). Two sets of wires were secured around the 30-mm-diameter circular base of the femoral component. One wire set was attached to a 200-N counterweight that acted opposite the vertical motion of the testing frame piston, which was attached to the other end of the wire set, thus completing the mechanical circuit. The cyclic vertical motion was thus
converted into cyclic axial rotation about the femoral axis, expressed in this report as a continuous smooth load cycle between internal and external rotation. To achieve testing consistency and to avoid the difficulties in locating the hip joint center, each specimen started at one rotational extreme (internal rotation) and ended at the other (external rotation). Testing was conducted for 3 cycles over a span of 6N at a rate of 0.3 (N·m)/s in load-control mode. This loading rate corresponds to similar procedures used in our laboratory when loading cadaveric spines in vitro and, more importantly, is low enough to provide quasi-static test conditions that minimize any viscoelastic effects from the soft tissue. The torque amplitude and rate were also chosen based on pilot testing that showed sufficient full external rotation of the femur without causing impingement of the greater trochanter on the acetabulum at terminal rotation.

Each hip was tested as follows: (1) neutral flexion with the capsule intact, (2) neutral flexion with a 4-cm interportal capsulotomy, (3) neutral flexion with a 6-cm interportal capsulotomy, and (4) neutral flexion with a repaired capsulotomy. Specimens were not loaded to failure because trial runs showed that the femur potted within the polymethyl methacrylate cement failed on shear forces before dislocation of the hip joint was achieved. When a T-capsulotomy is performed, the interportal capsulotomy is generally 4 cm; therefore, this was chosen as the initial capsulotomy length. Because no intra-articular arthroscopic view was available, we had to rely on palpable landmarks. For each specimen, the labral margin was palpated and the capsulotomy performed 5 mm distal to that level. For surgeons who do not perform a T-capsulotomy, an extensive interportal capsulotomy is used and can be approximately 6 cm depending on the size, morphology, and soft-tissue laxity. The interportal capsulotomies were performed through a muscle-sparing, mini-open direct anterior approach to the capsule (Fig 2). The capsule was repaired with 4 equally spaced (1.2 mm) high-tensile strength No. 2 Force Fiber sutures (Stryker, Kalamazoo, MI). A four-suture repair was chosen based on a technique article stating that the authors’ protocol for closure of the interportal capsulotomy used 2 to 3 nonabsorbable, high-strength sutures.5,23-28 In our study, given the expansive nature of the 6-cm capsulotomy created, we believed that the use of 4 sutures to adequately repair the interportal capsulotomy was warranted. All capsulotomies and repairs were performed with the hip in neutral rotation by a single investigator—a hip surgeon trained in these procedures (T.H.W.). The overlying soft tissue was closed after each condition before testing to best restore initial anatomic relations.

A total of 3 cycles were performed for each capsular condition. Only data from the last cycle were used for analysis, rendering the first 2 cycles as the preconditioning phase. Experimental data from the Instron 8874 were collected in a load (in newtons) versus-extension (in millimeters) format, where “load” refers to the vertical supplied force and “extension” refers to the vertical position of the servohydraulic frame. These values were then converted into a torque (in newton meters)—versus—angular displacement (in degrees) curve using a custom-written MATLAB script (release 2013b; The MathWorks, Natick, MA) to determine our chosen measures of joint stability (ROM, hysteresis area, and neutral zone). Any frictional losses were assumed to be negligible.
phenomenon has been thoroughly studied in other joints, such as the carpal joint, the knee, and the hip itself.10,13,14,16-20,31

Raw data were obtained in degrees for both ROM and neutral zone and in newton meters degrees for hysteresis area. Given the variation in absolute biomechanical measures between hip specimens, these data were converted into percentages and expressed relative to the intact state such that statistical analysis could be performed. A one-way analysis of variance with a post hoc Tukey test was used to determine the influence of different capsular conditions on our selected measures of joint kinematics (ROM, hysteresis area, and neutral zone), using the intact cadaveric specimen state as a control for the interventions performed on each individual specimen. A post hoc power analysis was conducted as a paired t test for each pair of possible combinations, yielding specific power for each paired comparison while seeking either superiority or equivalence.

Results
The specimens consisted of 4 female and 4 male donors with a mean age (± SD) of 67 ± 23 years and mean body mass index of 21.7 ± 2.0, comprising 4 left and 4 right hemipelvis. The specimens in this study had an average lateral center-edge angle of 48.9° ± 7.6° (range, 37.6° to 61.1°). The torque–angular displacement response was nonlinear, with a clear hysteresis area between the positively and negatively loaded curves (Fig 3). The mean ROM (throughout external and internal rotation) sequentially increased from 100% (intact) to 107.42% ± 5.69% (4 cm) and to 113.40% ± 7.92% (6 cm) before returning to 99.78% ± 3.77% on capsulotomy repair. A statistically significant relation regarding ROM existed between the intact and 6-cm conditions (P = .039), as well as between the intact and 6-cm conditions (P = .0001). Statistical significance was also present between the 4-cm and repair conditions (P = .033) and between the 6-cm and repair conditions (P = .0001). There was no statistically significant difference between the intact and repair conditions (P > .99) or between the 4- and 6-cm conditions (P = .126).

Hysteresis area, likewise, increased from 100% (intact) to 108.30% ± 9.30% (4 cm) and to 115.30% ± 13.92% (6 cm) before decreasing to 99.47% ± 4.12% (repair). For hysteresis area, a statistically significant relation was only seen between the intact and 6-cm capsulotomy conditions (P = .007) and between the 6-cm capsulotomy and repair conditions (P = .005).

Neutral-zone measurements also displayed sequential increases from 100% (intact) to 139.61% ± 62.35% (4 cm) and to 169.25% ± 78.19% (6 cm) and eventually decreased to 132.03% ± 64.38% (repair). However, none of the capsular conditions displayed
statistical significance ($P < .05$) regarding any other capsular condition.

Table 1 summarizes the results of the stability measurements, and Figure 4 presents the findings graphically. There was a statistically significant relation between the size of both the 4-cm capsulotomy and the 6-cm capsulotomy and the intact hip in terms of ROM. Similarly, significance was seen between the repaired state and capsulotomy conditions. $P$ values for the hysteresis area and neutral zone are presented in Table 2. There was a lack of a statistically significant difference between the intact and repaired hips regarding ROM ($P > .99$), hysteresis area ($P = .999$), and neutral zone ($P = .706$). As for joint stiffness, although there was no statistical difference between the positive and negative loading slopes ($P > .05$), both parameters were significantly larger relative to the neutral-zone slope for all capsular conditions ($P < .05$).

<table>
<thead>
<tr>
<th>Capsular Condition</th>
<th>Range of Motion</th>
<th>Hysteresis Area</th>
<th>Neutral Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intact</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>4 cm</td>
<td>107.42% ± 5.69%</td>
<td>108.30% ± 9.30%</td>
<td>139.61% ± 62.35%</td>
</tr>
<tr>
<td>6 cm</td>
<td>113.40% ± 7.92%</td>
<td>115.30% ± 13.92%</td>
<td>169.25% ± 78.19%</td>
</tr>
<tr>
<td>Repair</td>
<td>99.78% ± 3.77%</td>
<td>99.47% ± 4.12%</td>
<td>132.03% ± 64.38%</td>
</tr>
</tbody>
</table>

NOTE. Data are presented as mean ± standard deviation.
A post hoc power analysis showed equivalence of the repaired and intact conditions but superiority (or inferiority) of the 4- and 6-cm conditions depending on the direction of the scores (Table 3).

**Discussion**

Under the conditions of this biomechanical study, the size of the interportal capsulotomy exhibited a dose-dependent relation regarding joint mobility whereas complete capsular closure effectively restored these measures when compared with their intact condition. Our study explored the biomechanical effect of 2 different sizes of interportal capsulotomy and subsequent repair in a model that included the hip joint and surrounding soft-tissue envelope using kinematic parameters to assess the stability and movement constraints of the joint under external rotation in the neutral position. The size of the capsulotomy had a dose-dependent effect on hip ROM, hysteresis area, and neutral zone and provides further biomechanical evidence that a capsulotomy has significant effects on hip stability as it pertains to rotational motion about the transverse plane. On repair of the interportal capsulotomy, these 3 measures of joint stability decreased to conditions similar to those of the intact capsular state as evidenced by the lack of statistically significant differences ($P > .05$) between the intact and repaired conditions as seen in all 3 measures of stability.

**Table 2.** $P$ Values Distinguishing Differential Results Between Each Testing Condition ($\alpha = .05$)

<table>
<thead>
<tr>
<th>Comparison of Capsular Conditions</th>
<th>Range of Motion</th>
<th>Hysteresis Area</th>
<th>Neutral Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intact v 4 cm</td>
<td>.039</td>
<td>.241</td>
<td>.551</td>
</tr>
<tr>
<td>Intact v 6 cm</td>
<td>&lt;.0001</td>
<td>.007</td>
<td>.116</td>
</tr>
<tr>
<td>Intact v repair</td>
<td>&gt;.99</td>
<td>.999</td>
<td>.706</td>
</tr>
<tr>
<td>4 cm v 6 cm</td>
<td>.126</td>
<td>.382</td>
<td>.753</td>
</tr>
<tr>
<td>4 cm v repair</td>
<td>.033</td>
<td>.195</td>
<td>.994</td>
</tr>
<tr>
<td>6 cm v repair</td>
<td>&lt;.0001</td>
<td>.005</td>
<td>.600</td>
</tr>
</tbody>
</table>

**Table 3.** Achieved Statistical Power for Each Paired Comparison

<table>
<thead>
<tr>
<th>Comparison</th>
<th>ROM</th>
<th>Neutral-zone ROM</th>
<th>Hysteresis Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intact v 4 cm</td>
<td>.701</td>
<td>.173</td>
<td>.355</td>
</tr>
<tr>
<td>Intact v 6 cm</td>
<td>.912</td>
<td>.350</td>
<td>.533</td>
</tr>
<tr>
<td>Intact v repair</td>
<td>.018</td>
<td>.105</td>
<td>.022</td>
</tr>
</tbody>
</table>

NOTE. The analysis was performed a posteriori.
ROM, range of motion.
The nature of this type of experimental study only allows one to assess the biomechanical properties at “time zero,” and therefore, such a study is not able to take into account any potential effects of healing and rehabilitation on ROM and stability. Furthermore, in vivo the overall stability of the hip might be more significantly affected by the underlying anatomy with abnormal osseous constraints (e.g., coxa profunda, pincer deformity, mild hip dysplasia) and soft-tissue conditions in patients with hyperlaxity (e.g., Ehlers-Danlos syndrome).

All 3 chosen measures of biomechanical joint stability successively increased with larger capsulotomies, and capsular repair was able to completely restore both ROM and hysteresis area to intact states. On the basis of these findings, capsular conditions might be ordered from most to least stable as follows: intact, repair, 4-cm capsulotomy, and 6-cm capsulotomy. Despite the lack of a statistically significant difference between the 4- and 6-cm capsulotomies, a 2-cm extension of a 4-cm capsulotomy to a 6-cm capsulotomy did create sizable increases in kinematic parameters. There is an inherent limitation in choosing an absolute parameter such as distance as opposed to a relative parameter such as percentage of capsular circumference. With larger hips, 4 or 6 cm might have less clinical impact compared with smaller hips. However, the study did not aim to provide the clinician with a specific number for a safe interportal capsulotomy; rather, it was intended to highlight the dose-dependent nature of destabilization created by larger capsulotomies. The clinical relevance lies in cautioning surgeons to minimize their interportal capsulotomies to prevent potential iatrogenic microinstability and minimize the risk of potential macroinstability with a possibly elevated risk of dislocation. Another consideration that could explain this difference is the possibility that depending on the location of the capsulotomy relative to the IFL, a complete transection of the IFL may have occurred during testing at the 6-cm capsulotomy size, leading to the observed results. Thus statistically significant differences in instability may occur as a factor of the anatomic construct rather than a chosen capsulotomy size. Although our results clearly show a significant increase in the measured parameters of joint kinematics with large interportal capsulotomies, the lack of observed clinical instability in this setting is likely a reflection of the dynamic contributions to the hip capsule that act in concert to maintain an in vivo joint kinematic profile under these conditions. It is our belief that capsular repair should be performed to best restore the structure and static stabilizing function of the capsuloligamentous complex back to that of its intact condition.

Prior studies have provided evidence of altered biomechanical behavior after hip joint capsulotomy. When hips were tested in a neutral position, there was an increase in distal, lateral, and anterior translation of the femoral head relative to the acetabulum.22,32 With hips tested in flexion, there appeared to be a greater degree of rotational motion as opposed to translation. Further investigation of internal/external rotational stability and translational effects of the hip joint with capsulotomies is necessary to understand the consequences of these interventions.

The very concept of hip stability and its method of assessment have been subject to debate. On one side of the discussion, it is argued that stability and the method to evaluate it are not validated for the hip. Proponents of this idea claim that the load-displacement diagram as presented in cases of spine kinematics12,14,16,20 would not be applicable to the study of hip motion in vitro because the spine can be characterized as an amphiarthrodial joint instead of a diarthrodial joint like the hip. Another point of contention is not acknowledging the existence or biomechanical utility of the concept of the neutral zone beyond the spinal flexion-extension motion. It is further stated that even though the findings of increased ROM, neutral zone, and hysteresis area with capsulotomy are founded on a sound study design, the extrapolation to “stability” is not valid. These findings for the hip would be better categorized as changes in mobility or stiffness, rather than stability, and should be changed.

On the other side of the discussion, we argue that yes, it is appropriate to study any joint in the body as it has been done before. We acknowledge that the use of the term “stability” in this case may be open to debate because it has not been standardized, and in biomechanics, we draw knowledge and terminology from several scientific fields. Some applicable synonyms or at least similar concepts would be joint “laxity,” joint “stability”/“instability,” and to a certain extent, “mobility,” as suggested by the opposing camp in this discussion. The main feature of the work described in this article is that the kinematic features of the hip joint are (as expected) altered when the capsule is incised and/or repaired. The established experimental method to quantify and visualize the changes in these properties is to plot the corresponding load-displacement diagram because this is a load-control experiment.

When a load is applied to 2 rigid bodies that are connected, the resulting “raw data” outcome constitutes the load-displacement diagram, a sigmoid curve that describes both the stiffness and kinematics of the construct (or joint for that matter) being analyzed. The main indicators that describe the joint kinematics are (1) the hysteresis loop, indicative of the influence of mainly internal material friction on the energy applied to deform the material, resulting in its dissipation, and (2) a means to describe the instability of the joint or construct by measuring the length of the neutral zone.
and calculating the slope of the loading/unloading and neutral-zone portions of the curve to provide information about its stiffness and the proportion of the neutral-zone ROM with respect to the overall ROM. The latter indicator is the part that concerns us. These are proven methods to describe the quality of the motion, that is, how “wobbly” or “unstable” a construct is. Because such behavior is independent of the testing method used to characterize it, it does in fact constitute an invariant feature of the joint (i.e., its “mechanical phenotype”). This means that the method used to produce said diagram is not tied to any specific musculoskeletal joint.

Furthermore, biomechanists and clinicians alike know that the human hip (or any other joint) is not a mechanism manufactured with tightly controlled tolerances, and there are some small translations and rotations when motion takes place. With greater fluid and unrestricted motion, the neutral zone will be larger and flatter and the stiffness of the joint (the slopes) will tend to be more vertical. This fact has been observed in other musculoskeletal joints (and other manmade joints) as shown in the following small but representative list of cases, which further support and validate this approach: hip, knee, spine, carpal joint, and structural steel frames. Therefore we believe that this method does not need any further validation for the specific case of the hip.

The IFL is thought to be the primary stabilizer for the hip joint, but the acetabular labrum is also thought to contribute to hip joint stability. A recent study simulating typical capsulotomy incisions used during hip arthroscopy found that external rotation and anterior translation were both significantly increased when the IFL alone was sectioned. Further increases occurred when the labrum and IFL were both sectioned. Repair of the labrum alone, however, did not result in normalization of external rotation or anterior translation. Repair of the labrum in conjunction with repair of the IFL adequately restored these parameters to the native intact state.

A recent study by Walters et al. explored the capsular anatomy of the hip and showed that there exist important static and dynamic contributions to the hip capsule, which have been speculated to have varying overall effects on stability. The horizontal and vertical limbs of the IFL are the primary static stabilizers of the anterior capsule, and their location and course have been previously characterized. These are supplemented by the dynamic capsular contributions including a broad superior and superolateral capsular contribution by the gluteus minimus, by the reflected head of the rectus superomedially, and by the iliocapsularis anteriorly and medially. In combination, these dynamic and static pericapsular structures resemble an arc that the previous authors called the “stability arc.” Per their description, the stability arc lies directly anterior to the femoral head and spans the anterior hip capsule from its acetabular apex to its lateral insertion along the intertrochanteric line. The borders of this arc are outlined by the dynamic (iliocapsularis, reflected head of rectus, and minimus) and static (horizontal and vertical limbs of IFL) contributions to the anterior hip capsule. Given these findings, the authors proposed that a small interportal capsulotomy parallel to the labrum poses little risk to the stability arc because it does not violate the arc complex. If, however, a lateral capsulotomy is performed (by itself or as a T-capsulotomy in combination with an interportal capsulotomy), the arc complex is violated with the proximal and distal components separated. This results in the dynamic muscular contributions of the proximal (gluteus minimus) and distal (iliocapsularis) limbs separating the superior and inferomedial capsular components. In turn, subluxation of the femoral head is facilitated when moving into extension and external rotation. As a result, there is a greater risk of postoperative instability because of capsular integrity issues, and the authors have therefore advocated capsular repair in this setting to re-create stability.

Because hip arthroscopy typically demands visualization of the central and peripheral compartments, the capsulotomy unfortunately is required to allow the surgeon to address chondrolabral injury and osseous pathomorphology. The risk of inducing iatrogenic dislocation or macroinstability has been well documented but is also thought to be under-reported. Furthermore, increasing capsulotomy size, particularly if left unrepaird, is a significant risk factor for both macroinstability in cases of iatrogenic dislocation and microinstability. Microinstability may be much more common and describes a clinical scenario in which patients may present postoperatively with vague pain, apprehension, normal radiographs, and capsular abnormalities or defects on magnetic resonance imaging.

Until now, the utility of capsular repair has been debated after several observations of instability and persistent pain after hip arthroscopy in select patient populations without capsular closure. Given recent anatomic and biomechanical studies, we believe that capsular repair facilitates the restoration of the anatomic structure and function of the IFL. Favorable mid-term outcomes have been reported across patient cohorts in which capsular cuts were left untreated. Our findings, however, show that both 4-cm and 6-cm capsulotomies led to an increase in joint ROM and viscoelastic dissipation. Thus capsular repair may facilitate biomechanical restoration of stability and provide static tensioning of the anterior capsule, at least initially postoperatively, and therefore may prevent postoperative macroinstability and microinstability.
External rotation from a neutral flexion position was assessed with intact soft tissue overlying the hip capsule. This study shows the difficulties, at present, in analyzing hip stability in a clinically relevant model using cadaveric hips. A better clinical model must be developed to better understand the relative contributions of static and dynamic capsular stabilizers. Further investigation into iatrogenic instability created with inclusion of a lateral capsulotomy or T-capsulotomy would expand on the current knowledge and could contribute to further suggestions regarding capsular management in hip arthroscopy.

Limitations
Because we used a cadaveric model, the study’s clinical relevance is limited by the fact that static in lieu of dynamic forces were applied to and analyzed in the hip joint. Moreover, specimens were likely to have significantly decreased muscle mass given that subjects from whom specimens were obtained had a relatively advanced mean age of 67 years. This would affect the level of stabilization that a larger muscle mass would confer in the young target population. Another limitation is the fact that mini-open dissections were performed as opposed to an actual arthroscopic procedure. During the process, requiring a significant deal of blunt dissection and retraction, tissue relations had become altered. A minor potential source of error includes the frictional forces exerted by the wire/pulley system, which could have an effect on the ROM data collected. Conditions for the capsular repair, although performed at neutral rotation as is performed in the typical hip arthroscopy case, were suboptimal because the specimens underwent intervention while still vertically oriented on the servohydraulic frame. Moreover, only movements in pure external and internal rotation were analyzed because any more complicated maneuvers, such as those similar to actual gait or athletic maneuvering, were not performed, and the specimens were not tested in hyperextension. The pulley system used in this study was not configured with a jig capable of testing other motions such as flexion/extension. The study was underpowered in some comparisons, but these comparisons still are meaningful given the expected findings resulting from the altered capsular structure.

Conclusions
Under laboratory-based conditions, larger-sized capsulotomies were accompanied by increases in all 3 measures of joint mobility: ROM, hysteresis area, and neutral zone at time zero. Complete capsular closure effectively restored these measures when compared with the intact condition.

Acknowledgment
The authors acknowledge and thank Rush University’s Research Mentoring Program and Dr. Kumar B. Rajan for providing statistical analysis support.

References


Clinical Examination of the Hip

Hal David Martin, DO

The hip history involves the standard medical history review components in addition to screening for hip related complaints with emphasis on function and activity. Primary systems of diagnosis have direct correlation of historical relevance, requiring a systematic approach to the history. The patient's function status can be defined by symptoms reported during rotation with load. Rotation sports commonly have been associated with injuries to the intra-articular structures, including the acetabular labrum and ligamentum teres. The twenty-point examination is a tool to help organize the structure of the physical examination. It will aid in the diagnosis or screening of the osseous, ligamentous, and musculotendinous pathological conditions. The physical exam is performed in three positions: the standing, sitting, lateral and supine examinations. A thorough evaluation takes time and thorough understanding of the anatomy.

Oper Tech Orthop 15:177-181 © 2005 Elsevier Inc. All rights reserved.

KEYWORDS history, symptoms, hip physical exam

Key components in the history and physical examination are of paramount importance in assisting with a diagnosis in patients presenting with hip pain. Most authors agree on the basics of traditional quality, region, severity, and timing of pain. The hip history is composed of the first 3 steps in standard form of age, chief complaint, and presence or absence of trauma. In addition, hip pain history is assessed through documentation of length of symptoms, previous treatments, past injuries, limitations, associated complaints, and sports and activity level. Patient expectations and the goals of treatment also should be addressed.

The physical examination of the hip is evolving as our technology for understanding normal and pathological hip conditions progresses. To make an accurate diagnosis and treatment recommendations, examinations should be performed in a systematic, reproducible order. The benefit to understanding the osseous, ligamentous, and musculotendinous contributions, which may coexist in pathological presentation, cannot be underestimated. Conditions related to genitourinary, gastrointestinal, neurologic, and vascular etiology compound the importance of a thorough, all-encompassing examination.

Patient History

A thorough evaluation of the patient history is necessary. The modalities used by the patient or other physicians to treat the hip, including nonsteroidal anti-inflammatory drugs, physical therapy, injections, or use of assistive devices, such as cane or crutches, should be documented. Any previous surgical intervention should also be considered useful information on hip pathology. It is important to determine whether the patient has reinjured himself or herself after the previous surgery or if his or her symptoms did not improve or worsen after surgery.

In addressing the history of the present illness, symptoms, such as pain, severity of symptoms, and timing of the injury, are standard questions. The date of onset is first recorded with the presence or absence of trauma. The location of pain or discomfort with description of pain type is useful with exacerbating or decreasing factors. In addition to pain, the presence of popping or locking and anatomical locations of the symptoms is useful in determining intra-articular or extra-articular emphasis in examination. The positions in which the symptoms occur and which positions aid in diminishing the discomfort or locking are noted. The presence of mechanical symptoms has a positive predictive value in determining the possible outcome in hip arthroscopy related treatment of internal derangement, such as a torn acetabular labrum. Back pain also can be a common diagnostic tool and may exist in combination with hip pathology. The exact location, with degree of discomfort, is expressed as a dominant or mild component to the primary complaint. The
presence of nocturnal awakening with discomfort, numbness, and weakness are expressed with the exact region involved.

The patient's functional status can be useful in determining the presence of symptoms with rotation under load. The ability to perform sports, level of activity from running, jogging, walking, stairs, sitting, work capacity, activity of daily living, and any household activity restriction is documented. The nature of sports in which the patient is involved is useful again to determine the type of injury. Rotation sports, such as golf, tennis, ballet, and martial arts, have been associated commonly with injuries to the intra-articular structures including the acetabular labrum and ligamentum teres. Damage to the iliofemoral ligament with similar sports has been reported.

Treatment may vary based on the patient's expectations and postoperative goals. Unrealistic goals should be addressed before any diagnostic testing and treatment recommendations. Understanding of the expected outcome for each option should be explained thoroughly and completely. Good communication is important to obtaining any history. Time, understanding, empathy, and compassion are of paramount importance in working through differences in expectation and can save much undue hardship later.

**Physical Examination**

The 20-point examination is a tool to help organize the structure of the physical examination in a simple, reproducible manner, to aid in the diagnosis or screening of the osseous, ligamentous, and musculotendinous pathological conditions. The physical examination is performed in 3 positions: the standing, sitting, and lateral and supine examinations. Each position has 5 components for assessment.

**The Standing Examination**

The 5 points in this position to be evaluated include gait, spinal alignment, Trendelenburg's test, laxity test, and leg length. The gait should be observed so that full stride length can be observed from the frontal and sagittal planes. Common key points should include the stride length, stance phase, foot rotation (internal/external progression angle), pelvic rotation in the x and y axes, Trendelenburg gait, antalgic gait patterns, leg length issues, and pelvic winks. The pelvic winks demonstrate excessive rotation in axial plane greater than the normal 40° toward the affected hip to obtain terminal hip extension. This gait pattern is associated with internal hip pathology and secondary hip flexion contracture.

Shoulder heights should then be observed with the iliac crest to further address leg length issues. Measure the anterior superior iliac spine to medial malleolus and record any discrepancy. Forward bending will allow the inspection of the spine from behind for scoliosis, and lateral inspection of the lumbar spine for any excessive lordosis or paravertebral muscle spasm. A tight iliospos will produce an increase in the lumbar lordosis, similar to the finding in neuromuscular disease. Trendelenburg's test should be performed on both legs, first nonaffected and then the pathologic, to help establish a baseline proprioceptive function (Fig. 1). The acetabular labrum is dense with receptors. The Trendelenburg's test is helpful in testing not only the strength of the abductor mechanism, but also the entire affective loop. Laxity examination should include inspection of the middle finger, knee, and elbow. Hyperextension at the knee or the elbow greater than 30° is important in the determination of the interrelationship of the osseous, ligamentous, and musculotendinous function.

**The Sitting Examination**

The sitting examination is composed primarily of the basics of extremity assessment. Neurologic evaluation comprises the motor assessment of the obturator, superior gluteal, sciatic, and femoral nerve function graded on a standard 0 to 4/4 scale. Sensory of the L2 through S1 should be compared left to right. The straight leg raise should be performed to aid in the differential of radicular etiologies. The deep tendon reflexes are recorded in traditional fashion at the Achilles and patellar region and graded 0 to 4/4. The pulses of the dorsalis pedis and posterior tibialis are recorded as present or absent. The skin and lymphatics are inspected, compared, and any scarring of extremity noted.

Many differential diagnoses exist in the presentation of hip pain. One of the most common is lumbar spine pathology, which may exist concomitantly or independently of hip pa-
tion of hip pain with rotation in the abducted position, opposing the anterior superior rim of the femoral neck adjacent to the twelve-o'clock position of the acetabulum. Pain may be referred to the spine or the sacroiliac joint directing further evaluation to these areas. The abdominal examination should include the basics of inspection, palpation for mass or fascial hernia, which can be assessed by isometric contraction of the rectus abdominis and obliques. The ilioinguinal region should be inspected; Tinel's at the femoral nerve and palpation of the femoral pulse are assessed. Palpation for abdominal or iliopsoas mass should be performed on all patients. Palpation of the adductor tubercle as the patient adducts the extended leg may help identify adductor tendinitis. Finally, Stinchfield and Fulcrum tests will aid in the diagnosis of internal derangements primarily of the anterior portion of the acetabulum.

Lateral Hip Examination

The lateral hip examination is performed with the patient in the lateral position lying on the unaffected hip with shoulders at 90° to the table. The tests of the lateral position are useful in the determination of lateral based hip pain and in further confirmation of intra-articular pathology. First, palpation of the sacroiliac joint, gluteus maximus origin, piriiformis, sciatic nerve, iliobial band, greater trochanteric bursae, tensor fascia lata, and ischial tuberosity are performed to locate the exact area of discomfort. The Ober's test, flexion adduction internal rotation test, and the abduction extension external rotation complete the five tests in the lateral position (Figs. 4-6). The Ober's test is performed in both the extended hip with the knee flexed in traditional fashion, as well as with the shoulders rotated back toward the table starting with the knee straight to assess the gluteus maximus contribution to the iliobial band. Knee flexion may decrease the pain at the maximus origin in cases with specific gluteus maximus con-
combination with flexion and extension will help in distinction of internal and external popping. The Scour's can also be performed in the supine position. It attempts to elicit pain of clicking with passive flexion through an arc of external rotation to internal rotation. The abduction extension external rotation test is comparable to the apprehension test in the shoulder. The knee is straight with the hip abducted at 30°, in neutral rotation, and brought from 10° flexion to terminal extension externally rotating the straight leg while pushing forward on the greater trochanter to reproduce any complaint of pain or discomfort. A positive test is relief of the pain once the anteriorly directed force is released. A positive test can be associated with microinstability or combined anterior anteverision, acetabular anteverision, or strain of the iliopsoas tendon, either chronic or acute.

The examiner stands behind the patient with the arm beneath the patient’s lower leg, grasping the knee, while the opposite hand of the examiner is monitoring the hip in front with the index finger and thumb behind. Passive rotation in
will produce a positive examination. The emphasis in lateral examination should be directed toward the primary area of complaint and additional examinations performed as necessary.

The prone examination or additional tests are included as necessary. The Ely test is performed to check for rectus femoris contracture. The Craig's test is intermittently helpful in determination of femoral anteverision. The modified Thomas test is also useful in determination of isolated iliopsoas contracture or in combination of rectus femoris contracture. The prone position is helpful in palpation of the exact location of the sacroiliac (SI)-related pain. The SI region should be palpated in 3 areas: the infra SI region adjacent to the origin of the glutus maximus, the spinous process of L5-L4, and the supra SI region. The knee and ankle should be considered as additional examinations or as part of the routine physical assessment.

**Discussion**

The differential of hip pain can be vast and confounding to even experienced hip surgeons and diagnosticians. Patient history and the physical examination will assist in screening the patient with a painful hip and in directing further evaluative studies. The history should be recorded in a reproducible and systematic method using useful questions to direct the physical examination. Next to age, the presence of trauma is next most important in directing the course of the physical examination to be performed, and in which order. As with any examination, practice is essential to gain an appreciation of nuances of normal and pathologic. When used consistently and with practice, the twenty point hip examination will help formulate an osseous, ligamentous and musculotendinous differential diagnosis. Many times, the patient with hip pain is presenting with multifactorial symptoms. A thorough evaluation takes time and thorough understanding of the anatomy, of osseous, ligamentous, and musculotendinous structures in and about the hip.

**References**

The hip assumes an essential role in most sports-related activities. The hip is not only responsible for distributing weight between the appendicular and axial skeleton, but it is also the joint from which motion is initiated and executed. It is known that the forces through the hip joint can reach three to five times the body’s weight during running and jumping [1,2]. Considering the amount of demand athletes place on their hips, orthopedic surgeons will evaluate them as patients having hip pain.

Ten percent to 24% of athletic injuries in children are hip related, and 5% to 6% of adult sports injuries originate in the hip and pelvis [3]. Ballet dancers are most likely to have a hip-related injury, and runners, hockey players, and soccer players are also prone to hip injuries [3]. Athletes participating in rugby and martial arts have also been reported as having increased incidence of degenerative hip disease [4–10]. Hip pain often stems from some type of sports-related injury [11–14]. In patients presenting with hip pathology, the hip is not recognized as the source of pain in 60% of all cases [15].

Hip pain has been documented in three categories: anterior-, lateral-, and posterior-based hip pain [16], with multiple etiologies. A short physical examination, complete with a history and evaluation of present illness, is fundamental and necessary in determining the source and cause of the presenting complaint. The results of these two assessment techniques will direct which radiological examination to consider. The history of present illness and physical assessment should be adequate if the physician suspects a specific diagnosis, and radiographic examination should be enough for a conclusive diagnosis to be made [1,4].

Diagnosing hip pain in athletes has been difficult for physicians in the past because of the parallel presenting symptoms shared with back pain, which may exist concomitantly or independently of hip problems [17]. Radiating pain below the knee, palpable pains in the hip and back, and weakness or sensory limitations...
blur the lines in appropriately differentiating between the hip and back [17–22]. Low back pathology involving the paravertebral muscles can lead to an abnormal soft tissue balance, causing an irregular tension absorbed by the hip joint, which leads to knee pain, groin pain, leg length discrepancies, and limited ranges of motion in the hip [23]. Muscle contractures of the hip flexors or extensors as well as leg length discrepancy have also been identified as factors that can cause hip and low back pain to present together [24–28]. Brown and colleagues [17] proposed that limited internal rotation associated with a limp and groin pain were the physical signs to make the distinction of hip-related pathology. The biggest problem facing physicians treating hip-related pathologies is the absence of a valid diagnosis [29].

The physical examination of the hip is evolving as the ability to understand normal and pathological conditions of the hip progresses. The physical examination of the hip is designed to detect a wide variety of pathologies, and has been developed by many generations of surgeons, therapists, and physicians [30–32]. The examination of the hip is optimally performed in a systematic and reproducible fashion in order to facilitate accurate diagnoses and treatment recommendation. The benefit of understanding the osseous, ligamentous, and musculotendinous contribution to the underlying pathology cannot be overestimated. Surgical and nonsurgical treatment outcomes will depend on a consistent method of evaluation to understand which treatments produce the optimal results for a particular type of patient. Conditions related to genitourinary, gastrointestinal, neurologic, and vascular systems, though unlikely in a sports-related injury, can compound the complexity of the assessment. This complexity also emphasizes the importance of a thorough examination.

An 11-point physical evaluation is a tool presented here to help organize the structure of the physical examination of athletes in a simple, reproducible manner, in order to differentiate between hip and back pathology and categorize the hip pain presented. The evaluation aids in the diagnosis of anterior, lateral, and posterior etiologies of the hip in regards to the osseous, ligamentous, and musculotendinous structures. An organized approach, with a systematic structure as used in evaluating other joints, will benefit both the patient and the physician.

The 11-point examination is described below in five parts: the standing, seated, supine, lateral, and prone examinations. The technique of the physical examination is discussed, along with the diagnostic tools that may further the investigation of suspected pathology.

A verbal history including mechanism, time of injury, location, and severity of pain should be obtained. The focus of this article is to describe the physical element of the examination. It should be noted that with any clinical examination the reproduction of pain or limited movement constitutes a positive test sign.

**ELEVEN-STEP EXAMINATION**

**Standing Examination**

The initial element in the structured evaluation (Table 1) should be the general body habitus, principally gait and alignment. Because of the hip’s role in
supporting body weight, hip pathology can often be identified in gait abnormalities [1]. An antalgic gait (one that involves a self-protecting limp caused by pain, characterized by a shortened stance phase on the painful side so as to minimize the duration of weight bearing) is an indication of hip, pelvis, or low back pain [33,34]. The gait should be observed so that the full stride length can be assessed from the front and side [30]. Common key points of evaluation should include stride length, stance phase, foot rotation (internal/external progression angle), and the pelvic rotation in the X and Y axes [1,30,32]. It is recommended that the patient walk down the hall if the room is not big enough to give the physician a chance to observe six to eight full strides.

A Trendelenburg gait is indicative of hip abductor weakness, and is often referred to as an abductor lurch. The pelvic wink displays excessive rotation in the axial plane (greater than the normal 40°) toward the affected hip to obtain terminal hip extension. This gait pattern is associated with internal hip pathology or with hip flexion contractures, especially when combined with increased lumbar lordosis or a forward-stooping posture. Special attention should be given to a limp, noting that a limp with an external foot progression could indicate effusion or traumatic condition. Consideration should also be given to any snapping or clicking the patient or physician hears, noting location as internal or external to the hip joint or derived from within the joint itself. This audible sign could be indicative of psoas contracture (coxa sultans interna), tightness of the iliotibial band (coxa sultans externa) or intra-articular pathology. Coxa sultans interna/externa can be distinguished by the patient actively demonstrating the pop by recreating the sound as he rotates the hip.

The second aspect in observing general body habitus is alignment. Compare the patient’s shoulder heights with the heights of the iliac crests to further any leg length discrepancy issues. Other palpable bony structures for pelvic alignment assessment include the anterior superior iliac spine and posterior superior iliac spine. A tilted pelvis can indicate a leg length discrepancy, which can be further investigated by measuring leg lengths manually from the anterior superior iliac spine (ASIS) to the ipsilateral medial malleolous in order to differentiate between

<table>
<thead>
<tr>
<th>Table 1</th>
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<tbody>
<tr>
<td>Standing examination</td>
</tr>
<tr>
<td>Examination</td>
</tr>
<tr>
<td>Body habitus</td>
</tr>
<tr>
<td>1. Spinal alignment</td>
</tr>
<tr>
<td>2. Gait</td>
</tr>
<tr>
<td>a. Trendelenburg</td>
</tr>
<tr>
<td>b. Antalgic</td>
</tr>
<tr>
<td>c. Pelvic rotational wink</td>
</tr>
<tr>
<td>d. Excessive external rotation</td>
</tr>
<tr>
<td>e. Excessive internal rotation</td>
</tr>
<tr>
<td>f. Short leg limp</td>
</tr>
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</table>

**CLINICAL EXAMINATION OF THE ATHLETIC HIP**
true and functional leg length discrepancies [32]. A true leg length issue is present when the bony structures are of different proportions. Functional leg length issues arise when muscle spasms, scoliosis, or deformities of the pelvis cause the truly identical leg lengths to function as if they were disproportionate.

Lateral inspection of the lumbar spine is effective for detecting postural or kinetic abnormalities such as excessive lordosis or paravertebral muscle spasm. Increased lumbar lordosis is a common finding in patients who have hip flexor contractures involving the psoas muscle. The spine is initially evaluated with forward bending, recording the range of motion. This assessment will allow inspection of the spine from behind for the purpose of detecting types of scoliosis.

In addition to body habitus, the second point of examination in the standing position involves Trendelenburg’s sign. The Trendelenburg’s test should be performed on both legs, and the nonaffected leg should be examined first. This test helps to establish a baseline for the patient’s neuroproprioceptive function. As with the indications of the Trendelenburg’s gait abnormality, this assessment evaluates the proper mechanics of the hip abductor musculature and neural loop of proprioception. When the right foot is lifted, the left abductor muscles are being tested. If the musculature is weak, the pelvis will tilt toward the unsupported side. The shift of the pelvis should not be more than 2 cm at the midaxis in either the ipsilateral or contralateral direction. A shift of greater than 2 cm constitutes a positive Trendelenburg’s sign.

Seated Examination

The sitting examination (Table 2) is composed primarily of the basic evaluation points of extremity assessment, the neurocirculatory evaluation, and the rotational ranges of motion. Even in the healthy individual, standard basic assessment should be followed.

<table>
<thead>
<tr>
<th>Examination</th>
<th>Assessment/association</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neurocirculatory evaluation</td>
<td>Pulse, sensation, motor strength, deep tendon reflexes</td>
</tr>
<tr>
<td>Straight leg raise</td>
<td>Radicular neuropathy</td>
</tr>
<tr>
<td>Ranges of motion</td>
<td>Internal and external rotation</td>
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<table>
<thead>
<tr>
<th>Score</th>
<th>Motor function</th>
</tr>
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<tbody>
<tr>
<td>0</td>
<td>No muscle function</td>
</tr>
<tr>
<td>1</td>
<td>Some visible movement</td>
</tr>
<tr>
<td>2</td>
<td>Full range of motion, not against gravity</td>
</tr>
<tr>
<td>3</td>
<td>Movement against gravity, but not resistance</td>
</tr>
<tr>
<td>4</td>
<td>Movement against resistance, less than normal</td>
</tr>
<tr>
<td>5</td>
<td>Normal strength</td>
</tr>
</tbody>
</table>
The neurocirculatory evaluation consists of the motor function, perceived sensation, and circulation appraisal. The motor portion includes assessing muscles supplied by the obturator, superior gluteal, sciatic, and femoral nerves. The function is assessed and graded on a 0 to 4/4 scale (Table 3). The sensory assessment includes evaluation of the sensory nerves originating from the L2 through S1 levels, and the sensory function should be compared (left to right) to assess uniformity. Neurologic function can be further evaluated by the deep tendon reflexes (Table 4). Reflexes at the patella (knee-jerk) test the L2–L4 spinal nerves and femoral nerve. Reflexes at the Achilles (ankle-jerk) test the L5–S1 sacral nerves. A straight leg raise is helpful in detecting radicular neurological symptoms, such as the stretching of a centrally entrapped nerve root [35].

The vascular examination includes evaluating the pulses of the dorsalis pedis and posterior tibial arteries. These should be recorded as present or absent on a 0 to 4/4 scale (Table 5). Sensation is assessed by lightly touching both sides of the patient’s thigh and lower leg and asking the patient to compare these subjective findings with the other leg. A common neuralgia occurs on the anterior thigh, deriving from the anterior femoral cutaneous nerve compressed within the femoral nerve, as it passes near the psoas muscle through the pelvic brim [31,36–38]. The skin and lymphatics are also quickly inspected for swelling, scarring, or side-to-side asymmetry.

The second part of the seated examination involves examining internal and external rotational ranges of motion of the hip. The internal and external rotation measurements of the hip are recorded in the sitting position, because it provides sufficient stability and a fixed angle of 90° at the hip joint [16]. Differences may exist in the degree of internal and external rotation in extension and flexion, and assessment of these measurements is subject to substantial variability. The normal range of motion is 20° to 35° for internal rotation and

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
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<tbody>
<tr>
<td>0</td>
<td>No reflex</td>
</tr>
<tr>
<td>1+</td>
<td>Hypoactive (less than normal)</td>
</tr>
<tr>
<td>2+</td>
<td>Normal</td>
</tr>
<tr>
<td>3+</td>
<td>Hyperactive (more than normal)</td>
</tr>
<tr>
<td>4+</td>
<td>Hyperactive with clonus (like a muscle spasm)</td>
</tr>
</tbody>
</table>

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<tr>
<th>Traditional</th>
<th>Basic</th>
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<tbody>
<tr>
<td>4+</td>
<td>Normal</td>
</tr>
<tr>
<td>3+</td>
<td>Slightly reduced</td>
</tr>
<tr>
<td>2+</td>
<td>Markedly reduced</td>
</tr>
<tr>
<td>1+</td>
<td>Barely palpable</td>
</tr>
<tr>
<td>0</td>
<td>Absent</td>
</tr>
<tr>
<td>2+</td>
<td>Normal</td>
</tr>
<tr>
<td>1+</td>
<td>Diminished</td>
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<tr>
<td>0</td>
<td>Absent</td>
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30° to 45° for external rotation. Adequate internal rotation is important for normal hip function, and there should be at least 10° of internal rotation at terminal hip extension. The loss of internal rotation is an important physical finding, because it is one of the first signs of internal hip pathology [29]. The loss of internal rotation at the hip joint can be related to diagnoses such as arthritis, effusion, internal derangements, slipped capital femoral epiphysis, and muscular contracture [29,32]. Pathology related to osteocartilaginous impingement (femoroacetabular impingement) or to rotational constraint from increased or decreased femoral acetabular anteversion can result in significant side-to-side measurement differences [17]. An increased internal rotation combined with a decreased external rotation may indicate excessive femoral anteversion [32]. Further ranges of motion are assessed in the supine examination, below.

### Supine Examination

An important examination position to address the multifactorial presentation of complex hip pathology is the supine position (Table 6). The battery of tests, conducted with the patient in the supine position, helps to further distinguish internal from extra-articular sources of hip symptoms. There are four initial examinations of the athletic hip in the supine position.

The first examination completes the hip ranges of motion initiated in the seated position, focusing now upon flexion, adduction, and abduction. With the patient supine, abduct the affected leg by holding the ankle, and note the degree between the body’s center line and the shaft of the femur. A normal abduction is 45°. To adduct, the leg must cross over the nonaffected leg. Note the degree again between the center line and femoral shaft. Normal adduction is 20° to 30°. During this evaluation, place one hand on the ASIS to assess any

<table>
<thead>
<tr>
<th>Examination</th>
<th>Assessment/association</th>
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<tbody>
<tr>
<td>Ranges of motion</td>
<td>Abduction, adduction, flexion</td>
</tr>
<tr>
<td>Thomas test</td>
<td>Hip flexor contracture (psoas), femoral neuropathy, intra-articular pathology, abdominal etiology</td>
</tr>
<tr>
<td>McCarthy’s</td>
<td></td>
</tr>
<tr>
<td>1. Internal</td>
<td>Anterior femoroacetabular impingement, torn labrum</td>
</tr>
<tr>
<td>2. External</td>
<td>Superior femoroacetabular impingement, torn labrum</td>
</tr>
<tr>
<td>Patrick FABER</td>
<td>Distinguish between back and hip pathology, specifically sacroiliac joint pathology</td>
</tr>
<tr>
<td>Palpation</td>
<td></td>
</tr>
<tr>
<td>1. Abdomen</td>
<td>Fascial hernia or associated gastrointestinal/genitourinary pathology</td>
</tr>
<tr>
<td>2. Pubic symphosis</td>
<td>Osteitis pubis, calcification, fracture, trauma</td>
</tr>
<tr>
<td>3. Adductor tubercle</td>
<td>Adductor tendonitis</td>
</tr>
<tr>
<td>Trauma assessment</td>
<td></td>
</tr>
<tr>
<td>1. Log roll</td>
<td>Effusion, synovitis</td>
</tr>
<tr>
<td>2. Heel strike</td>
<td>Femoral fracture, trauma</td>
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</tbody>
</table>
compensatory motion in the pelvis. Limited adduction/abduction could result from a contracture of the respective musculature. Flexion is recorded by having the patient flex both thighs into the chest, flattening the lumbar spine and keeping the knee flexed to oppose any hamstring tightness. Normal flexion is 120°. Difficulties in flexion result in limited active daily living [1].

The Thomas test is performed to assess any hip flexor contracture that may be present. With the patient holding the nonaffected leg in the flexed position, lower the affected leg to the table. If the thigh cannot reach the table, this represents a positive Thomas test, and is a sign of the hip flexor contraction. Note the angle between the femoral shaft and the table [32]. If a clicking is audible during this test, it may be an indication of a labral tear [16], or coxa sultans externus. Clicking is most indicative of a tear and a louder, more audible pop, is snapping of the psoas tendon.

The McCarthy test is performed in an attempt to re-establish the discomfort felt by the patient in order to discover the underlying etiology. The cause of pain reconstructed from this test is likely a tear of the acetabular labrum. This test is relevant in that most tears occur in the anterior acetabulum, compounded in athletes who have acetabular dysplasia [39–44]. By rolling the hip in a wide arc of internal and external rotation through flexion to extension, the goal is to find a site of bony impingement that may have caused a tear [45]. A positive McCarthy sign is noted by recreation of the patients pain in a specific position.

The Patrick FABER (Flexion ABduction External Rotation) test is the classical physical examination test for the characterization of hip pain in the abducted position. The test is performed by laying the ankle of the affected leg across the thigh of the nonaffected leg proximal to the knee joint, creating a figure 4 position. This position displaces the anterior superior rim of the femoral neck to the twelve o’clock position of the acetabular rim. Pressure is applied to the knee of the affected leg, causing stress in the ipsilateral sacroiliac (SI) joint. Pain in the posterior hip should cause consideration of SI joint pathology. Pain in the groin can be caused by pathology of the iliopsoas muscle, resulting in an iliopsoas sign [32]. Pain in the lateral aspect of the hip can also be associated with lateral femoroacetabular impingement (FAI).

Because of the demands placed on the hip in sports-related activities, it is necessary to assess the hip for trauma. This assessment is made through the log roll test and the heel strike test. Rolling the leg in the Z axis on the table will reproduce pain in femoral fractures. Striking the heel of the foot will reproduce pain if the fracture has occurred in the femoral neck. Positive signs in either of these two tests should warrant radiographic investigation.

Finalizing the supine examination, bony and soft tissue structures around the pelvis should be palpated for tenderness. The abdominal examination should include inspection and palpation for fascial hernias. Fascial hernias may be difficult to detect by palpation, and the isometric contraction of the rectus abdominus and obliques can facilitate their detection. The region of the iliinguinal ligament should be inspected and the presence or absence of a Tinel’s sign (tingling sensation in the distribution of the femoral nerve) at the level of
the ilioinguinal ligament indicating femoral nerve pathology should be noted [32]. Palpation of the adductor tubercle as the patient adducts the extended leg may help identify adductor tendonitis, because point tenderness will be present in this location. Pain with palpation of the pubic symphysis is a cause for further examination of the area. Additional palpation should be continued in the lateral position.

**Lateral Position**

The lateral hip examination (Table 7) is performed with the patient in the lateral recumbent position lying on the unaffected hip with his shoulders perpendicular to the table. The physical examination tests in the lateral position are useful in the determination of lateral-based hip pain, and can further confirm the presence of intra-articular pathology.

Palpation for tenderness is continued, with special attention given to the SI joint, gluteus maximus origin, piriformis, sciatic nerve, iliotibial band (ITB), greater trochanteric bursae, tensor fascial lata and ischial tuberosity [1,16,31, 32,46,47]. Tenderness in one of these regions warrants further examination.

Ober’s test is used to assess the tightness of the ITB and fascia lata. Three positions are examined in this test: extension, neutral, and flexion. These refer to the positions of the affected leg in respect to the nonaffected leg. In extension, the affected leg is abducted with the knee flexed. When the force abducting the leg is removed, the affected leg should adduct due to gravity. If the leg remains abducted, this is a positive Ober’s sign. The neutral position is performed similar to extension with the knee flexed, and is a test of the gluteus medius tension. In flexion, the ipsilateral shoulder should be rotated posteriorly (making both shoulders come into contact with the table) and the knee extended to assess the gluteus maximus origin in cases with gluteus maximus contractures. The ITB tension may be released by flexing the knee, and this technique can

<table>
<thead>
<tr>
<th>Examination</th>
<th>Assessment/association</th>
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<tbody>
<tr>
<td><strong>Palpation</strong></td>
<td></td>
</tr>
<tr>
<td>1. Greater trochanter</td>
<td>Greater trochanteric bursitis, iliotibial band contracture</td>
</tr>
<tr>
<td>2. Sacroiliac joint</td>
<td>Distinguish between hip and back pathology, gluteus maximus assessment</td>
</tr>
<tr>
<td>3. Ischium</td>
<td>Biceps femoris contracture, avulsion fracture, bursitis</td>
</tr>
<tr>
<td><strong>FAI assessment</strong></td>
<td></td>
</tr>
<tr>
<td>1. Flexion, abduction, internal rotation</td>
<td>Anterior FAI, torn labrum</td>
</tr>
<tr>
<td>2. Lateral rim impingement</td>
<td>Lateral FAI, torn labrum</td>
</tr>
<tr>
<td><strong>Ober’s</strong></td>
<td></td>
</tr>
<tr>
<td>1. Extension</td>
<td>Tensor fascia lata contracture</td>
</tr>
<tr>
<td>2. Neutral</td>
<td>Gluteus medius contracture/tear</td>
</tr>
<tr>
<td>3. Flexion</td>
<td>Gluteus maximus contracture, contribution to iliotibial band</td>
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be helpful in isolating and assessing the gluteus medius, specifically for musculo-
tendinous tears. If the affected leg in any position cannot adduct to the table, this constitutes a positive Ober’s sign.

The last examination in the lateral position assesses the degree of FAI present. This series of examinations includes the FADDIR (flexion adduction internal rotation) test. When examining the hip with the patient in the lateral recumbent position, the examiner stands behind the patient with the examiner’s arm beneath the patient’s lower leg. The examiner holds the knee with the supporting hand while the opposite hand monitors the hip. The hand monitoring the hip should grasp the joint with the index finger anteriorly and the thumb posteriorly. Position the leg in FADDIR to assess impingement from the femoral neck, which may have caused an acetabular labral tear. Reproduction of the patient’s pain with this maneuver is suggestive for anterior FAI. A lateral rim impingement can also be assessed by taking the leg from flexion to extension in continuous abduction, trying to reproduce the pain in order to identify impingement. The emphasis in lateral examination should be toward the primary area of complaint, and additional examinations should be performed as necessary.

**Prone Examination**

The prone position is optimal for identifying the precise location of pain related to the SI joint region (Table 8). The SI joints and surrounding region should be palpated in three areas: the infra SI region adjacent to the origin of the gluteus maximus, the supra SI location adjacent to the spinous process of L4–L5, and the SI joint location itself.

<table>
<thead>
<tr>
<th>Table 8</th>
<th>Prone examination</th>
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<tbody>
<tr>
<td>Examination</td>
<td>Assessment/association</td>
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<tr>
<td>Ely Test</td>
<td>Hip flexor contracture, rectus contracture</td>
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<table>
<thead>
<tr>
<th>Table 9</th>
<th>Eleven-step examination of the adult athletic hip</th>
</tr>
</thead>
</table>
| Standing | 1. Body habitus  
2. Trendelenburg’s test |
| Seated | 3. Neurocirculatory evaluation  
4. Ranges of motion |
| Supine | 4. Ranges of motion (continued)  
5. Thomas test  
6. McCarthy test  
7. Trauma assessment  
8. Palpation |
| Lateral | 8. Palpation (continued)  
9. FAI assessment  
10. Ober’s test  
11. Ely’s test |
| Prone | |
The physical examination test recommended for assessing any contracture of the rectus femoris muscle is Ely’s test. This assessment is performed by flexing the knee and drawing the lower leg into the thigh. A negative test demonstrates full flexion of the knee to the thigh with no movement in the pelvis. A positive Ely’s sign demonstrates that with flexion at the knee, the pelvis will tilt, raising the buttocks from the table.

**SUMMARY**

The 11-point athletic hip examination can be effective in screening and evaluating patients who have hip pain, and can be helpful to direct further diagnostic studies (Table 9). A marcaine injection test may be necessary to distinguish between hip and back pathology. This and other auxiliary clinical tests may be helpful in further evaluation of the hip (Table 10). The majority of examinations that compose the 11-point athletic hip examination were developed over many years, before the pathomechanics were fully understood. Individuals using these tests and the tests that have been more recently developed could benefit from validation to determine their accuracy in the detection of the various types of hip pathology. A thorough systematic physical examination coupled with history is the best method to determine subsequent radiologic or diagnostic testing recommendations. As with any examination, practice and repetition are essential to gain an appreciation of what constitutes a normal as well as an abnormal exam. When used consistently and with practice, the 11-point athletic hip examination will help the examiner to formulate an accurate list of diagnostic possibilities and to determine what other diagnostic examinations or techniques may benefit the patient.

**References**


**Table 10**

<table>
<thead>
<tr>
<th>Examination</th>
<th>Assessment/association</th>
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<tr>
<td>Scours</td>
<td>Intra-articular pathology, internal pop/click</td>
</tr>
<tr>
<td>Foveal distraction</td>
<td>Torn labrum</td>
</tr>
<tr>
<td>Extension, abduction, external rotation</td>
<td>Hyperlaxity, high instability index</td>
</tr>
<tr>
<td>Craig’s test</td>
<td>Femoral anteversion</td>
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</table>

The physical examination test recommended for assessing any contracture of the rectus femoris muscle is Ely’s test. This assessment is performed by flexing the knee and drawing the lower leg into the thigh. A negative test demonstrates full flexion of the knee to the thigh with no movement in the pelvis. A positive Ely’s sign demonstrates that with flexion at the knee, the pelvis will tilt, raising the buttocks from the table.


Closed Intramedullary Derotational Osteotomy and Hip Arthroscopy for Cam Femoroacetabular Impingement From Femoral Retroversion

Dean K. Matsuda, M.D., Nikhil Gupta, B.A., and Hal D. Martin, D.O.

Abstract: Femoral retroversion is an uncommon cause of cam femoroacetabular impingement that may require surgical treatment beyond arthroscopic or open femoroplasty. We present the case of a young adult with bilateral severe femoral retroversion in whom such treatment failed. We discuss the rationale, surgical technique, and outcome of this patient, who underwent bilateral closed intramedullary derotational proximal femoral osteotomies and interlocked nailing with adjunctive pre- and post-osteotomy hip arthroscopies. Clinical improvement with normal foot progression angles, radiographic union, and resolution of bilateral cam femoroacetabular impingement from femoral retroversion was achieved. This surgery permits rapid institution of weight-bearing ambulation and an early rehabilitative program. Femoral retroversion may be an underappreciated and insufficiently treated cause of cam femoroacetabular impingement that may be readily detected and successfully remedied with this less invasive procedure.

When the concept of femoroacetabular impingement (FAI) was introduced more than a decade ago, cam impingement from femoral retroversion was listed among several more common causes. On average, femoral anteversion ranges from 30° to 40° at birth and decreases progressively throughout growth, but the range of published normal values for adult femoral anteversion ranges from 8° to 20°, likely because of differences in imaging techniques and/or reference landmarks. One commonly used definition of femoral version is the angular difference between the axis of the femoral neck and the transepicondylar axis of the knee. A recent study found a mean femoral anteversion of 9° in patients who underwent hip arthroscopy for symptomatic FAI. Although the efficacy of surgery for FAI and the arthroscopic method in particular have gained support, there exists a paucity of information regarding the treatment of cam FAI from femoral retroversion. Femoral retroversion amplifies the effect of a cam lesion by engaging the cam lesion into the socket before the initiation of hip flexion. A cam lesion in a patient with normal or increased femoral anteversion may not be symptomatic until terminal hip flexion and internal rotation, with no significant restriction in range of motion, whereas a retroverted femur may engage the rim much sooner, resulting in significant pain and loss of internal rotation with daily activities. One large series showed femoral retroversion in 16.6% of patients with FAI and a significant correlation with osteoarthrosis in this patient population. Another study showed that although internal rotation improves after arthroscopic femoroplasty independent of femoral neck version, patients with abnormal version had altered internal rotation with increased values associated with increased anteversion and decreased values with relative retroversion.

We present a technical note on closed intramedullary derotational osteotomy with adjuvant hip arthroscopy for eradication of secondary cam impingement arising from severe bilateral femoral retroversion.

Case

A 26-year-old man was referred to the primary author (D.K.M.) for consideration of revision hip arthroscopy.
versus possible intertrochanteric osteotomy for severe bilateral femoral retroversion with unabated bilateral deep groin pain despite right and sequential left arthroscopic hip surgeries. He had undergone arthroscopic acetabuloplasty with labral refixation and femoroplasty on each hip approximately 2 years earlier by the coauthor (H.D.M.). He stated that he still walked "like Charlie Chaplin" with noticeable out-toeing and had "never been able to in-toe." His hip examinations showed marked limitation of internal rotation in both extension (internal rotation to 5°) and flexion (internal rotation to 5° with anterior impingement test). Radiographs showed postoperative recontouring of both hips with normal anterior offset ratios (0.21 on the right and 0.22 on the left) and alpha angles (45° bilaterally). Magnetic resonance imaging showed a transepicondylar femoral neck axis of −19° (right) and −9° (left) (Fig 1).

The patient underwent closed right derotational osteotomy with interlocked nailing and adjuvant hip arthroscopy. He subsequently had the same procedure performed on the left lower extremity 3 months later. Both surgeries were performed with overnight hospitalization with immediate weight bearing to tolerance on 2 crutches. The patient had uneventful postoperative courses with full weight bearing without upper extremity aids at 3 weeks and clinical and radiographic union by 3 months. At 15 months and 12 months after the right and left surgeries, respectively, he is able to walk and jog with improved foot progression angles and wants to return to military duty after removal of all metal implants.

**Surgical Technique**

This procedure is a modification of an osteotomy technique originated by Dr. Robert Buly with adjunctive arthroscopic assistance. The patient was placed on a fracture table in the supine position. Hip arthroscopy under general anesthesia was performed through the anterolateral viewing portal with a 70° arthroscope and a modified mid-anterior working portal. Under hip distraction, diagnostic and therapeutic hip arthroscopy was initiated. In this case the anterosuperior labrum was frayed without gross detachment (after previous acetabuloplasty and labral refixation), and the previous anterior femoroplasty site appeared sufficiently recontoured without gross under- or over-resection (Fig 2). Conservative arthroscopic selective labral debridement with a mechanical shaver was performed, with preservation of the labral fluid seal. Blocked internal rotation to 10° on intraoperative anterior impingement testing was confirmed on dynamic arthroscopic visualization with premature abutment of the anteromedial femoral head-neck junction against the anterosuperior acetabular rim. After hip arthroscopy, a seamless progression to derotational osteotomy was performed without a change in setup or re-draping.

**Fig 1.** Preoperative magnetic resonance image showing femoral retroversion of both lower extremities. Distal femoral transepiphyseal axis and femoral neck axis of left (black arrows) and right (grey arrows) lower extremities.
By use of a fluoroscopic C-arm device positioned between the legs so as to enable anteroposterior and lateral projections of the entire left femur, parallel lateral-based Steinmann pins were placed on each side of the proposed osteotomy. The proximal pin was placed through the anterolateral portal into the anterior aspect of the greater trochanter (to avoid intramedullary obstruction) and the distal pin in the transcondylar region. The anteroposterior location of the latter was not critical because the rod did not extend to this level.

A 3-cm vertical incision was made proximal to the greater trochanter with subsequent dissection to its apex. Apical trochanteric pin placement and proximal femoral entry were established under bi-plane fluoroscopic guidance. An intramedullary saw (Winquist saw; Biomet, Warsaw, IN) was selected to match the anticipated maximal external diameter of cortical bone at a level 5 to 6 cm distal to the lesser trochanter. With the saw blade retracted behind the protective cam-shaped tip, antegrade intramedullary insertion was achieved (Fig 3). Once confirmed in the desired intramedullary position, the saw blade was progressively protracted by clockwise rotation of a proximal-based external dial and axial saw rotation performed in incremental fashion until the closed transverse osteotomy was completed (Fig 4). The saw blade was then fully retracted behind the protective cam by continuing to dial in the same clockwise direction (until the dial read “0”) and carefully extracted from the femoral canal.

A reamed intramedullary rod (titanium trochanteric fixation nail system [TFN]; Synthes, West Chester, PA) was then partially seated across the osteotomy site, and controlled internal rotation of the distal segment was performed. To assess sufficient derotation, we viewed the divergence of the parallel-placed pins from a distal-based axial perspective.18 An angular guide (Blade plate guide; Synthes) was used to measure the relative angular degree of rotation. We chose to overcorrect slightly by using a 30° correction for this left femur. Once achieved, the intramedullary rod was fully inserted and proximal screw placement was performed under fluoroscopic guidance. Before placement of a distal interlocking screw, axial alignment and the absence of inadvertent osteotomy site distraction were confirmed.

Repeat hip arthroscopy confirmed impingement-free internal rotation to 30° with flexion—adduction—internal rotation testing. Once we were satisfied with the rotational correction of the femoral deformity, foot alignment in both hip and knee extension, as well as hip and knee flexion, was checked to ensure the absence of any significant compensatory tibial rotational deformity. The supplemental video demonstrates the aforementioned surgery and highlights key procedural steps (Video 1).

Discussion
The primary significance of this technical report is 2-fold. By bringing femoral retroversion into the differential diagnostic algorithm of FAI, perhaps some patients who have eluded diagnosis and/or sufficient treatment may benefit. Moreover, we describe a less
invasive option that may have applicability in correcting more severe deformities.

The classic description of cam FAI includes an abnormal thickness of the femoral neck and/or asphericity at the femoral head-neck junction. The former condition may be reflected by a decreased anterior offset ratio\(^{19}\); the latter, by an increased alpha angle.\(^{20}\) However, we submit that cam FAI may occur in the absence of these findings with femoral retroversion. Though defined as less than 5° of anteversion, femoral retroversion in a clinical sense may be better defined as less than 0° of anteversion (i.e., some degree of true retroversion). The detection of this deformity on physical examination may include an out-toeing gait and significantly less internal than external rotation tested in hip extension and in flexion (with anterior impingement testing). Among various imaging modalities measuring femoral version, magnetic resonance imaging and computed tomography are arguably the most used, with either the distal femoral transepicondylar axis or posterior condylar line being used as a reference.\(^{21-23}\) We suggest that symptomatic patients with suspected cam FAI from femoral retroversion on physical examination undergo magnetic resonance imaging or computed tomography.

If relatively minor retroversion is confirmed, we would consider arthroscopic treatment in the form of femoroplasty. Hip internal rotation can improve to some degree after arthroscopic femoroplasty even in the setting of femoral retroversion.\(^{17}\) Although, conceptually, femoroplasty can eradicate even severe cam FAI, volumetric resection of large amounts of bone at the femoral head-neck junction may predispose to iatrogenic femoral neck fracture.\(^{24}\) Moreover, in patients with a pincer component of FAI, anterosuperior rim reduction may help gain hip internal rotation. Traditional open corrective osteotomy at the intetrochanteric or subtrochanteric level may be quite invasive. Hip arthroscopy before derotational osteotomy permits arthroscopic diagnosis and treatment of chondrolabral dysfunction and acetabular and/or femoral bony protrusions. Moreover, it enables precise assessment of the severity and location of residual femoroacetabular abutment from femoral retroversion after cam decompression with femoral osteochondroplasty. The Winquist intramedullary saw enables a less invasive uniplanar derotational osteotomy through small incisions. Controlled rotational correction by internal rotation of the distal femoral shaft is confirmed with an axial change in initial parallel pin placement, improved foot position, and increased internal rotation with the anterior impingement test. Though uncommon, significant compensatory tibial external torsion may affect the desired amount of derotation and, in fact, may merit tibial derotation osteotomy\(^{25}\) (distal segment rotated externally), yielding a 2-level procedure (R. Buly, oral communication, September 2012). Secure interlocked intramedullary fixation permits early postoperative weight bearing through a stable transverse osteotomy. Post-osteotomy hip arthroscopy confirms eradication of ongoing FAI with dynamic testing. Although this can be performed
without traction, we have not had any complications with the brief reapplication of traction through the osteotomized and stabilized femur.

Our patient had rapid radiographic union of both proximal femurs by 3 months postoperatively. The right osteotomy site healed without noticeable deformity (Fig 5). The left osteotomy site had 6° of varus deformity (Fig 6) with the mechanical axis into the medial compartment of the knee. Selecting an undersized intramedullary saw may not complete the osteotomy, but an oversized saw may require excessive reaming that may decrease tight control of valgus-varus/flexion-extension.

Closed derotational osteotomy may have expanded applications. Excessive femoral anteversion, especially when combined with excessive acetabular anteversion, may cause symptomatic anterior instability. With the exception of external rather than internal rotation of the distal femoral segment, select patients with excessive femoral anteversion may benefit from the described procedure. Moreover, patients with acquired rotational deformities due to malunited femur fractures may be candidates for this procedure.26,27

The ideal technique for femoral derotational osteotomy has been described as simple, involving little or no immobilization and reliably maintaining operative correction, with a high level of cosmesis and a low risk of complications.28 Closed derotational femoral osteotomy achieves these goals. In addition, early weight bearing with load-sharing intramedullary rod fixation is allowed and in fact encouraged, making possible single staged bilateral derotational osteotomies. The infection risk may be lessened because the osteotomy site is not formally opened. Moreover, arthroscopic assistance enables assessment and treatment of intra-articular pathology before derotational osteotomy and confirmation of improved dynamic femoroacetabular interaction afterward.

Femoral retroversion is a potential treatable cause of secondary cam FAI, even despite previous arthroscopic femoroplasties. Closed intramedullary derotational osteotomy with adjunctive hip arthroscopy is feasible, offering a less invasive option than open derotational osteotomy plus the benefits of load-sharing fixation. Concurrent hip arthroscopy enables dynamic assessment of the often critical femoroacetabular interaction and treatment of coexistent intra-articular pathology. This procedure may have an application in the treatment of severe femoral retroversion and anteversion deformities.

Acknowledgment
The authors acknowledge Robert Buly, M.D., from the Hospital for Special Surgery, New York, New York.

References


Editorial Commentary: Another Drop of Knowledge on Ischiofemoral Impingement

Abstract: In patients with symptomatic hip ischiofemoral impingement, mean femoral neck anteversion and the angle between the femoral neck and lesser trochanter is higher, whereas mean lesser trochanter version is not increased.

Hip arthroscopists are like explorers, pioneers at Terra Nova, or inventor scientists gathering information about conditions and problems. As they go forward, they draw a map of hip problems we did not even know about until a few years ago. Ischiofemoral impingement (IFI) is one of these conditions. There is little one can read about IFI in textbooks, but this has grown into a hot topic. Last year we published a study from the same center as this current article filling this gap, describing the clinical and radiological presentation of IFI, along with surgical techniques and 2-year outcome.1 Other authors have described anatomic abnormalities, such as the decreased ischiofemoral space and quadratus femoris space along with quadratus femoris edema.2

Gómez-Hoyos et al. present us with a level III diagnostic cohort study in which they investigated the relationship between femoral neck version (FNV) and lesser trochanteric version (LTV) in symptomatic patients with IFI.3 They compared 11 symptomatic with 250 asymptomatic patients using MRI scan. Although the number of symptomatic patients is small, we need to bear in mind that this is still an uncommon problem and the aforementioned study1 included only 5 patients.

The authors found a significantly increased angle between the femoral neck and lesser trochanter (FNV-LTV angle) in the symptomatic patients, due to an increased FNV. Equally important is the finding that LTV did not differ between the 2 cohorts. IFI, however, is a dynamic condition and this study further emphasizes this.

All we can ask of the Magellans and Edisons of hip arthroscopy: keep sailing to the unknown, keep searching the secrets. There is still much we do not know.

Arpad Konyves, M.D., F.R.C.S. (Edin)
Associate Editor

References
WHAT THE PAPERS SAY

The papers say

Journal of Hip Preservation Surgery (JHPS) is not the only place where work in the field of hip preservation may be published. Although our aim is to offer the best of the best, we continue to be fascinated by work that finds its way into journals other than our own. There is much to learn from it so JHPS has selected six recent and topical articles for those who seek a brief summary of what is taking place in our ever-fascinating world of hip preservation. What you see here are the mildly edited abstracts of the original articles, to give them what JHPS hopes is a more readable feel. Thanks to Ajay Malviya (UK), JHPS Editorial Correspondent, for his hard work in bringing this section together. If you are pushed for time, what follows should take you no more than 10 minutes to read. So here goes...

INFLUENCE OF CAPSULAR REPAIR VERSUS UNREPAIRED CAPSULOTOMY ON 2-YEAR CLINICAL OUTCOMES AFTER ARTHROSCOPIC HIP PRESERVATION SURGERY

Researchers in Chicago set up a prospective study to determine the influence of primary capsular repair on clinical outcome after arthroscopic hip preservation surgery at a minimum of 2-year follow-up [1].

Four hundred and three patients met the inclusion criteria and had complete data available, 235 in the unrepaired group (Group A) and 168 in the capsular repair group (Group B). All patients completed four patient-reported outcome (PRO) questionnaires preoperatively and at a minimum of 2-year follow-up. These included the Hip outcome score-activities of daily living (HOS-ADL) and HOS-sport-specific subscale (HOS-SSS) subsets, nonarthritic hip score (NAHS) and modified Harris hip score (mHHS).

The groups were unmatched in terms of age, body mass index (BMI) and gender with Group A having significantly older patients with higher BMI and Group B with a female preponderance. Group A patients also had greater chondral damage and lower preoperative PROs. The PROs significantly improved in both groups with Group B showing a significantly greater improvement in HOS-ADL and NAHS; however, after adjusting for confounding variables the significance was lost.

The authors concluded that capsular repair did not confer clinical superiority over the unrepaired capsulotomy group, although it did not negatively influence the results either.

COMPLICATIONS ASSOCIATED WITH THE PERIACETABULAR OSTEOTOMY: A PROSPECTIVE MULTICENTER STUDY

The purpose of this North-American prospective multicenter study was to determine and categorize all complications associated with the periacetabular osteotomy performed by experienced surgeons [2].

The authors prospectively analysed perioperative complications in 205 consecutive unilateral periacetabular osteotomies performed at seven institutions by 10 surgeons. All perioperative complications were recorded at an average of 10 weeks and 1 year after surgery in standardized fashion using a validated complication grading system applied to hip preservation procedures. The mean patient age was 25.4 years. There were 143 female and 62 male patients.

Major complications (Grade III or IV) occurred in 12 patients (5.9%). Seven complications were evident at the 10-week visit and five at the 1-year visit. Nine of the complications required a second surgical intervention, including repair for acetabular migration or implant adjustment (four patients), incision and drainage for a deep infection (two patients), and heterotopic bone resection, contralateral peroneal nerve decompression, and posterior column fixation (one patient each). Three thromboembolic complications were managed medically. There were no vascular injuries, permanent nerve palsies, intra-articular osteotomies and/or fractures or acetabular osteonecrosis. The most common Grade-I or II complication was asymptomatic heterotopic ossification. Concomitant procedures most commonly included femoral osteochondroplasty (58%) or hip arthroscopy (20%), which could include labral repair or resection.

For surgeons experienced with the periacetabular osteotomy, it is a safe procedure but is associated with a 5.9% risk of Grade-III or IV complications beyond the learning curve. The majority of these complications...
resolved without permanent disability and one out of five patients require hip arthroscopic intervention to deal with labral tear.

ANTEVERTING PERIACETABULAR OSTEOTOMY FOR SYMPTOMATIC ACETABULAR RETROVERSION: RESULTS AT 10 YEARS

Prof. Siebenrock’s group from Bern have reported their 10-year results in a previously described patient cohort that had corrective periacetabular osteotomy for the treatment of symptomatic acetabular retroversion [3].

Clinical and radiographic parameters were assessed pre-operatively and at 2 and 10 years post-operatively. A Kaplan-Meier survivorship analysis of the 22 patients (29 hips) with a mean follow-up of 11 years (range, 9–12 years) was performed. In addition, a univariate Cox regression analysis was done with conversion to total hip arthroplasty as the primary end point and progression of the osteoarthritis, a fair or poor result according to the Merle d’Aubigné score or the need for revision surgery as the secondary end points.

The mean Merle d’Aubigné score improved significantly from 14 points (range, 12–17 points) preoperatively to 16.9 points (range, 15–18 points) at 10 years. There were also significant improvements with regard to hip flexion, internal rotation and adduction compared with the preoperative status. No significant increase of the mean Tonnis osteoarthritis score was seen at 10 years. The cumulative 10-year survivorship, with conversion to a total hip arthroplasty as the primary end point, was 100%. The cumulative 10-year survivorship in achievement of one of the secondary end points was 71% (95% confidence interval, 54–88%). Predictors for poor outcome were the lack of femoral offset creation and overcorrection of the acetabular version resulting in excessive anteversion.

The authors concluded that anteverting periacetabular osteotomy for acetabular retroversion leads to favourable long-term results with preservation of the native hip at a mean of 10 years. Overcorrection resulting in excessive anteversion of the hip and omitting concomitant offset creation of the femoral head-neck junction are associated with an unfavourable outcome.

DIAGNOSIS AND 2-YEAR OUTCOMES OF ENDOSCOPIC TREATMENT FOR ISCHIOFEMORAL IMPINGEMENT

Surgeons from the hip preservation centre at Dallas, USA investigated the clinical and radiographic presentation of patients with ischiofemoral impingement (IFI) and assessed the outcomes of endoscopic treatment with partial resection of the lesser trochanter. The diagnosis of IFI was on the basis of physical examination tests provoking the impingement between the lesser trochanter and ischium and reproducible pain lateral to the ischium with the long-stride walking test. The presence of quadratus femoris muscle edema and a decreased ischiofemoral space on magnetic resonance imaging was also used to establish the diagnosis [4].

Five patients with IFI who underwent endoscopic treatment with partial resection of the lesser trochanter were retrospectively reviewed. The outcomes were assessed at a mean follow-up of 2.3 years (range, 2–2.5 years) through the mHHS and a visual analogue scale score for pain.

The mean mHHS increased significantly from 51.3 points preoperatively to 94.2 points at the final follow-up. The mean visual analogue scale score for pain significantly decreased from 6.6 before surgery to 1 at the final follow-up. The mean duration to return to sport after surgery was 4.4 months. No complication was observed.

The authors concluded that endoscopic treatment of IFI was effective at 2 years in patients with consistent clinical and imaging diagnostic findings.

RESIDUAL DEFORMITY IS THE MOST COMMON REASON FOR REVISION HIP ARTHROSCOPY: A THREE-DIMENSIONAL CT STUDY

Research done at the University of Michigan, USA has attempted to confirm whether residual deformity is the commonest reason for revision hip arthroscopy. The purpose of this study was to define the three-dimensional (3D) morphology of hips with residual symptoms before revision femoroacetabular impingement (FAI) surgery and determine the limitation in range of motion (ROM) in these patients using dynamic, computer-assisted, 3D analysis [5].

The study includes 50 revision arthroscopic FAI procedures on 47 patients with residual FAI deformity and symptoms after prior unsuccessful arthroscopic surgery and compared with a control of 65 patients who underwent primary arthroscopic FAI procedure by the same surgeon during the study period. Three-dimensional models of the hips were created to allow measurements of femoral and acetabular morphology and ROM to bony impingement using a validated, computer-based dynamic imaging software. A comparison of the virtual correction with the actual correction in the primary successful FAI treatment cohort was performed. Correspondingly, a comparison of the recommended virtual correction with the
correction evident at the time of presentation after failed primary surgery in the revision cohort was performed.

Ninety percent of patients undergoing revision surgery for symptomatic FAI had residual deformities; the mean maximum alpha angle in revision hips was 68° and was most often located at 1:15, considering the acetabulum as a clock face. Twenty-six percent of hips had signs of overcoverage with a lateral center-edge angle greater than or equal to 40°. Dynamic analysis revealed mean ROM before osseous contact was less in the revision group than those in the control group.

The authors concluded that marked radiographic evidence of incomplete correction of deformity was found on 3D reconstruction of CT scan images in patients with residual symptoms after FAI surgery and recommend careful attention to full 3D resection of impinging structures.

DOES RADIOGRAPHIC COXA PROFUNDA INDICATE INCREASED ACETABULAR COVERAGE OR DEPTH IN HIP DYSPLASIA?

Researchers in Japan set out to determine the prevalence of radiographic coxa profunda in patients with hip dysplasia, the morphologic differences of the acetabulum and pelvis between patients with hip dysplasia and control subjects and the morphologic differences between hip dysplasia with and without coxa profunda [6].

The authors retrospectively reviewed the pelvic radiographs and CT scans of 70 patients with hip dysplasia. Forty normal hips were used as controls.

Normal hips were defined as those with a lateral center-edge angle between 25° and 40°. Coxa profunda was defined as present when the acetabular fossa was observed to touch or was medial to the ilioischial line on an antero-posterior pelvic radiograph. CT measurements included acetabular version, acetabular coverage, acetabular depth and rotational alignment of the innominate bone.

The prevalence of coxa profunda was 44% in dysplastic hips and 73% in the control hips (odds ratio, 3.32). Dysplastic hips had a significantly more anteverted and globally shallow acetabulum with inwardly rotated innominate bone compared with the control hips. Dysplastic hips with coxa profunda had significantly more anteverted acetabulum and inwardly rotated innominate bone compared with those without coxa profunda, whereas the acetabular coverage and depth did not differ between the two groups, with the numbers available.

The authors concluded that radiographic coxa profunda was not a sign of increased acetabular coverage and depth in patients with hip dysplasia, but rather indicates classic acetabular dysplasia, defined by an anteverted acetabulum with anterolateral acetabular deficiency and an inwardly rotated pelvis. Thus, the presence of coxa profunda does not indicate a disease in addition to hip dysplasia, and the conventional maneuvers during periacetabular osteotomy are adequate for these patients.

REFERENCES

What is this duplicate publication thing?

One of the commonest queries I receive as Editor-in-Chief is whether a submission can be accepted when the author’s message is already known. The paper may have been presented at meetings a couple of times and might even have appeared in abstract form. Can we, as a journal, go ahead and publish without eyebrows being raised and the accusation of duplicate publication being made?

The story starts with a classic of the editing world. His name was Franz Ingelfinger, a German-American, and for 9 years (1967–76) he was the Editor of the New England Journal of Medicine. You may have heard of him, although on the other hand you may not.

Ingelfinger [1], in 1969, proposed a key rule of the publication game by which we all adhere to this day. He laid out the definition of what we now call duplicate (or dual) publication. This is when the same material is published more than once by either the author or the publisher. It is not the same as plagiarism, which is when someone different performs republication [2]. Duplicate publication is more common than you think. Have a look at Déjà vu [3], a database of highly similar citations, where you will see the problem laid out before you. Duplicate publication does certainly exist, is regarded as a form of research misconduct, and is something that as an editor you need always to keep in the back of your mind.

I can see the pressure, of course. Journals take time to reach a decision, so why not submit the same paper to two, three, maybe four or five journals simultaneously? After all, is that not what creative authors do in the big, bad world of mass-market writing? Then before you know it, two of your identical submissions are accepted, one some months after the other and ... bingo! ... you have entered the ranks of the duplicate publishing author.

Or, you may be a particularly prolific author and have forgotten that one of your team submitted a paper on a specific topic 2 years earlier. It may have been published in some lesser-known journal and may even have passed you by. It happens. A subsequent trainee has a go, unaware of his predecessor’s actions and out comes that second paper. Again, unwittingly you have become a duplicate author and it is not a happy place to be.

Anyway, why should a journal worry? Why should anyone be concerned? After all, each of us seeks to disseminate our work as widely and as rapidly as we can. Yet the publishing dilemma is clear because duplicate publications can cause trouble for a number of reasons [4]:

1. They waste finite resources. Journals have a limited number of pages available and duplicate submissions will be reviewed twice, indexed twice, copyedited twice, distributed twice and so on.
2. They overload available medical information. It simply takes longer to find what you need.
3. They overemphasize the findings. The classic is a meta-analysis looking at the antiemetic efficacy of ondansetron [5]. This showed that duplicate publication led to an overestimation of ondansetron’s efficacy by 23%.
4. Duplicate publications contravene copyright law, if you have signed your copyright across to another journal. This is less of a problem these days with Open Access, where the requirement for an author to hand over copyright is becoming rare.

Language bias is also an issue, especially for an international journal and certainly when it comes to the influence on meta-analyses. One study [6] assessed whether authors were more likely to publish positive results in English language journals rather than German. The answer was a resounding ‘yes’. However, in the process, the authors had to exclude 19 of their 62 studies (31%) because they were duplicate publications, one in English and the other in German. That is a huge number.
The Anglo-German study may be exceptional but the problem is manifestly global. In the former Journal of Bone and Joint Surgery (Br) a study of so-called original articles in that journal showed one in 13 to be duplicate or fragmented publications [7]. Fragmented publishing is the same as so-called salami-slicing. A more recent paper from South Korea in 2008 [8] looked specifically at publications in Korean Medical Journals indexed in KoreaMed and found 27 of 455 (5.93%) articles were duplicates.

On Medline presently, there sit 22 million references [9] to journal articles in the life sciences, predominantly biomedicine. Just think how much space there might be for the rest of us if the duplicates were removed? There is clearly a problem out there and each of us—authors, reviewers and editors—needs to be on our guard.

So what are the rules of the game? These are well described by the International Committee of Medical Journal Editors (ICMJE) and followed by many [10]. The guidelines look at four things: duplicate submission, duplicate publication, acceptable secondary publication and manuscripts based on the same database. I would suggest reading them in full. There is nothing surprising about any of them.

Two things are very clear, however. First, submitting the same paper to two journals simultaneously is a non-starter. Second, if your submission is very similar to work reported elsewhere then (i) reference that work and (ii) say so in your letter of submission. However, if your work has appeared as a presentation or abstract before, that does not matter, but do reference it anyway.

Of course, none of what I have written here is applicable to JHPS, but duplicate publication is certainly a topic about which I am asked repeatedly by potential authors. That need for us each to publish frequently and widely seems insatiable. So please have a read of the ICMJE guidelines [10] and, if your submission fits, by all means send it in.

Now turning to JHPS and its content, which in many respects is why I am here, what specifically grabbed my attention in the last issue (2.2)? Naturally every paper we publish has done well to appear on our pages and each has added its own aliquot of information to the ever-expanding field of hip preservation surgery. However, I was especially caught by Kalisvaart and Safran’s [11] review on hip micro-instability, as this is manifestly an area of hip surgery that is expanding fast. Watch that space, for sure. I was also incredibly impressed by the minisymposium on evolving concepts in extra-articular hip pathology [12–16], put together by some really supportive authors and with Hal Martin’s truly dedicated lead. I recommended it last time and I do it again now. Do read the whole minisymposium; in fact do please peruse every last paper published. You will not be disappointed.

And for this issue? Issue 2.3? Oh boy, things are beginning to take off at such a pace and in a way that I for one never expected so early in the life of a fledgling journal. Downloads are skyrocketing and our submission inbox always, always, always contains something interesting. Actually, everything sent in is interesting. Why, oh why can we not publish the lot?

It is our reviewers, you see. They have an eye for the uncanny, the worthwhile, the message we can all take home. They are a tremendous lot and deserve the largest vote of thanks any editor can give.

So when you look at issue 2.3 do be sure to read everything, although I confess to lingering a little longer over two papers in particular. The first was the excellent review by Bardakos [17] on all those impingements that are not femoroacetabular. There are plenty of them out there. The other was that wonderful paper by Cvetanovich et al. [18] on hip arthroscopy after Bernese periacetabular osteotomy. I loved that one, not only for its content but also for its subject matter. Those of us who have been around for longer than most well remember the days when osteotomists and arthroscopists would rarely speak. Now look at it. There are papers being submitted from groups that offer both. The true friendship that hip preservation has now engendered is there for us all to see.

My very best wishes to you all.

Richard Villar
Editor-in-Chief,
Journal of Hip Preservation Surgery

REFERENCES
Editorial Commentary: Hip Femoroacetabular Impingement Surgery Requires Improved Radiologic Research and Expert Understanding of Hip Clinical Examination

Abstract: Hip femoroacetabular impingement (FAI) is overwhelmingly the primary cause of revision surgery after hip arthroscopy. FAI imaging is confusing and requires additional research. Therefore, hip arthroscopic surgeons must become experts at clinical evaluation and examination.

Revised after arthroscopic surgery is disappointing and fortunately rare. However, it is important to study revision so we can improve. When it comes to hip arthroscopy, we really need to improve our understanding of femoroacetabular impingement (FAI). A systematic review1 by Cvetanovich, Harris, Erickson, Bach, Bush-Joseph, and Nho, from Rush University Medical Center, included 5 studies. Cvetanovich et al. report that the most common indication for revision was FAI; in fact, the reason for revision was FAI a whopping 81% of the time.

Last month, readers may recall that we commented2 on Frank, Harris, Erickson, Slikker, Bush-Joseph, Salata, and Nho’s “Prevalence of femoroacetabular impingement imaging findings in asymptomatic volunteers.”3 We wrote, “when it comes to imaging of the hip, we need to better refine our radiologic signs, and better determine what actually constitutes abnormal...for now, hip pathologic diagnoses must ‘emphasize patient history and physical exam.’ However, patient history may be vague, and physical examination of the hip may be difficult.”

Hip surgeons should review the following classic articles4: “The pattern and technique in the clinical evaluation of the adult hip: The common physical examination tests of hip specialists” by Martin, Kelly, Leunig, Philippon, Clohisy, Martin, Sekiya, and Pietrobon, published in Arthroscopy in 2010,5 and “Differential diagnosis of pain around the hip joint” by Tibor and Sekiya, published in Arthroscopy in 2008.6

James H. Lubowitz, M.D.
Editor-in-Chief

References
CASE REPORT

Richard F. Costello · Douglas P. Beall · Bryan L. Van Zandt · Annette M. Stapp · Hal D. Martin · Samuel W. Steury

Contrast reaction from hip arthrogram

Abstract Arthrography is considered a safe procedure with rare reactions to intra-articular contrast administration. Although the use of intra-articular contrast carries a small risk of reaction, no prior serious complications had been encountered in our experience with arthrography. We report a patient’s prolonged reaction to contrast media after an arthrogram of the hip. Literature review demonstrated no prior report of contrast media reactions to hip arthrography. Therefore, we decided to review the literature and report our case.

Keywords Arthrography · Contrast media · Magnetic resonance · Reactions · Hip

Contrast reaction from hip arthrogram

Arthrography is a minimally invasive procedure consisting of the injection of iodinated contrast under fluoroscopic guidance. A small amount of gadolinium may also be mixed with the solution for the purpose of performing a Magnetic Resonance (MR) arthrography evaluation of the joint of interest. Magnetic resonance imaging of the hip joint has been considered the procedure of choice for evaluation of the acetabular labrum and the ligamentous structures and is also helpful in evaluating the musculo-tendinous and osseous structures. The general indication for arthrography of a joint is for evaluation of pain that is unresponsive to conservative treatment. Complications associated with arthrography are very unusual, but the procedure is not without inherent risk. We report a case of contrast reaction caused by arthrography of the hip joint.
Case report

Mr. N arrived for a left hip arthrogram to be followed by MR imaging exam. Informed consent was obtained from the patient and he was placed in a supine position on the fluoroscopy table. The patient was steriley prepped and draped and the left hip joint was accessed with a 22-gauge spinal needle using fluoroscopic guidance. Confirmation of needle tip within the left hip joint was confirmed with the injection of a total of 2 ml of Renograffin-60. Subsequently, 13 ml of a mixture containing 50% lidocaine (1%) and 50% Renograffin-60 with dilute (1:200) gadolinium was infused into the left hip joint. Fluoroscopic spot radiographs were obtained of the left hip in internal rotation, external rotation, and neutral position (Fig. 1).

The patient complained of slight nausea during and at the end of the arthrogram procedure. After transfer to the MRI suite, the patient complained of chest tightness, light-headedness, and had a brief loss of consciousness (15–30 s).

At this point a code blue was called and the code team arrived promptly to the MRI suite and assessed the patient. Patient evaluation demonstrated the following: normal electrocardiogram, blood pressure 110/60, heart rate 60 bpm, O2 saturation 99%, with 2 l per nasal cannula. A small rash was then noted on his left thigh, calf, and left cheek, and the patient was then transferred to the emergency department (ED).

Under the direction of the ED doctor the patient received a mixture of diphenhydramine, methylprednisolone, and ranitidine. His blood pressure and heart rate remained stable and he remained in the ED for approximately 45 min for observation and was released. The MR imaging exam of the left hip was then obtained.

The patient was seen 24 h after the contrast reaction and reported that he was in his normal state of health. He was instructed to follow a preparation regimen consisting of diphenhydramine, steroids, and ranitidine before any further administration of iodinated contrast.

Discussion

Severe adverse reactions from intravascular administration of iodinated contrast are seen in approximately 0.26 to 3% of cases [1, 2]. The incidence of death from intravascular iodinated contrast administration is small with a reported rate of 0.005% [3]. Severe complications including dyspnea, sudden hypotension, cardiac arrest, loss of consciousness, and death, have been reported to occur in less than 0.2% of all reported reactions [1]. Complications more associated with intra-articular administration of iodinated contrast include chemical synovitis/pain, septic arthritis, and nerve palsy.

Two large questionnaire-based retrospective studies have described complications after intra-articular administration of iodinated contrast material [4, 5]. The questionnaire-based studies evaluated responses to more than a combined 388,000 arthrographic procedures [4, 5]. The most recent study by Hugo and colleagues [5] includes 262,000 arthrograms, of which there were approximately 13,300 MR arthrograms. The same study reported a total complication rate of 3.6%, of which 0.03% were considered severe. Reported minor reactions (9,594 cases) included chemical synovitis, vagal reaction, and urticaria (both immediate and delayed). Severe reactions (75 cases) included 29 cases of septic arthritis, 16 cases of cellulitis, eight cases of anaphylaxis, and five cases of vascular complications. Miscellaneous reactions (17 cases) included ten cases of seizures, four cases of nerve palsy, and with the remainder a combination of neuritis and fat necrosis. No deaths were reported [5]. No specific comment was made as to location of the arthrogram that was associated with the complications, nor was differentiation made between the use of ionic and non-ionic iodinated contrast media.

An adverse reaction to gadolinium would be somewhat difficult to exclude given the concurrent administration of iodinated contrast within the joint, but it has been shown that local injections are very safe when administering gadolinium-DTPA [6]. In fact, almost no side effects have been reported [6].

In conclusion, arthrography is considered a safe procedure as indicated by the few serious complications reported in the two large-scale studies to date [4, 5]. Despite this optimal safety profile, this case illustrates that serious reactions to contrast media can occur with small amounts of iodinated contrast injected into a joint. To our knowl-

![Fig. 1 a Fluoroscopic view of the left hip in internal rotation. Note communication of the hip joint with the iliopsoas bursa (black arrows). This is a normal variant seen in approximately 15% of the population. b Fluoroscopic view of the left hip in neutral position.](image-url)
edge, this is the first reported case of a serious contrast reaction after a hip arthrogram.

References

Contribution of the Pubofemoral Ligament to Hip Stability: A Biomechanical Study

Hal D. Martin, D.O., Anthony N. Khoury, M.S., Ricardo Schröder, P.T., Eric Johnson, B.S., Juan Gómez-Hoyos, M.D., Salvador Campos, M.D., and Ian J. Palmer, Ph.D.

Purpose: To determine the isolated function of the pubofemoral ligament of the hip capsule and its contribution to hip stability in external/internal rotational motion during flexion greater than 30° and abduction. Methods: Thirteen hips from 7 fresh-frozen pelvis-to-toe cadavers were skeletonized from the lumbar spine to the distal femur with the capsular ligaments intact. Computed tomographic imaging was performed to ensure no occult pathological state existed, and assess bony anatomy. Specimens were placed on a surgical table in supine position with lower extremities resting on a custom-designed polyvinylchloride frame. Hip internal and external rotation was measured with the hip placed into a combination of the following motions: 30°, 60°, 110° hip flexion and 0°, 20°, 40° abduction. Testing positions were randomized. The pubofemoral ligament was released and measurements were repeated, followed by releasing the ligamentum teres. Results: Analysis of the 2,106 measurements recorded demonstrates the pubofemoral ligament as a main controller of hip internal rotation during hip flexion beyond 30° and abduction. Hip internal rotation was increased up to 438.9% (P < .001) when the pubofemoral ligament was released and 412.9% (P < .001) when both the pubofemoral and teres ligament were released, compared with the native state. Conclusions: The hypothesis of the pubofemoral ligament as one of the contributing factors of anterior inferior hip stability by controlling external rotation of the hip in flexion beyond 30° and abduction was disproved. The pubofemoral ligament maintains a key function in limiting internal rotation in the position of increasing hip flexion beyond 30° and abduction. This cadaveric study concludes previous attempts at understanding the anatomical and biomechanical function of the capsular ligaments and their role in hip stability. Clinical Relevance: The present study contributes to the understanding of hip stability and biomechanical function of the pubofemoral ligament.

To date, the proper biomechanical contribution of the pubofemoral ligament to hip stability is not understood. The anatomic structure and origin of the capsular ligaments, both visually and arthroscopically, have been studied. The stabilizing functions of the iliofemoral and ischiofemoral ligaments have been well documented. Subsequent studies have reported on the function of the ligamentum teres in limiting hip rotation. A complete understanding of the isolated function of the pubofemoral ligament contributing to hip instability is required.

The capsule enclosing the hip joint significantly contributes to stability during dynamic and static motions. There are 4 ligaments that comprise the hip capsule: medial and lateral arms of the iliofemoral, ischiofemoral, and pubofemoral ligaments. The fibers of the 4 primary ligaments are longitudinally oriented and insert anteriorly and posteriorly along the acetabulum. The fibers continue distally around the femoral neck and are inserted along the intertrochanteric line, and they partially cover the posterior portion of the femoral neck. A shallow layer of circularly oriented fibers known as the zona orbicularis exists within the capsule. These fibrous structures work in conjunction with the labrum and osseous structures to create a stable hip joint during motion.

The pubofemoral ligament runs from 3:30 to 5:30 using an acetabular clock-face reference system.
comparison to the iliofemoral and ischiofemoral ligaments, the pubofemoral ligament has the smallest origin on the acetabulum. From the origin, the pubofemoral ligament is described to wrap around the femoral neck inferiorly, as a sling. Distally the pubofemoral ligament blends with the medial iliofemoral ligament anteriorly, and the ischiofemoral ligament posteriorly. Previous cadaveric studies demonstrated the role of the pubofemoral ligament as a controller of external rotation in hip flexion below 30° and extension.

The purpose of this manuscript is to determine the isolated function of the pubofemoral ligament of the hip capsule and its contribution to hip stability in external/internal rotational motion during flexion greater than 30° and abduction. The hypothesis states that the pubofemoral ligament is one of the contributing factors of anterior inferior hip stability by controlling external rotation of the hip in flexion beyond 30° and abduction.

**Methods**

**Specimens**

Thirteen hips from 7 fresh-frozen pelvis-to-toe cadaveric specimens were skeletonized from the lumbar spine to the distal femur, preserving the hip capsular ligaments. The specimens were thawed to room temperature prior to experiments. Physical examinations of the hip, pelvis, and spine were performed by a hip preservation fellowship-trained orthopaedic surgeon (J.G.H.) with 2 years in practice, to ensure no occult pathologic state existed. Computed tomographic (CT) imaging was performed prior to experiments for anatomic measurements. Exclusion criteria include deformities that restrict motion, including signs of arthrosis, osseous pathology, or surgical intervention. Hips were then examined arthroscopically by the same orthopaedic surgeon to assess the integrity of the ligamentum teres.

**CT Imaging Evaluation**

Axial and sagittal CT scan sequences (General Electric Medical Systems LightSpeed RT16 XTRA; GE Healthcare, Waukesha, WI) of the pelvis and lower limbs were performed on all cadavers prior to testing to ensure no pathologic state exists and to assess bone anatomy. The feet were fixed in a neutral position with 0° abduction during the imaging assessment. Images were analyzed in GE MediaViewer (GE Healthcare) to determine the McKibbins index and anatomic measures, including femoral neck version.

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**Fig 1.** Cadaver testing setup. The cadaveric specimens placed in the supine position with the pubic symphysis on the same horizontal plane as both anterior superior iliac spines and secured with 4 holding pins placed through the ilium.

**Fig 2.** Pubofemoral ligament release sequence. The pubofemoral ligament release sequence is identified by the blue line. Specifically, the pubofemoral ligament was released at the inferior border, through the zona orbicularis, and adjacent to the labrum to the border of the iliofemoral ligament. Specimen shown is right hip.
acetabular version measured at the 3-o’clock position, femoral neck shaft angle, knee varus/valgus angle, and CT leg length, to exclude any excessively or constrained unstable hips.

Measurement and Hip Positions

Testing protocols were performed using validated cadaveric studies as reference. Specimens were positioned supine, with the pubic symphysis on the same horizontal plane as both anterior superior iliac spines, and secured with 4 holding pins. A frame was designed to hold the lower extremity in each measurement position while allowing unobstructed hip rotation (Fig 1).

A 30° arthrooscope (Smith & Nephew, Andover, MA) was used without irrigation for visualization of the ligamentum teres, pubofemoral ligament, and labral pathology. Specimens with a torn ligamentum teres prior to testing were excluded from the study.

After the arthroscopic examination, 3 independent measures of maximal internal and external rotation range of motion were conducted in 9 hip positions and measured with a digital goniometer using a previous validated technique. A trained physical therapist (R.G.S.) manually performed all hip maximal internal and external rotation. The hip positions were a combination of abduction (0°, 20° abduction, 40° abduction) and flexion (30°, 60°, and 110° of flexion). The order of positioning was randomized so that 7 hips are initially positioned at 30° flexion and ending in 110° flexion and the other 6 are initially at 110° flexion and ending in 30° flexion. Positioning in the frontal plane was performed so that 7 hips are positioned in 40° abduction ending in 0° adduction, and the other 6 hips opposite. Three measurements of maximal internal and external rotation were recorded at each endpoint position. The pubofemoral ligament was released at the inferior border, through the zona orbicularis, and adjacent to the labrum to the border of the iliofemoral ligament (Fig 2). The maximum internal and external rotation was then measured in a similar manner (referred to as -pubofem). The ligamentum teres was then released using an arthroscopic blade, and maximum internal and external rotation measurements were performed in a similar manner (referred to as -pubofem&teres). In total, 162 measurements were recorded in each hip: 54 measurements in the native state, 54 with the pubofemoral ligament cut, and 54 with the pubofemoral ligament and teres cut.

All hip rotation maneuvers and measurements were consistently performed by the same examiner, respectively, based on a previously validated technique with 0.99 intraclass correlation coefficient reliability. In the case of hip subluxation, the event was marked accordingly by the data collector for further analysis.

Statistical Analysis

The average of the 3 measures of internal and external rotation in each of the 9 positions was used for analysis. Repeated measures analysis of variance by ligamentous state (native vs -pubofem; vs -pubofem&teres) were run for internal and external rotation at each position of flexion and abduction. Subsequent repeated measures analysis of variance by position were run for internal and external rotation at each ligamentous state. When a main effect of internal or external rotation was found, post hoc independent t-test analyses were performed. Alpha level was set at 0.05.

Results

Cadaveric Specimen Data

Fourteen human fresh-frozen cadaveric hips were considered for this study. The left hip of the first

Table 1. Cadaver Specifications

<table>
<thead>
<tr>
<th>Cadaver</th>
<th>Age</th>
<th>Sex</th>
<th>McKibbins Index</th>
<th>FNV</th>
<th>AV</th>
<th>FNSA</th>
<th>KA</th>
<th>CT Leg Length</th>
<th>FNA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1R</td>
<td>70.0</td>
<td>M</td>
<td>50.4</td>
<td>28.1</td>
<td>22.3</td>
<td>123.0</td>
<td>17.2</td>
<td>79.01 cm</td>
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<tr>
<td>2L</td>
<td>60.0</td>
<td>M</td>
<td>33.8</td>
<td>12.3</td>
<td>21.5</td>
<td>127.4</td>
<td>-2.2</td>
<td>86.3 cm</td>
<td>14.5</td>
</tr>
<tr>
<td>2R</td>
<td>38.5</td>
<td>M</td>
<td>11.9</td>
<td>26.6</td>
<td>128.4</td>
<td>6.9</td>
<td>86.6 cm</td>
<td>5.0</td>
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<tr>
<td>3L</td>
<td>65.0</td>
<td>M</td>
<td>17.5</td>
<td>-0.4</td>
<td>17.9</td>
<td>131.0</td>
<td>-17.0</td>
<td>85.3</td>
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<td>M</td>
<td>4.1</td>
<td>-7.2</td>
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<tr>
<td>4R</td>
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<td>M</td>
<td>0.5</td>
<td>9.1</td>
<td>126.1</td>
<td>-13.8</td>
<td>78.8</td>
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<tr>
<td>5L</td>
<td>38.7</td>
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<td>32.5</td>
<td>6.2</td>
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<td>76.8</td>
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<tr>
<td>5R</td>
<td>46.3</td>
<td>M</td>
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<tr>
<td>6L</td>
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<td>F</td>
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<td>12.7</td>
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<td>3.5</td>
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<tr>
<td>6R</td>
<td>32.5</td>
<td>F</td>
<td>19.8</td>
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<tr>
<td>7L</td>
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<td>128.9</td>
<td>-3.6</td>
<td>79.4</td>
<td>16.1</td>
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NOTE. All specimens were imaged using CT. AV, acetabular version; CT, computed tomography; F, female; FNA, femoral neck angle; FNSA, femoral neck shaft angle; FNV, femoral neck version; KA, knee angle; M, male.
specimen was used as a pilot to determine a proper cut procedure for the pubofemoral ligament, and is not included in the present data. In total, 13 hips from 7 cadavers are included in the presented data. The donors included 5 males and 2 females with an average age of 56.1 years (range, 37-72; standard deviation [SD] ±14.5).

CT imaging of each specimen was used to investigate the relative anatomy and is available in Table 1. The average results for the measures include McKibbins
Table 2. Percent Change at 30° Hip Flexion

<table>
<thead>
<tr>
<th></th>
<th>0° Abduction</th>
<th>20° Abduction</th>
<th>40° Abduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IR</td>
<td>ER</td>
<td>IR</td>
</tr>
<tr>
<td>Native → Pubofem</td>
<td>19.09% *</td>
<td>2.10%</td>
<td>17.95%</td>
</tr>
<tr>
<td>Native → Pubofem&amp;Teres</td>
<td>35.01% *</td>
<td>13.27%</td>
<td>30.66% *</td>
</tr>
<tr>
<td>-Pubofem → native</td>
<td>13.37% *</td>
<td>10.94% *</td>
<td>10.78%</td>
</tr>
</tbody>
</table>

NOTE: Column 1 is the measured position. The study compared IR and ER after releasing the pubofemoral ligament (Pubofem) and after releasing the pubofemoral ligament and ligamentum teres (Pubofem&Teres).

ER, external rotation; IR, internal rotation.

*P ≤ .05.

index (26.3; range 4.1-50.4; SD ±15.6), femoral neck version (12.5°; range -7.2° to 33.2°; SD ±12.7), acetabular version measured at the 3-o’clock position (13.8°; SD ±7.6°), femoral neck shaft angle (128.9°; SD ±4.6°), knee varus/valgus angle (-3.6°; SD ±10.1°), and CT leg length (79.4 cm; SD ±3.1 cm). The function of the pubofemoral ligament was determined by measuring hip internal and external rotation randomized in a native state (all capsular ligaments intact), after releasing the pubofemoral ligament, and then releasing the ligamentum teres. The observed significant effects are reported. Post hoc analysis was completed to investigate the rotational control of the pubofemoral ligament in 0°, 20°, and 40° abduction during hip flexion (Fig 3). The most profound response to releasing the pubofemoral ligament occurred during internal rotation in all 3 levels of hip flexion. In 30° hip flexion, a significant increase of 19% (P < .002) in internal rotation was observed after releasing the pubofemoral ligament in 0° hip abduction, and a 35% increase (P < .001) was observed after releasing the pubofem&Teres (Table 2, Fig 3). A significant increase of 30.6% of internal rotation occurred in 30° flexion/20° abduction and when the pubofem&Teres was released, in comparison to a native state (P < .01). During 60° hip flexion/40° abduction, a significant increase of internal rotation 214% (P < .03) was observed after releasing the pubofemoral ligament. Significant increases of internal rotation in 60° hip flexion/20° and 40° hip abduction of 161.8% (P < .03) and 292% (P < .004), respectively, were observed when the pubofem&Teres were released (Table 3, Fig 3). Deep hip flexion to 110° resulted in significant increases of internal rotation during 0°, 20°, and 40° abduction when the pubofemoral ligament was released (P < .001, P < .001, and P < .001; 285.7%, 373.2%, and 438.9% increase, respectively) and subsequently when both the pubofem&Teres were released (P < .001, P < .001, and P < .001; 375.1%, 403.9%, and 412.9% increase, respectively) (Table 4, Fig 3).

Post hoc analysis was completed to investigate the rotational control of the pubofemoral ligament in 30°, 60°, and 110° hip flexion during abduction (Fig 4). During 0° hip abduction, there is a significant effect between pubofemoral release compared with native (110° flexion), and pubofem&Teres (110° flexion) release compared with only the pubofemoral released (P < .001, P < .002) during internal rotation. In 20° hip abduction/110° flexion, releasing the pubofemoral significantly contributes the internal rotation compared with the native state (P < .001) and compared with 20° hip abduction/60° flexion (P < .007). These results are identical when the pubofem&Teres is released. The results are comparable for the pubofemoral release in 40° hip abduction/110° flexion during internal rotation compared with the native state (P < .001) and compared with 40° abduction/60° flexion (P < .003). When the pubofem&Teres is released the increase in internal rotation compared with native is significant (P < .001), as well

Table 3. Percent Change at 60° Flexion

<table>
<thead>
<tr>
<th></th>
<th>0° Abduction</th>
<th>20° Abduction</th>
<th>40° Abduction</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>IR</td>
<td>ER</td>
<td>IR</td>
</tr>
<tr>
<td>Native → Pubofem</td>
<td>43.02%</td>
<td>6.68%</td>
<td>119.33%</td>
</tr>
<tr>
<td>Native → Pubofem&amp;Teres</td>
<td>51.75%</td>
<td>17.82%</td>
<td>161.83%</td>
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<tr>
<td>-Pubofem → native</td>
<td>6.10%</td>
<td>10.44%</td>
<td>19.38%</td>
</tr>
</tbody>
</table>

NOTE: Column 1 is the measured position. The study compared IR and ER after releasing the pubofemoral ligament (Pubofem) and after releasing the pubofemoral ligament and ligamentum teres (Pubofem&Teres).

ER, external rotation; IR, internal rotation.

*P ≤ .05, **P ≤ .001.
as compared with 40° hip abduction/60° flexion. A significant effect was observed between the pubofo-
mal release and native state in 40° abduction/60° flexion ($P < .03$).

Conversely there were less significant effects observed during external rotation (Fig 3). In 30° hip flexion/
0° abduction, a significant increase ($P < .01$) was observed in samples that had the pubofem&teres released compared with only releasing the pubofo-
lamen ligament. In this position, there was trend for signi-
ficance in 60° flexion ($P < .05$). Significant increase ($P < .03$) was observed in 60° hip flexion/0° abduction
between the cut pubofem&teres state and native state. This finding was also observed in 110° flexion/40° ab-
duction ($P < .03$).

**Subluxation Effect Observed**

A common observation during testing was the sub-
luxation of the hip joint during internal and external rotation, occurring as a result of releasing the pubofo-
lamen ligament, in addition to the ligamentum teres,
and moving the hip in higher levels of flexion and ab-
duction. The subluxation occurred 103 times in varying positions of deep hip flexion and abduction.
The most notable region of subluxation occurred in 110
degrees of hip flexion and ranges of abduction. Addi-
tional subluxation occurred in 60 degrees of hip flexion,
with both 20 and 40 degrees of abduction. These in-
stances were recorded in the data as having 180° of rotation.

**Discussion**

The experimental results from this human cadaveric study show the pubofo-
lamen ligament maintains a key
function in limiting internal rotation in the position of
increasing hip flexion beyond 30° and abduction, dis-
proving the hypothesis. The contribution of the pubofo-
lamen ligament to hip stability was investigated to
conclude previous efforts aimed at quantifying the hip
capsular ligaments. Testing parameters were chosen to
examine how the pubofo-
lamen ligament functions in a
range of normal hip flexion and abduction to deep
hip flexion and abduction. The testing procedure was

<table>
<thead>
<tr>
<th></th>
<th>0° Abduction</th>
<th>20° Abduction</th>
<th>40° Abduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Native → Pubofem &amp; Teres</td>
<td>285.77%</td>
<td>17.55%</td>
<td>373.22%</td>
</tr>
<tr>
<td>Native → - Pubofem &amp; Teres</td>
<td>375.18%</td>
<td>28.72%</td>
<td>403.94%</td>
</tr>
<tr>
<td>-Pubofem → - Pubofem &amp; Teres</td>
<td>23.18%</td>
<td>9.51%</td>
<td>6.49%</td>
</tr>
</tbody>
</table>

**Table 4. Percent Change at 110° Flexion**

NOTE: Column 1 is the measured position. The study compared IR and ER after releasing the pubofo-
lamen ligament (Pubofem) and after releasing the pubofo-
moral ligament and ligamentum teres (Pubofem&Teres).

ER, external rotation; IR, internal rotation.

* $P < .05$, ** $P < .001$.

The most profound response to releasing the pubofo-
lamen ligament occurred during internal rotation in
all 3 levels of hip flexion. Figures 3 and 4 depict a
consistent increase in internal rotation both during
flexion and as a result of abduction. Contrary to the
authors’ primary hypothesis of the pubofo-
lamen ligament limiting external rotation, the data clearly depict
the ligament as a major contributor to controlling in-
ternal rotation in hip flexion beyond 30° and abduction
(Figs 3 and 4), and thus the hypothesis must be rejec-
ted. The absence of a steady pattern at external rotation
indicates that the pubofo-
mamen ligament does not have a
significant influence on controlling hip stability
during the test positions.

The stabilizing functions of the iliofo-
lamen and ischiofo-
lamen ligaments have been well documented
and the pubofo-
lamen ligament’s contribution to hip
stability in flexion is not well described because of the
lack of experiments that isolate the ligament exclu-
sively. In a study performed by Martin et al., the
capsular ligaments were meticulously described
anatomically and assessed biomechanically in regards to
a normal walking swing path from 10° hip extension to
30° hip flexion. In regards to the testing sequence, the
medial and lateral arms of the iliofo-
lamen ligament
were released prior to releasing the pubofo-
lamen ligament, and abduction was not measured. A biome-
chnical assessment of the capsular ligaments was
performed by van Arkel et al., during which the
igament release order was randomized and therefore did
not focus on the pubofo-
mamen ligament alone. Hidaka
et al. measured capsular ligament strain without reporting flexion data and internal rotation. The methods of the present study maintain the capsular ligaments for native testing on all specimens and release the pubofemoral ligament only on the adjacent borders of surrounding structures, with the teres released after all biomechanical testing is performed. The method ensures the only controllable variable in the testing scenario is the pubofemoral ligament, followed by the ligamentum teres, and limits external factors as secondary ligamentous control.

The pubofemoral ligament and teres are noted to heavily influence control of hip internal rotation in tested parameters of hip flexion. Fuss and Bacher reported the pubofemoral ligament to contribute to abduction, independent of flexion-extension and of

**Fig 4.** Control of hip rotation within ligamentous state comparing increased flexion at 0°, 20°, and 40° abduction. \(^* P < .05\) compared with 30° flexion, \(^+ P < .05\) compared with 60° flexion. Native is all ligaments intact, -pubofem refers to the released pubofemoral ligament, and -pubofem&teres refers to the released pubofemoral ligament and ligamentum teres. (ABD, abduction; ER, external rotation; IR, internal rotation.)
rotation,” and a literature description within the study reported the external rotation—limiting function. There is one exception within the table reported by Fuss and Bacher that reports the pubofemoral ligament contributes to internal rotation control in a study by Joessel et al. published in 1884. Subsequent studies examining capsular ligament mechanics have reported the external rotation—limiting function of the pubofemoral ligament. In the cadaveric study previously mentioned by Martin et al. the medial arm of the iliofemoral ligament was termed the “greatest inhibitor to external rotation” between 0° and 30° hip flexion, and both the lateral and medial arms of the iliofemoral ligament contributed to more than 50% of external rotation. The ligamentous function clearly changes based on the degree of flexion. The authors hypothesize that releasing these ligaments before releasing the pubofemoral ligament may have altered the biomechanical support supplied by all 4 capsular ligaments. The internal and external measurements of the pubofemoral ligament may have been influenced because of the hip joint naturally moving to external rotation without the iliofemoral ligament. Hidaka et al. measured capsular ligament strain and reported similar findings of limiting external rotation. The ligament release order was randomized and therefore the pubofemoral ligament contribution may also have been affected. Additionally Hidaka et al. failed to test capsular ligament strain during flexion.

The contribution of the pubofemoral ligament to internal rotation control during hip flexion is explicitly depicted in Figures 3 and 4. Figure 3 shows an increase in internal rotation control by the pubofemoral ligament as hip flexion is increased from 30° to 60° and finally 110°. Figure 4 depicts the importance of the pubofemoral ligament for control of internal rotation as the hip was abducted from 0° to 40°. The pubofemoral ligament is generally described as a sling that originates at the pubic portion of the acetabular rim and runs distal and inferior to the medial arm of the iliofemoral ligament and medial-inferior to the iliopsoas femoral head. Inclusion of CT imaging allowed for a more in-depth understanding of how anatomic bony variations contribute to hip joint kinematics and capsular involvement.

**Limitations**

Limitations attributed to this study involve the use of cadaveric specimens. CT imaging revealed anatomic measures less than ideal regarding femoral and acetabular version; however, this represents a normal population and cannot be controlled. The center axis of the hip joint is difficult to maintain during testing, and human error during movement may affect positions.

**Conclusions**

The hypothesis of the pubofemoral ligament as one of the contributing factors of anterior inferior hip stability by controlling external rotation of the hip in flexion beyond 30° and abduction was disproved. The pubofemoral ligament maintains a key function in limiting internal rotation in the position of increasing hip flexion beyond 30° and abduction. This cadaveric study concludes previous attempts at understanding the anatomic and biomechanical function of the capsular ligaments and their role in hip stability.

**References**


7. Hidaka E, Aoki M, Izumi T, Suzuki D, Fujimiy M. Ligament strain on the iliofemoral, pubofemoral, and


The Development and Validation of a Self-Administered Quality-of-Life Outcome Measure for Young, Active Patients With Symptomatic Hip Disease: The International Hip Outcome Tool (iHOT-33)

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M. Elizabeth Pedersen, M.D., F.R.C.S.C., Denise Chan, M.B.T., M.Sc., Marc R. Safran, M.D.,
Nicholas Parsons, Ph.D., Jon K. Sekiya, M.D., Bryan T. Kelly, M.D.,
Jason R. Werle, M.D., F.R.C.S.C., Michael Leunig, M.D., Joseph C. McCarthy, M.D.,
Hal D. Martin, D.O., J. W. Thomas Byrd, M.D., Marc J. Philippon, M.D.,
RobRoy L. Martin, Ph.D., P.T., C.S.C.S., Carlos A. Guanche, M.D., John C. Clohisy, M.D.,
Thomas G. Sampson, M.D., Mininder S. Kocher, M.D., M.P.H., and Christopher M. Larson, M.D.,
for the Multicenter Arthroscopy of the Hip Outcomes Research Network (MAHORN)

Purpose: The purpose of this study was to develop a self-administered evaluative tool to measure health-related quality of life in young, active patients with hip disorders. Methods: This outcome measure was developed for active patients (aged 18 to 60 years, Tegner activity level ≥4) presenting with a variety of symptomatic hip conditions. This multicenter study recruited patients from international hip arthroscopy and arthroplasty surgeon practices. The outcome was created using a process of item generation (51 patients), item reduction (150 patients), and pretesting (31 patients). The questionnaire was tested for test-retest reliability (123 patients); face, content, and construct validity (51 patients); and responsiveness over a 6-month period in post-arthroscopy patients (27 patients). Results: Initially, 146 items were identified. This number was reduced to 60 through item reduction, and the items were categorized into 4 domains: (1) symptoms and functional limitations; (2) sports and recreational physical activities; (3) job-related concerns; and (4) social, emotional, and lifestyle concerns. The items were then formatted using a visual analog scale. Test-retest reliability showed Pearson correlations greater than 0.80 for 33 of the 60 questions. The intraclass correlation statistic was 0.78, and the Cronbach α was 0.99. Face validity and content validity were ensured during development, and construct validity was shown with a correlation of 0.81 to the Non-Arthritic Hip Score. Responsiveness was shown with a paired t test (P ≤ .01), effect size of 2.0, standardized response mean of 1.7, responsiveness ratio of 6.7, and minimal clinically important difference of 6 points. Conclusions: We have developed a new quality-of-life patient-reported outcome measure, the 33-item International Hip Outcome Tool (iHOT-33). This questionnaire uses a visual analog scale response format designed for computer self-administration by young, active patients with hip pathology. Its development has followed the most rigorous methodology involving a very large number of patients. The iHOT-33 has been shown to be reliable; shows face, content, and construct validity; and is highly responsive to clinical change. In our opinion the iHOT-33 can be used as a primary outcome measure for prospective patient evaluation and randomized clinical trials.
Traditionally, orthopaedic surgeons measured the success of their treatments by using so-called objective measures such as range of motion, strength, and radiographic appearance. Unfortunately, these measures have been found to be poor indicators of the functional ability of patients. To truly assess a patient’s ability to return to an active life, subjective measures of symptoms, emotional health, and social health need to be included. Quality-of-life outcome measures have been developed to capture the subjective aspect of health.

Most questionnaires for patients with hip pathology have been created for either patients with a hip fracture or those undergoing total hip arthroplasty. The existing outcomes often suffer from a ceiling effect, limiting their usefulness in the young, active population. These patients have different goals and expectations of their surgery and their quality of life in comparison with young patients with nonarthritic hip problems. Furthermore, most of these scores were not developed using rigorous methodology.

Three systematic reviews have evaluated hip outcome tools. Lodhia et al. identified 3 patient-reported outcomes—the Hip Outcome Score (HOS), the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), and the Non-Arthritic

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The authors report the following potential conflict of interest or source of funding in relation to this article: Canadian Orthopaedic Foundation, Calgary Orthopaedic Research and Development Fund, Calgary Surgical Research Development Fund, Alberta Bone and Joint Institute, and McCaig Professorship. All funding agencies represent noncommercial third-party granting agencies or charitable foundations.

Board member/officer/committee appointments: N.G.H.M. (Membership and Scientific Committees of International Society of Arthroscopy, Knee Surgery & Orthopaedic Medicine [ISAKOS] and Editorial Board Member of American Journal of Sports Medicine, Clinical Journal of Sport Medicine, The Physician and Sportsmedicine, and Sport-Orthopaedic–Sport-Traumatologie); M.R.S. (Executive Committee of American Shoulder and Elbow Surgeons; Treasurer and Board Member of International Society of Arthroscopy, Knee Surgery & Orthopaedic Sports Medicine; Chair of Council of Delegates, member of Education Committee, and Board Member of American Orthopaedic Society for Sports Medicine [AOSSM]; Editorial Board Member of American Journal of Sports Medicine; and President and Board Member of American Academy of Orthopaedic Surgeons [AAOS]); J.K.S. (American Orthopaedic Society for Sports Medicine Council of Delegates and Education Committee); J.C.M. (Past President of International Society for Hip Arthroscopy [ISHA], Hip Society Fellowship Match Committee, and Hip Society British Travelling Fellowship Committee); C.M.L. (Editorial Board for Arthroscopy and Learning Center Committee for Arthroscopy Association of North America); T.G.S. (President of ISHA); M.S.K. (American Academy of Orthopaedic Surgeons [AAOS] and AOSSM); J.W.T.B. (Executive Committee of ISHA); and M.J.P. (Board Member of Steadman Philippon Research Institute, owner of HIPCO and Micro-Imaging Solutions [MIS], and Committee Member of ISHA and AOSSM).

Royalties: M.R.S. (Stryker Medical [shoulder anchor], Lippincott Williams and Wilkins, and Elsevier/Saunders); J.K.S. (Elsevier [book royalties], Arthrex, and OrthoDynamix); J.C.M. (Stryker, Innomed, and Arthrex for implant and instrument design); C.A.G. (Wolters Kluwer); and M.J.P. (Smith & Nephew, Bledsoe, DonJoy, Slocum, Elsevier, and Arthrosurface).

Speakers bureau/paid presentations: B.T.K. (Smith & Nephew and C.M.L. [Smith & Nephew]); Paid consultant or employee: M.R.S. (Arthrocare); D.R.G. (ConMed Linvatec); J.K.S. (Arthrex); M.L. (Smith & Nephew and Biomet); J.C.M. (Stryker); J.W.T.B. (Smith & Nephew and A2 Surgical); C.A.G. (Smith & Nephew and Tornier); C.M.L. (Smith & Nephew and A2 Surgical); T.G.S. (ConMed Linvatec); H.D.M. (Smith & Nephew and Pivot Medical); M.S.K. (Smith & Nephew Endoscopy, Biomet, and Orthopediatrics); J.C.C. (Biomet Manufacturing); and M.J.P. (Smith & Nephew and MIS).

Unpaid consultant: M.R.S. (Biomedica and Cradle Medical); B.T.K. (Pivot Medical and A-2 Surgical); J.K.S. (Orthodynamic); and M.L. (Pivot). Research or institutional support from companies or suppliers: M.R.S. (fellowship support from Smith & Nephew, ConMed Linvatec, Ossur, and Zimmer); D.R.G. (Wright Medical); J.C.M. (Institutional-Zimmer, Biomet, and Smith & Nephew); J.W.T.B. (Smith & Nephew); C.M.L. (Smith & Nephew and Arthrex); J.C.C. (Zimmer); and M.J.P. (Smith & Nephew, Siemer, Ossur, and Arthrex).}

Note: To access the supplementary table accompanying this report (Table 3), visit the May issue of Arthroscopy at www.arthroscopyjournal.org.
Hip Score (NAHS)—that “have shown clinimetric evidence to support their use to measure outcomes in FAI [femoroacetabular impingement] and labral pathology patients. The HOS has the greatest amount of clinimetric evidence and is the most proven instrument for use in this population. This review shows that further clinimetric evaluation of commonly used PRO [patient-reported outcome] instruments for non-arthritic hip pathology is warranted.” However, the HOS did not include patients in its development and represents a functional score only. The WOMAC is specific for patients with arthritis and was developed in an older population. The NAHS uses 10 questions from the WOMAC and suffers from the potential of ceiling effects.22 A second systematic review focused on patient-reported outcome questionnaires when assessing hip and groin disability.33 This review suggested that the Hip Dysfunction and Osteoarthritis Outcome Score is recommended for evaluating patients with osteoarthritis, and the HOS is recommended for patients undergoing hip arthroscopy. The authors resolved by stating that “a new PRO [patient-reported outcome] questionnaire focusing on the evaluation of hip and groin disability in young and physically active patients is needed.”33

The latest systematic review looked at psychometric evidence of outcomes used in hip arthroscopy.34 The authors identified the Modified Harris Hip Scale (MHHS), the NAHS, and the HOS as the 3 possible outcome measures. They evaluated each outcome using the COSMIN (Consensus-Based Standards for the Selection of Health Status Measurement Instruments) checklist.35 They concluded, on the basis of the available evidence, that a combination of the NAHS and the HOS should be used as outcome measures for patients undergoing hip arthroscopy.34 They also stated that “more studies on the validity and reliability of these questionnaires are warranted.” The HOS was not patient derived, as noted earlier, and the MHHS is a clinician-based tool originally adapted for hip “mold replacement” surgery.6

The purpose of this study was to develop a self-administered evaluative tool to measure health-related quality of life in young, active patients with hip disorders. The main focus was to ensure that this measure was patient based and represented a young, active population with hip disorders, given that these patients have been shown to have different ideas about what is important than do their surgeons.36 The measurement goal of the proposed outcome was to create an evaluative instrument that would be used to measure the outcomes of various treatments in young, active patients with hip joint disorders.

**METHODS**

The University of Calgary Sport Medicine Centre Research Ethics Board and the institutional review boards from all participating centers approved this prospective study. Members of the Multicenter Arthroscopy of the Hip Outcomes Research Network (MAHORN) participated, and patients were recruited from the MAHORN members’ practices from Canada, the United States, England, and Switzerland. The International Hip Outcome Tool (iHOT) was developed using the methodology described by Guyatt et al. 37-39 which has also been used to develop several other similar tools.23-25,27,28,40,41

**Inclusion/Exclusion Criteria**

This outcome measure has been developed in young, active patients aged between 18 and 60 years presenting with hip pathology to orthopaedic surgeons (Table 1). A patient was define as active if he or she had an activity level of 4 or greater on a modified Tegner Activity Scale (Table 2).42 Hip pathology was define as the abnormal functioning of the hip leading to pain, instability, stiffness, or physical impairment due to improper biomechanics of the joint. Patients with hip pain as a result of muscular strains or with referred pain from the back or knee were not included. Differential diagnoses included bony pathology such as avascular necrosis or osteochondral fracture, damage to the cartilage in the form of chondral lesions and arthritis, ligamentous injury, tearing of the labrum or

<table>
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<th>Table 1. Inclusion and Exclusion Criteria</th>
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<tbody>
<tr>
<td><strong>Inclusion criteria</strong></td>
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<tr>
<td>Age 18-60 yr</td>
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<tr>
<td>Primary musculoskeletal hip pathology</td>
</tr>
<tr>
<td>Active (≥4 on modified Tegner Activity Scale)</td>
</tr>
<tr>
<td>Presentation with hip pain to orthopaedic surgeon</td>
</tr>
<tr>
<td>Literate and English speaking</td>
</tr>
<tr>
<td><strong>Exclusion criteria</strong></td>
</tr>
<tr>
<td>Pre-existing comorbid medical conditions that interfere with patient’s ability to participate in sports or other physical activities</td>
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<tr>
<td>Polytrauma patients with ipsilateral or contralateral lower extremity injuries or spinal injuries with neurologic deficit</td>
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<tr>
<td>Patients who have language, psychiatric, or cognitive difficulty that prevent reliable completion of questionnaire</td>
</tr>
<tr>
<td>Active hip joint infection</td>
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<td>Local bone- or joint-related malignancy</td>
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joint capsule, inflammation in the hip joint and surrounding structures, loose bodies, or abnormal anatomy leading to dysplasia, impingement, or instability. Participants received a wide range of treatments, including pharmacologic, rehabilitative, and surgical interventions. Patients were included regardless of their stage of treatment. Some patients were treated nonsurgically, with hip-preserving surgery, and some ultimately underwent resurfacing or total hip arthroplasty; however, the majority were treated with an arthroscopic procedure. No exclusions were made based on subsequent treatments.

**Initial Development of iHOT Questionnaire**

The first phase of this methodologic approach was item generation as a 3-step process. The first step was to identify a comprehensive list of items from the existing hip outcome literature, including quality-of-life questionnaires for other orthopaedic conditions in populations of a similar age.\(^{25,28}\) The list of items was organized into 5 categories: (1) symptoms; (2) functional limitations; (3) occupational concerns; (4) sports and recreational activities; and (5) social, emotional, and lifestyle concerns, as a result of hip problems. The second step was to ask orthopaedic surgeons and physiotherapists who routinely manage young, active patients with hip problems to add items to this list. The final and most critical step was to interview eligible patients with an open-ended format to identify additional items that relate to how their quality of life is impacted by their condition. Comprehensiveness was ensured by repeated surveying of patients and sampling to the point of redundancy, when no new items were generated.\(^{43}\) This process is generally considered the most important step in the process of creating a new outcome measure.\(^{43}\)

The second phase was to perform item reduction. This phase was necessary to ensure that the final items/questions were important to patients, avoided redundancy, and were comprehensive with respect to all aspects of patient-related quality of life. The generated items were formatted into an item reduction questionnaire, which was distributed to a different group of eligible patients. An iterative quantitative and qualitative approach was used in the item reduction phase. The quantitative approach included calculation of frequency-importance products, factor analysis, and item-total correlation. The qualitative approach included consensus agreement between the research team and the MAHORN surgeons to address redundancy and comprehensiveness. Each item was rated by both eligible patients and the MAHORN surgeons for its relevance and importance, using a 6-point ordinal scale (0 to 5), where 0 indicated that

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\text{Table 2. Modified Tegner Activity Scale}
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<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
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<tbody>
<tr>
<td>10</td>
<td>Competitive sports played at a world or Olympic level or professionally</td>
</tr>
<tr>
<td>9</td>
<td>Competitive sports such as track and field racquet/ball sports, gymnastics, rowing, skiing, or martial arts played at a national or international level</td>
</tr>
<tr>
<td>8</td>
<td>Competitive sports such as water sports, cycling, hockey, curling, or horseback riding/rodeo played at a national or international level</td>
</tr>
<tr>
<td>7</td>
<td>Recreational sports such as running, ball/racquet sports, weight training, curling, rowing, golf, yoga, or gymnastics at least 5 times per week</td>
</tr>
<tr>
<td>6</td>
<td>Recreational sports such as swimming, water sports, skiing, hockey, rollerblading, cycling, horseback riding, or mountain climbing at least 5 times per week</td>
</tr>
<tr>
<td>5</td>
<td>Work—heavy labor such as construction Recreational sports at least twice weekly</td>
</tr>
<tr>
<td>4</td>
<td>Work—moderately heavy labor such as truck driving Recreational sports once a week or less</td>
</tr>
<tr>
<td>3</td>
<td>Work—light labor such as nursing Daily activities such as gardening, climbing multiple flight of stairs, carrying loads, pushing/pulling a load, or ability to run if late Recreational sports less than once a month</td>
</tr>
<tr>
<td>2</td>
<td>Work—light labor Daily activities such as cleaning house, climbing 1 or 2 flight of stairs, or walking carrying a light load</td>
</tr>
<tr>
<td>1</td>
<td>Work—sedentary (secretarial, computer based) Daily activities limited (e.g., do not take stairs, unable to carry loads)</td>
</tr>
<tr>
<td>0</td>
<td>Sick leave or disability pension because of health problems</td>
</tr>
</tbody>
</table>
the item was “not experienced or important” and 5 indicated that the item was “experienced and extremely important.” On the basis of these responses, a frequency-importance product was calculated for each item by multiplying the frequency (i.e., the number of patients ranking the item above 0) by the mean importance of that item (i.e., the sum of all rankings, excluding 0, divided by the number of patients). On the basis of the patients’ responses, an a priori frequency-importance product of 50% or greater was considered the cut point for inclusion. Factor analysis was used to determine which items loaded on the same factors (i.e., belonged to the same domain or category defined in the item generation phase). Item-total correlations were calculated to confirm the reduced items. Pearson correlations were calculated between each item and the total score within each domain. Items that highly correlated with the a priori construct were identified as items that should be retained in the questionnaire.

The third phase involved formulating the items into actual questions with an appropriate response format. The reduced items were subsequently formatted into a self-administered pretest questionnaire. A visual analog scale (VAS) response format was used for each question. The 100-point VAS scale format was chosen because it has been used successfully in many other questionnaires. The VAS scoring requires no mathematical transformation, and with a normal distribution of data, it allows for parametric statistical analysis. Furthermore, the VAS response format has shown good internal consistency, is intuitively understood, and converts easily to computer- and Web-based administration.

Each question is scored out of 100, with 0 representing the worst possible quality-of-life score and 100 representing the best. Totaling the scores from all questions answered and then dividing by the number of questions determined the patient’s final score out of 100. It is also possible to calculate a separate score for each domain. However, no attempt was made to analyze each domain separately.

The final component of the initial questionnaire development was pretesting the questionnaire. Pretesting ensured that the wording was clear and that the patients interpreted the items as they were intended. A separate group of eligible patients completed the pretest questionnaire and participated in a formal 1-to-1 interview process. They were asked to give their interpretation of each item, identify questions with unclear wording, and confirm that all of their relevant concerns with respect to their hip condition were addressed in the questionnaire. Groups of 5 patients were subsequently interviewed, with modifications being made to the questionnaire after each pretesting round. Changes to the questionnaire based on the patients’ comments were made only if group consensus was achieved. In addition, the patient responses on each item were analyzed to ensure that the response scale was appropriate and represented the full distribution of possible choices for the patient.

Validation of iHOT

Validation of the iHOT questionnaire involved several components: measurement of test-retest reliability; evaluation of face, content, and construct validity of the outcome; and assessment of responsiveness and minimal clinically important difference (MCID).

Reliability: Reliability was assessed using a test-retest protocol. A group of 123 patients, who had not participated in any prior phases of this research, completed the questionnaire on 2 separate occasions at least 2 weeks apart but with no intervention between test points. The mean number of days between administrations was 24 days (range, 14 to 90 days). When completing the questionnaire the second time, the patients also completed a global rating scale to indicate whether their hip condition had improved, had deteriorated, or had no change since the previous administration of the questionnaire. This global assessment was measured using a single VAS ranging from −100 to +100. Fifty patients with less than 5% change on the global rating scale were included in the reliability analysis. The questions were then assessed for internal consistency with the Cronbach α and test-retest correlations with Pearson and intraclass correlation coefficients. The reliability data were also analyzed using a principal component analysis and bi-plots to look at the variance within the data. Regression analysis was used to identify the items that accounted for the largest part of the variation. A forward-selection procedure was used to select these items.

Face Validity: Face validity is a qualitative measure that is present if the iHOT appears to measure the issues relevant to hip problems. This form of validity was determined throughout the development of the questionnaire by reviewing the relevant literature, as well as through the direct involvement and contribution from representative samples of patients with hip problems, orthopaedic hip surgeons, and physiotherapists.
**Content Validity:** Content validity was assessed through consensus agreement with a group of participating orthopaedic hip arthroscopists. This group, the MAHORN, provided input at all stages of the development of the questionnaire. Members of the MAHORN provided feedback into the original set of items and rated each of the items with respect to importance in a similar fashion to the patients in the item reduction phase. The surgeons also evaluated each item in the pretest questionnaire for its relevance, whether the item would change as a result of treatment, and whether the response format was appropriate. In this way the treating surgeons were able to include input toward those items that were most likely to be evaluative and therefore responsive to change.

**Construct Validity:** Construct validity was determined by administering the iHOT to a separate group of 51 eligible patients and comparing the questionnaire with the results of the NAHS.46 It was hypothesized that the iHOT and the NAHS should correlate highly because both were created for a population of young, active patients with hip disorders.

**Responsiveness and MCID:** Responsiveness and MCID were assessed by administering the iHOT questionnaire to an additional group of 27 young, active patients with hip problems preoperatively and postoperatively at 6 months after arthroscopy (i.e., the responsiveness cohort). A population of 50 patients from the reliability phase of validation was also used to act as a comparison group (i.e., the reliability cohort). Clinical change was determined using the same global rating scale used for reliability testing. An anchor- and distribution-based approach to determine the MCID was used. Responsiveness was determined using several different measures, including a comparison of baseline and 6-month data with a paired t test, standardized effect size, standardized response mean, and responsiveness ratio.37,47,48

**RESULTS**

**Patient Population**

Over 400 patients were involved at different stages of the project (Table 3, available at www.arthroscopyjournal.org). There were no differences in the demographics of the patients at any phase, with an equal number of male and female patients represented. The mean age of the entire group was 40 years (range, 18 to 60 years). The specific diagnosis was unknown in 127 cases.

**Item Generation**

The item generation list was distributed to 51 patients, 4 orthopaedic surgeons, and 4 physiotherapists. Two hundred twenty-six items were generated. To avoid redundancy, similar or repetitive items were identified between and within each section and removed, combined, and/or reworded. These decisions were based on consensus agreement between the research team and participating orthopaedic surgeons. As a result, the list was decreased to 146 items, which were categorized into 5 domains: symptoms (27 items); functional limitations (36 items); sports and recreational activities (28 items); occupational issues (27 items); and social, emotional, and lifestyle concerns (28 items).

**Item Reduction**

The 146-item reduction questionnaire was administered to 150 patients and 9 MAHORN surgeons. The process of item reduction decreased the number of items from 146 to 60 in 4 domains: (1) symptoms and functional limitations (21 items); (2) sports and recreational activities (18 items); (3) job-related concerns (9 items); and (4) social, emotional, and lifestyle concerns (12 items).

The items with a frequency-importance product of 50% or greater were retained; however, none of the items from the job-related concerns domain reached this cutoff point. Consensus agreement between the research team and the participating MAHORN orthopaedic surgeons was to include items from this domain. Therefore the top 12 items from the job-related concerns domain were retained because 1 of the following criteria was met: (1) at least 50% of the patients rated the item as important; (2) the mean rating for these items was greater than 3.5 (of 5); or (3) a significant proportion of patients rated the item as relevant and extremely important (i.e., 5 of 5 on the scale).

The factor analysis determined that the items in the symptoms and functional limitations domains loaded onto the same factor. This clearly indicated that all of these items belonged to 1 domain.

Frequency-importance products were then calculated for each item based on the responses from the 9 orthopaedic surgeons and were compared with the results from the patients. There was a discrepancy between the items identified as relevant and important from the patients’ perspectives and from the surgeons’ perspectives.36 For example, the surgeons rated groin pain as the highest item, with an average importance
of 4.8 of 5. The patients rated this item at 2 of 5. To reflect content validity, 10 additional items were included based on consensus agreement between the research team and the MAHORN surgeons. Therefore a total of 60 items were formatted into a pretesting questionnaire. Content validity was confirmed by the MAHORN surgeons, who evaluated the content of the questionnaire from a clinical perspective. These surgeons reviewed the formatted pretest questionnaire for wording and content validation. They were asked specifically if the content of each question would be amenable to treatment. This process confirmed the inclusion of all 60 items before reliability testing.

**Pretesting**

Four rounds of pretesting were completed with 31 patients. Modification included changes in wording, changes to the order of the questions, separation of items into 2 questions, and further identification and removal of redundant items. The 60 questions remained after this stage.

**Reliability Testing**

One hundred twenty-three patients completed the questionnaires. Of these patients, 50 indicated less than 5% change in their hip condition. These 50 patients were considered stable clinically, and reliability was calculated on this sample. Each of the 60 questions was analyzed for test-retest reliability (repeatability) using Pearson correlation coefficient and calculating the difference between test periods. Those questions with a Pearson correlation of greater than 0.80 were retained, resulting in a total of 33 questions. The standard error of the difference in the total score was 3 points (95% confidence interval, −5.5 to +6.8). The intraclass correlation coefficient for the questionnaire using these 33 items was 0.78, and internal consistency measured by the Cronbach α was .99.

The 33 questions were distributed within the 4 domains as follows: symptoms and functional limitations, 16 questions; sports and recreational activities, 6 questions; job-related concerns, 4 questions; and social, emotional, and lifestyle concerns, 7 questions. The scores of these 33 questions showed no floor or ceiling effects (Appendix 1).

**Scoring**

A VAS response format ranging from 0 to 100 was used for each question, where a higher score represents better quality of life. For those patients who were retired or unemployed for reasons other than their hip joint problem, the 4 “job-related” questions would be omitted. The overall score would still be calculated by taking the average out of 100 from the remaining questions.

**Validation**

Face validity was ensured because of patient involvement at all stages of the development of the questionnaire. The MAHORN surgeons addressed content validation.

Construct validation was addressed by comparing the 33-item International Hip Outcome Tool (iHOT-33) outcome with the NAHS. This construct showed that the new quality-of-life questionnaire showed a correlation coefficient of 0.81, indicating very good correlation (Fig 1).

**Responsiveness**

The reliability cohort (50 patients) had no clinically meaningful change, and the responsiveness cohort (27 patients) had much improvement at the 6-month postoperative time point. The mean score was 32 of 100 at baseline and 65 of 100 at 6 months, with a mean change in score of 33 and SD of 19.3. The paired t test showed highly significant differences, with P ≤ .01. By use of these 2 patient groups, the standardized effect size was 2.0, the standardized response mean

![Figure 1. Correlation of iHOT-33 quality-of-life (QoL) score with Non-Arthritic Hip Score (NHS).](image-url)
was 1.7, and the responsiveness ratio was 6.7. The MCID was calculated to be 6.1.

**DISCUSSION**

There has been increasing interest in the evaluation and management of nonarthritic hip problems in young, active patients. This is because of a much greater understanding of hip biomechanics and improved imaging techniques. However, there is a paucity of reports regarding validated hip outcomes in the younger person. Recently, there have been 3 outcome measures developed to assess patients treated with hip arthroscopy: the NAHS, the HOS, and the Copenhagen Hip and Groin Outcome Score (HAGOS). The HOS included physician and physical therapy input during item generation without patient involvement. The HOS has been reported to show reliability and responsiveness within the context of its 2 subscales, activities of daily living and sports. Similarly, it has been shown to be valid for patients with labral tears and in hip arthroscopy patients, but only with respect to physical function. The HOS is not designed to measure symptoms; emotional, social, or lifestyle dimensions; or the impact of the patients’ problems on their jobs. The NAHS was based on the WOMAC. The WOMAC is a 24-item questionnaire completed by the patient and focusing on joint pain, stiffness, and loss of function related to osteoarthritis of the knee and hip. It has 2 subscales: pain and function. The NAHS uses 10 items directly from the WOMAC from the domains of pain and physical function and adds 4 questions related to mechanical symptoms and 6 questions related to activity level. All items from the WOMAC are patient derived. The additional 10 questions were generated through pilot test interviews with patients of varying educational levels and with health professionals. The NAHS has been shown to be reliable and valid, but it also lacks specific items relating to other important aspects of patient-related quality of life. The HAGOS has been developed using similar methodology to the iHOT. However, the 37-item questionnaire involved a total of 126 patients who were used at more than 1 stage of the questionnaire development. The iHOT used over 400 patients with independent groups at each stage of questionnaire development. The basis for the item generation process for the HAGOS was 43 items/questions (40 from the Hip Dysfunction and Osteoarthritis Outcome Score and 3 from the HOS). An expert group (N = 7), comprising 2 orthopaedic surgeons, 1 physician, and 4 physiotherapists, added an additional 8 questions. A representative focus group of 25 patients added 2 questions and removed 1 question, resulting in a 52-item questionnaire. Because item generation is considered the most important phase of questionnaire development, the HAGOS may have missed potentially important items. The remaining stages of questionnaire development were based on 101 patients, resulting in a final questionnaire of 37 questions in 6 separate subscales: pain (10 items), symptoms (7 items), activities of daily living (5 items), sports/recreation (8 items), physical activities (2 items), and quality of life (5 items). Content validity was suggested based on the input from the original 25 patients and expert group (N = 7) involvement. Test-retest reliability was measured 1 to 3 weeks after baseline, in 44 of the 101 patients. Responsiveness was determined at 4 months from baseline in 87 of 101 patients. Ironically, the subscale with the highest standardized response mean and effect size was the quality-of-life subscale, at 1.46 and 1.78, respectively. Construct validity was determined by comparing the HAGOS with the Short Form 36, which has significant limitations because the Short Form 36 is a generic outcome measure. The comparison with respect to a priori correlations was satisfactory but not consistent. Ultimately, evaluative patient-reported outcomes should be able to measure the minimal important change and/or minimal important difference. The HAGOS showed that the minimal important change for each subscale ranged from 10 to 15 points based on using the estimate of one-half of the reported standard deviation. The authors identify the limitation that if the HAGOS were used as the primary outcome measure in a clinical trial, more patients would be needed to achieve a meaningful sample size.

Most recently, Briggs and Philippon reported on the Vail Hip Score, which included 10 particular questions that were most responsive to patients treated with hip arthroscopy. These items were “mined” from a database of thousands of patients who had arthroscopic procedures and comprised 3 items related to pain, 2 with respect to stiffness, 1 with respect to limping, and 4 related to function. The Vail Hip Score was not patient derived or generated. It specifically includes questions from the MHHS, the NAHS, and the HOS.

These outcome scores or measures, as well as many others that are currently used, have merit in 1 respect or another because most have been “validated” in certain contexts. There is a lot of similarity and some consistency between these measures. However, no
tool created to date has been based on the population of patients with hip disorders who are young and active and has included all dimensions of health-related quality of life.

The iHOT questionnaire was developed to address all of the previous deficiencies with respect to outcome assessment for young, active patients with hip disorders. The appropriate population for this tool includes patients aged between 18 and 60 years who have a Tegner activity level of 4 or higher, meaning that they are engaged in recreational physical activities at least once a week or have an occupation involving moderately heavy labor (Table 2). The development of the iHOT-33 involved 433 patients from Canada, the United States, England, and Switzerland. This number far exceeds similar validated outcome measures.23-28,60-64 The large number and variety of patients involved in creating and testing this questionnaire imply generalizability for multiple populations of young patients with hip disorders. The confirm and specific diagnosis was unknown in 32% of the patients. Nevertheless, every patient with an unconfirmed diagnosis had a hip joint problem, the majority were preoperative, and such patients were identified from the same practices as those where the diagnosis was confirmed.

The purpose of the described outcome tool is to evaluate patients so that they can be followed up over time and the success of various treatments can be assessed. Evaluative tools require the property of responsiveness.37 Wright and Young65 have published a comparison of the responsiveness properties of 5 different patient-reported outcomes. They compared multiple measures of responsiveness including the responsiveness statistic/ratio, standardized response mean, and effect size. The iHOT-33 showed a responsiveness ratio of more than twice the highest-ranked outcome (WOMAC disability domain).65 The iHOT-33 has an effect size of 2.0, which is higher relative to the HOS activities of daily living and sports subscales, at 1.2 and 1.5, respectively. Similarly, the MCID of the iHOT-33, at 6.1, shows that it is very sensitive to change compared with the HAGOS (i.e., 10 to 15 points) and International Knee Documentation Committee subjective knee form, which is sensitive to change at a score of 11.5 points out of 100. Therefore, compared with similar questionnaires, the iHOT-33 is highly responsive with a small MCID, showing great value for use as an evaluative outcome measure.

Some quality-of-life questionnaires can discriminate between patients and thus guide treatment decision making.66 The iHOT-33 has yet to be specifically evaluated for its discriminative properties, and this requires a future study. The response format is a VAS. Although such a format is easily adaptable to a computer or Web-based interface, phone-based administration has only recently been evaluated in 1 setting and using the short form of the iHOT.67 The age limits of 18 to 60 years were determined to represent younger active patients. Therefore assessing outcomes in the pediatric and elderly populations may not be appropriate. These limits were determined a priori to ensure that the questionnaire was self-administered and easily understood.

CONCLUSIONS

We have developed a new quality-of-life patient-reported outcome measure, the iHOT-33. This 33-item questionnaire uses a VAS response format designed for computer self-administration by young, active patients with hip pathology. Its development has followed the most rigorous methodology involving a very large number of patients. The iHOT-33 has been shown to be reliable; shows face, content, and construct validity; and is highly responsive to clinical change. In our opinion the iHOT-33 can be used as a primary outcome measure for prospective patient evaluation and randomized clinical trials.

Acknowledgment: The authors acknowledge Jocelyn Fredine for data collection and entry and the research assistants from the participating sites for data collection; Lisa Phillips, M.D., for data collection, analysis, and reporting the responsiveness; Carol Hutchison, M.D., Richard Buck- ley, M.D., Tim Lee, David Lindsay, and Dason Sparling for their contribution in the item generation phase; and Ricardo Pietrobon for his help with the item-total correlation analysis.

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41. Mohtadi NG, Pedersen ME, Chan D. The creation of a hip outcome measure for young patients with hip disease. Presented at the World Congress of Sports Trauma, Hong Kong, April 12, 2008.
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APPENDIX 1

International Hip Outcome Tool (iHOT-33).

INSTRUCTIONS

- These questions ask about the problems you may be experiencing in your hip, how these problems affect your life, and the emotions you may feel because of these problems.
- Please indicate the severity by marking the line below each question with a slash.
  - If you put a mark on the far left, it means that you feel you are significantly impaired. For example:
  
  ![SIGNIFICANTLY IMPAIRED](image)
  
  No problems at all

  - If you put a mark on the far right, it means that you do not think that you have any problems with your hip. For example:
  
  ![SIGNIFICANTLY IMPAIRED](image)
  
  No problems at all

  - If the mark is placed in the middle of the line, this indicates that you are moderately disabled, or in other words, between the extremes of 'significantly impaired' and 'no problems at all.' It is important to put your mark at either end of the line if the extreme descriptions accurately reflect your situation.
- Please let your answers describe the typical situation in the last month.

SECTION 1 | SYMPTOMS AND FUNCTIONAL LIMITATIONS

The following questions ask about symptoms that you may experience in your hip and about the function of your hip with respect to daily activities. Please think about how you have felt most of the time over the past month and answer accordingly.

---

Q01  How often does your hip/groin ache?

![CONSTANTLY](image)

![NEVER](image)

---

Q02  How stiff is your hip as a result of sitting/resting during the day?

![EXTREMELY STIFF](image)

![NOT STIFF AT ALL](image)
**International Hip Outcome Tool (iHOT-33)**

**Q03** How difficult is it for you to walk long distances?

EXTREMELY
DIFFICULT

NOT DIFFICULT
AT ALL

**Q04** How much pain do you have in your hip while sitting?

EXTREME PAIN

NO PAIN AT ALL

**Q05** How much trouble do you have standing on your feet for long periods of time?

SEVERE TROUBLE

NO TROUBLE AT
ALL

**Q06** How difficult is it for you to get up and down off the floor/ground?

EXTREMELY
DIFFICULT

NOT DIFFICULT
AT ALL

**Q07** How difficult is it for you to walk on uneven surfaces?

EXTREMELY
DIFFICULT

NOT DIFFICULT
AT ALL

**Q08** How difficult is it for you to lie on your affected hip side?

EXTREMELY
DIFFICULT

NOT DIFFICULT
AT ALL

**Q09** How much trouble do you have with stepping over obstacles?

SEVERE TROUBLE

NO TROUBLE AT
ALL

**Q10** How much trouble do you have with climbing up/down stairs?

SEVERE TROUBLE

NO TROUBLE AT
ALL

**Q11** How much trouble do you have with rising from a sitting position?

SEVERE TROUBLE

NO TROUBLE AT
ALL

**Q12** How much discomfort do you have with taking long strides?

EXTREME
DISCOMFORT

NO DISCOMFORT
AT ALL
Q13  How much difficulty do you have with getting into and/or out of a car?

EXTREME DIFFICULTY  NO DIFFICULTY AT ALL

Q14  How much trouble do you have with grinding, catching or clicking in your hip?

SEVERE TROUBLE  NO TROUBLE AT ALL

Q15  How much difficulty do you have with putting on/taking off socks, stockings or shoes?

EXTREME DIFFICULTY  NO DIFFICULTY AT ALL

Q16  Overall, how much pain do you have in your hip/groin?

EXTREME PAIN  NO PAIN AT ALL

SECTION 2 | SPORTS AND RECREATIONAL ACTIVITIES

The following questions ask about your hip when you participate in sports and recreational activities. Please think about how you have felt most of the time over the past month and answer accordingly.

Q17  How concerned are you about your ability to maintain your desired fitness level?

EXTREMELY CONCERNED  NOT CONCERNED AT ALL

Q18  How much pain do you experience in your hip after activity?

EXTREME PAIN  NO PAIN AT ALL

Q19  How concerned are you that the pain in your hip will increase if you participate in sports or recreational activities?

EXTREMELY CONCERNED  NOT CONCERNED AT ALL

Q20  How much has your quality of life deteriorated because you cannot participate in sport/recreational activities?

EXTREMELY DETERIORATED  NOT DETERIORATED AT ALL
Q21 How concerned are you about cutting/changing directions during your sport or recreational activities?

☐ I do not do this action in my activities

EXTREMELY CONCERNED _______________________________ NOT CONCERNED AT ALL

Q22 How much has your performance level decreased in your sport or recreational activities?

EXTREMELY DECREASED _______________________________ NOT DECREASED AT ALL

SECTION 3 | JOB RELATED CONCERNS

The following questions relate to your hip with respect to your current work. Please think about how you have felt most of the time over the past month and answer accordingly.

☐ I do not work because of my hip (please skip section)

☐ I do not work for reasons other than my hip (please skip section)

Q23 How much trouble do you have pushing, pulling, lifting or carrying heavy objects at work?

☐ I do not do these actions in my activities

SEVERE TROUBLE _______________________________ NO TROUBLE AT ALL

Q24 How much trouble do you have with crouching/squatting?

SEVERE TROUBLE _______________________________ NO TROUBLE AT ALL

Q25 How concerned are you that your job will make your hip worse?

EXTREMELY CONCERNED _______________________________ NOT CONCERNED AT ALL

Q26 How much difficulty do you have at work because of reduced hip mobility?

EXTREME DIFFICULTY _______________________________ NO DIFFICULTY AT ALL
SECTION 4 | SOCIAL, EMOTIONAL AND LIFESTYLE CONCERNS

The following questions ask about social, emotional and lifestyle concerns that you may feel with respect to your hip problem. Please think about how you have felt most of the time over the past month and answer accordingly.

Q27  How frustrated are you because of your hip problem?

EXTREMELY FRUSTRATED ............................................. NOT FRUSTRATED AT ALL

Q28  How much trouble do you have with sexual activity because of your hip?

☐ This is not relevant to me

SEVERE TROUBLE ................................................................. NO TROUBLE AT ALL

Q29  How much of a distraction is your hip problem?

EXTREME DISTRACTION ...................................................... NO DISTRACTION AT ALL

Q30  How difficult is it for you to release tension and stress because of your hip problem?

EXTREMELY DIFFICULT ...................................................... NOT DIFFICULT AT ALL

Q31  How discouraged are you because of your hip problem?

EXTREMELY DISCOURAGED ............................................. NOT DISCOURAGED AT ALL

Q32  How concerned are you about picking up or carrying children because of your hip?

☐ I do not do this action in my activities

EXTREMELY CONCERNED ...................................................... NOT CONCERNED AT ALL

Q33  How much of the time are you aware of the disability in your hip?

CONSTANTLY AWARE ............................................................. NOT AWARE AT ALL
<table>
<thead>
<tr>
<th>Phase (No. of Patients)</th>
<th>Mean Age (yr)</th>
<th>Gender</th>
<th>Affected Hip</th>
<th>Mean Time Hip Has Been a Problem (yr)</th>
<th>Diagnoses</th>
<th>Mean Tegner Activity Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item generation (n = 51)</td>
<td>38.2</td>
<td>29 M/21 F/1 unknown</td>
<td>23 L/20 R/7 both/1 unknown</td>
<td>2.5</td>
<td>After Perthes osteoarthritis, degenerative labral tear, early osteoarthritis, previous congenital hip dysplasia, previous osteotomy, FAI, grade 3 and grade 4 chondromalacia acetabulum and femoral head, chondromalacia rim of acetabulum, sclerosis, osteophytes, bursitis, snapping hip, iliotibial syndrome, short iliotibial band, arthrosis, adhesive capsulitis, damaged bone</td>
<td>6.4</td>
</tr>
<tr>
<td>Item reduction (n = 150)</td>
<td>41.7</td>
<td>72 M/76 F/2 unknown</td>
<td>41 L/76 R/32 both/1 unknown</td>
<td>5.3</td>
<td>Torn labrum, possible minor labral tear and chondral lesion, arthritis, dysplasia, tendinitis, torn cartilage, impingement, bone lesion, ligament tears, bone spur, avascular necrosis, Perthes, joint replacement, piriformis syndrome, oversized femur, FAI, Ehlers syndrome, hypermobility, dislocation, hip pain, degenerative arthritis, bursitis, hip flexo contracture, iliotibial band syndrome</td>
<td>6.0</td>
</tr>
<tr>
<td>Pretesting (n = 31)</td>
<td>43.8</td>
<td>15 M/16 F</td>
<td>13 L/17 R/1 both</td>
<td>6.3</td>
<td>Possible ilioinguinal nerve entrapment or return of inguinal hernia, FAI, labral tear, bony abnormality, snapping iliotibial tendon, early osteoarthritis, chondral injury, fibromyalgia/Sjögren syndrome, possible iliotibial bursitis, early arthrosis with pincer impingement, Perthes disease, bilateral hip dysplasia</td>
<td>7.4</td>
</tr>
<tr>
<td>Reliability n = 123</td>
<td>39.9</td>
<td>46 M/77 F</td>
<td>38 L/62 R/22 both/1 unknown</td>
<td>5.3</td>
<td>Labral debridement, abnormal labrum and acetabulum with minor cam impingement, labral tear, osteoarthritis, mild hip dysplasia, hip pain, anterior-superior labral detachment, chondral damage, FAI, RA, gluteus medius tear, synovial chondromatosis</td>
<td>6.2</td>
</tr>
<tr>
<td>Reliability cohort n = 50</td>
<td>38.6</td>
<td>17 M/33 F</td>
<td>16 L/28 R/6 both</td>
<td>5.6</td>
<td>Labral debridement, abnormal labrum and acetabulum with minor cam impingement, labral tear, osteoarthritis, mild hip dysplasia, hip pain, anterior-superior labral detachment, chondral damage, FAI, arthropathy/RA, gluteus medius tear, synovial chondromatosis</td>
<td>6.1</td>
</tr>
<tr>
<td>Responsiveness (n = 27)</td>
<td>39.2</td>
<td>14 M/13 F</td>
<td>14 L/13 R</td>
<td>4.7</td>
<td>FAI, cam and pincer FAI, labral tear, chondromalacia acetabulum, os acetabulum, early osteoarthritis, chondral bruising, chondral damage, osteophyte, ligamentum teres tear/avulsion, synovial osteochondromatosis</td>
<td>6.8</td>
</tr>
<tr>
<td>Construct validity (n = 51)</td>
<td>35.1</td>
<td>20 M/31 F</td>
<td>21 L/24 R/6 both</td>
<td>4</td>
<td>FAI, labral tear, early osteoarthritis, instability, previous trauma, loose bodies, Perthes, avascular necrosis, slipped capital femoral epiphysis, hip dysplasia</td>
<td>6.5</td>
</tr>
</tbody>
</table>

Abbreviations: F, female; FAI, femoroacetabular impingement; L, left; M, male; R, right; RA, rheumatoid arthritis.
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DOI: 10.1177/0363546509333851

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Differences in Physician and Patient Ratings of Items Used to Assess Hip Disorders

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Background: The purpose of this study was to determine what issues are important to active individuals with hip lesions and to assess whether these issues are different from those that surgeons think are important.

Hypothesis: A discrepancy will be noted between what patients and surgeons believe to be important.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: This study comprised 150 consecutive patients (73 men, 77 women) from the international practices of 9 orthopaedic surgeons specializing in the management of hip disorders. All participants were seeking treatment for musculoskeletal hip disease. Average patient age was 42 ± 11 years (range, 18-60). Patients and surgeons rated the importance of 146 potential hip outcome assessment items on a 6-point Likert-type scale.

Results: Of the 23 items identified as being important to patients, 16 were in the sports and recreation category. The top 11 items that the clinicians thought were most important were rated significantly lower by patients (P < .0005). Specifically, surgeons rated several items as being important that fell into the symptoms, functional limitations, and occupational issues categories, whereas patients did not. That is, a difference was found between patients and clinicians in how they rated items related to symptoms, functional limitations, and occupation (P < .01). A difference was not found between patients and surgeons in how they rated items related to sports and recreation and social-emotional lifestyle (P > .01).

Conclusion: The hypothesis of this study was affirmed: a discrepancy was found between what issues patients believe are important and what surgeons perceive as being important to patients. This information may be particularly important when assessing treatment outcomes from a patient’s perspective. Clinicians must be careful in presuming that the issues that they are attempting to improve with treatment are issues that are important to patients. These findings also emphasize the importance of discussing appropriate postoperative expectations for those considering surgery.

Keywords: outcome; questionnaire; self-report; instrument; patient perspective
The assessment of treatment outcome is an essential component of patient care. Outcomes can be assessed using a variety of objective and subjective measures, including patient-centered self-administered questionnaires. For patient-centered outcome assessment to be properly accomplished, we need to know what issues are important to active individuals with musculoskeletal hip disease. A related concern involves the factors that physicians believe are important to patient care—namely, that they may be abandoned. However, do physicians and other health care providers know what is important to patients? The purpose of this study was to address these concerns as they relate to outcome assessment for active individuals with musculoskeletal hip disease.

Outcome studies that incorporate patient-centered assessment commonly use some type of questionnaire. The methods used to develop these questionnaires can affect the usefulness of the information they provide. Appropriate methods for developing outcome questionnaires have been outlined in 6 stages: item selection, item reduction, questionnaire format, pretesting, evidence for reliability and responsiveness, and evidence for validity. The first 2 stages may be the most critical, therefore, obtaining patients’ input for item selection and item reduction is recommended for outcome questionnaire construction. Because getting patients’ input can be tedious, time-consuming, and expensive, obtaining information from the opinion of experts, such as surgeons, would be advantageous if the same information could be obtained.

Although surgeons often think that they know what is important to their patients, it is possible that patients and surgeons may have different ideas concerning what issues are important, which can have implications not only in outcome assessment but also in treatment planning and defining treatment expectations. If issues important to the patient are not communicated to physicians and other health care practitioners, treatment outcomes may be compromised in terms of patient satisfaction and quality of life. Issues that are important to patients with various knee conditions have been determined. The purpose of this study was to define what issues active patients with musculoskeletal hip disease believe are important. In addition, we assessed whether the issues that surgeons thought were important differed from the issues that patients thought were important. This point is relevant in that the issues that clinicians believe are important and thus attempt to improve with treatment need to be issues that are important to patients. These topics were addressed in relation to items being considered for a self-reported hip outcome questionnaire. Such items addressed issues related to symptoms, function, occupation, sports-related activities, and social-emotional lifestyle. We hypothesized that there would be a discrepancy between the issues that surgeons and patients believe are important.

MATERIALS AND METHODS

This study is part of a larger project to develop a self-reported health-related quality of life outcome questionnaire for active individuals with musculoskeletal hip problems using the 6 stages previously outlined. This study represents data collected during stages 1 and 2. Institutional review board approval was obtained for this study.

Initial Item Generation

Pilot work was done to generate a list of items representing what patients with musculoskeletal hip pain experience to some degree. Participants included patients who were seeking treatment for a musculoskeletal hip problem. A list of 128 items was produced by 30 participants. As a continuation of this pilot work, these 128 items were given to another independent group (n = 51). In a yes/no format, participants were asked if they ever experienced the items in question. The goal of this item generation process was to capture every possible issue that could be important to someone with a musculoskeletal hip problem. Therefore, these participants were asked to contribute to this list by adding any issue that was not included. This item generation pilot work produced 146 items. Based on our consensus, these items were organized per item content into 5 categories (see Appendix, available in the online version of this article at http://ajs.sagepub.com/supplemental/): symptoms (n = 27), functional limitations (n = 36), occupational issues (n = 27), sports and recreational activities (n = 28), and social-emotional lifestyle issues (n = 28).

Item Reduction

Once this item generation stage was completed, the item reduction stage was initiated. The list of 146 items was given to active patients (ie, reportedly able to tolerate greater than a light workload) being evaluated by 9 orthopaedic surgeons specializing in hip arthroscopy.

Participants

In sum, 150 patients participated in the item reduction process. These patients were independent from those who participated in the item generation process. Patients were consecutively selected from 9 orthopaedic surgeons practicing in the United States, Canada, and Europe. To be included, individuals had to be (1) seeking treatment for musculoskeletal hip disease, (2) between the ages of 18 and 60 years, and (3) able to function at a level greater than a light workload, as defined by Tegner level 4, either currently or immediately before their injury. This group was selected to be younger and more active than those who developed such questionnaires as the WOMAC index (ie, Western Ontario and McMaster Universities). Exclusion criteria included (1) not being able to read or understand English and (2) having a primary concern or injury not primarily related to the hip (eg, abdominal pain, low back pain). These patients were at various stages of treatment for their hip-related concerns, including initial presentation, follow-up, and preoperative and postoperative visits. Participants were not excluded on the basis of their hip-related diagnoses or the location of their symptoms; that is, those with lateral, anterior, posterior, and/or groin pain were included.
Item-Rating Process

The patients rated the 146 items on a 6-point Likert-type scale:

- 0: I do not experience this / not applicable.
- 1: I experience this but it is not important.
- 2: I experience this and it is of little importance.
- 3: I experience this and it is somewhat important.
- 4: I experience this and it is very important.
- 5: I experience this and it is extremely important.

The mean patient response to each item was calculated. Information regarding age, gender, level of activity, and operative procedure was obtained from an intake information data collection sheet completed by the participant. All information was obtained voluntarily and anonymously; therefore, informed consent was not required.

Nine orthopaedic surgeons specializing in hip arthroscopy were given the same 146 questions to rate. They were instructed to rate each question using the same scale and the same rating process as the patients. Therefore, the surgeons were to rate the items in terms of what they thought young active patients with musculoskeletal hip problems experience and perceive to be important. The results of the patients’ assessment were blinded. The mean surgeon response from their 1-time rating of each item was also calculated.

Statistical Methods

Based on mean scores, items were identified that patients rated 3 or greater (“I experience this and it is somewhat important”). Also identified were the 10 most important items, as well as the items with mean ratings of 3 or greater in each category, according to the surgeons. The Mann-Whitney U test (nonparametric t test) was performed to compare the perceived importance between surgeons and patients for the 10 most important items as rated by surgeons, as well as the items that clinicians ranked, on average, 3 or greater in each of the 5 categories. Alpha level was adjusted to .01 to reduce the risk of type II error associated with multiple comparisons.

RESULTS

Participants

The average patient age was 42 ± 11 years (range, 18-60), with 73 men and 77 women. Duration of symptoms averaged 6.5 ± 5.9 years (range, 0-29). All patients had the primary concern of musculoskeletal hip/pelvic pain (lateral, anterior, posterior, and/or groin), with 32 participants reporting bilateral symptoms. Because these patients were at various stages of treatment for their musculoskeletal hip pain, a primary diagnosis was available for only 70 of them: labral tear (n = 38), arthritis (n = 13), hypermobility (n = 8), femoroacetabular impingement (n = 7), avascular necrosis (n = 2), and chondral lesion (n = 2). Forty-one participants underwent surgery, whereas 109 were managed more conservatively. Of those who underwent surgery, 31 had an arthroscopic procedure; 8, total hip replacement; 2, open reduction internal fixation; and 1, hardware removal.

Item Rating

Table 1 presents the number of items in each domain rated 3 or greater by the surgeons and the patients. Compared with the surgeons, patients identified approximately 30% fewer items. These 23 items are listed in Table 2, 16 of which are in the sports and recreation category, with no items being in the symptoms or occupation category. Table 3 lists the 11 items that surgeons thought were most important; they rated these 11 items higher than patients did (P < .0005). Five items, all in the sports and recreation category, were thought to be important to patients and were in the surgeons’ top-10 list. Table 4 displays the results of the analyses comparing the mean ratings for items that surgeons thought were important. A difference was found between patients and surgeons in how they rated items related to symptoms, functional limitations, and occupation (P < .01). A difference was not found between how patients and clinicians rated items related to sports and recreation and social-emotional lifestyle (P > .01).

DISCUSSION

Outcome assessment for active individuals with musculoskeletal hip disorders should address issues related to sports and recreational activities and social-emotional lifestyle issues more so than issues related to symptoms, function, and occupation. The hypothesis of this study was affirmed; that is, a discrepancy was found in how patients perceived issues and what surgeons believed were most important. In fact, 5 of the 11 items that surgeons thought were most important were rated by patients to be of little importance. This included the item about groin pain, which surgeons believed was one of the most important items. In addition, surgeons rated several items as being important in the symptoms, functional limitations, and occupational issues categories, whereas patients did not. The results of this study may be useful when attempting to assess treatment outcomes from a patient’s perspective.

The International Classification of Functioning, Disability and Health can be used to define what is being measured when treatment outcomes are assessed. According to this
model, 2 domains or factors can be assessed, defined as (1) body structure and function and (2) activity and participation. The assessment of symptoms (eg, groin pain) and signs (eg, hip range of motion) are measures of body structure and function. Activities are tasks executed by an individual (eg, running), and participation is involvement in life situations (eg, sports). This study found that clinicians, when compared to patients, seemed to perceive items in the body structure and function domain to be more important. In fact, the largest disparity in ratings between clinicians and patients was noted with the items regarding symptoms, which implies that clinicians may overestimate the value of assessing issues relating to symptoms when assessing treatment outcome, patient satisfaction, and/or patient-related quality of life. An assessment of symptoms may provide valuable information in the diagnostic process, but it may not be perceived as being important to the patient. Also, symptoms such as pain and tightness may be important to patients only to the degree that they limit sports and recreational activities.

Contrary to items in the symptom, function, and occupation categories, the items in the sports and recreational activities and social-emotional lifestyle categories were not rated differently by patients and clinicians. The largest disparity in ratings between patients and clinicians was noted with the items regarding symptoms, which implies that clinicians may overestimate the value of assessing issues relating to symptoms when assessing treatment outcome, patient satisfaction, and/or patient-related quality of life.

### TABLE 2
Items That Patients Rated to Be at Least Somewhat Important

<table>
<thead>
<tr>
<th>Item Content</th>
<th>Category</th>
<th>Mean Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concern about maintaining desired level of fitness</td>
<td>Sports-recreation</td>
<td>4.0</td>
</tr>
<tr>
<td>Concern about making hip worse while playing sports</td>
<td>Sports-recreation</td>
<td>3.6</td>
</tr>
<tr>
<td>Concern about ability to perform at pre-injury status</td>
<td>Sports-recreation</td>
<td>3.6</td>
</tr>
<tr>
<td>Fear of increasing pain with activity</td>
<td>Sports-recreation</td>
<td>3.5</td>
</tr>
<tr>
<td>Frustrated because of hip</td>
<td>Social-emotional lifestyle</td>
<td>3.5</td>
</tr>
<tr>
<td>Concern about participating in sports that are important</td>
<td>Sports-recreation</td>
<td>3.4</td>
</tr>
<tr>
<td>Pain or an increase in pain after sports or activity</td>
<td>Sports-recreation</td>
<td>3.4</td>
</tr>
<tr>
<td>Concern about twisting or pivoting</td>
<td>Sports-recreation</td>
<td>3.4</td>
</tr>
<tr>
<td>Pain during sports or recreational activity</td>
<td>Sports-recreation</td>
<td>3.3</td>
</tr>
<tr>
<td>Concern about moving into certain positions</td>
<td>Sports-recreation</td>
<td>3.3</td>
</tr>
<tr>
<td>Concern about the future</td>
<td>Social-emotional lifestyle</td>
<td>3.3</td>
</tr>
<tr>
<td>Concern about running, jogging, or sprinting</td>
<td>Sports-recreation</td>
<td>3.3</td>
</tr>
<tr>
<td>Change in habits</td>
<td>Social-emotional lifestyle</td>
<td>3.3</td>
</tr>
<tr>
<td>Frustrated at always worrying about hip in sports</td>
<td>Sports-recreation</td>
<td>3.2</td>
</tr>
<tr>
<td>Fear of living with more pain than I have now</td>
<td>Social-emotional lifestyle</td>
<td>3.2</td>
</tr>
<tr>
<td>Constant awareness of disability</td>
<td>Social-emotional lifestyle</td>
<td>3.2</td>
</tr>
<tr>
<td>Deterioration in quality of life due to inability to play</td>
<td>Sports-recreation</td>
<td>3.1</td>
</tr>
<tr>
<td>Walking long distances</td>
<td>Functional</td>
<td>3.1</td>
</tr>
<tr>
<td>Apprehensive about playing sports</td>
<td>Sports-recreation</td>
<td>3.1</td>
</tr>
<tr>
<td>Tightness in hip joint</td>
<td>Sports-recreation</td>
<td>3.1</td>
</tr>
<tr>
<td>Distracted by hip problem</td>
<td>Social-emotional lifestyle</td>
<td>3.1</td>
</tr>
<tr>
<td>Frustrated at inability to relieve stress through activity</td>
<td>Sports-recreation</td>
<td>3.1</td>
</tr>
<tr>
<td>Concern about cutting or changing direction quickly</td>
<td>Sports-recreation</td>
<td>3.0</td>
</tr>
</tbody>
</table>

**Bold items represent items in the surgeons’ top-10 list.**

### TABLE 3
Eleven Items That Surgeons Thought Were Most Important

<table>
<thead>
<tr>
<th>Item Content</th>
<th>Category</th>
<th>Patients</th>
<th>Surgeons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groin pain</td>
<td>Symptoms</td>
<td>2.0</td>
<td>4.8</td>
</tr>
<tr>
<td>Concern about twisting or pivoting</td>
<td>Sports-recreation</td>
<td>3.4</td>
<td>4.8</td>
</tr>
<tr>
<td>Concern about cutting or changing direction</td>
<td>Sports-recreation</td>
<td>3.0</td>
<td>4.7</td>
</tr>
<tr>
<td>Pain during sport or recreational activities</td>
<td>Sports-recreation</td>
<td>3.2</td>
<td>4.6</td>
</tr>
<tr>
<td>Pain or an increase in pain after sports or activity</td>
<td>Sports-recreation</td>
<td>3.4</td>
<td>4.6</td>
</tr>
<tr>
<td>Getting into or out of a car</td>
<td>Functional limitation</td>
<td>2.3</td>
<td>4.6</td>
</tr>
<tr>
<td>Grinding, catching, or locking in the hip</td>
<td>Symptoms</td>
<td>2.2</td>
<td>4.4</td>
</tr>
<tr>
<td>Concern about moving into certain positions</td>
<td>Sports-recreation</td>
<td>3.3</td>
<td>4.4</td>
</tr>
<tr>
<td>Putting on or taking off socks/stockings</td>
<td>Functional limitations</td>
<td>2.2</td>
<td>4.4</td>
</tr>
<tr>
<td>Concern about running, jogging, or sprinting</td>
<td>Sports-recreation</td>
<td>3.3</td>
<td>4.3</td>
</tr>
<tr>
<td>Squatting or crouching at work</td>
<td>Occupational issues</td>
<td>2.2</td>
<td>4.3</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>2.8</td>
<td>4.5</td>
</tr>
</tbody>
</table>

*P < .0005.
Because item content relates to issues of validity. The hypothesis of this study was affirmed; that is, a discrepancy was found between the issues that patients believe are important and the issues that surgeons perceive as being important to patients. Treatments and outcome assessment may need to address issues related to sports and recreational activities more so than issues related to symptoms, function, and occupation. Furthermore, surgeons also tend to overestimate the number of issues that are important to patients. Results of this study reveal that although surgeons think that they know what is important to their patients, they may often be incorrect. Therefore, as clinicians, we must be careful in presuming that the issues that surgeons believe are important and the issues that patients perceive as being important may need an opportunity to offer input about issues that are important to them.

The hypothesis of this study was affirmed; that is, a discrepancy was found between the issues that patients believe are important and the issues that surgeons perceive as being important to patients. Treatments and outcome assessment may need to address issues related to sports and recreational activities more so than issues related to symptoms, function, and occupation. Therefore, although this research offers a list of items for clinicians to consider, each patient may need an opportunity to offer input about issues that are important to them.

The results of this study may affect the development of self-reported outcome questionnaires. Patient input seems critical for generating questionnaire items to be used as a self-reported outcome instrument. If items are inappropriately selected, there is no questionnaire formatting or statistical analysis that will correct the problem in later stages of development. Inappropriate selection of items can affect the interpretation of the obtained scores. This is especially true because item content relates to issues of validity. According to the results of this study, if treatment outcomes are to assess issues that are important to patients, they may often be incorrect. Therefore, as clinicians, we must be careful in presuming that the issues that we are attempting to improve with treatment are issues that are important to patients. This information may be particularly important when assessing treatment outcomes from a patient's perspective and in the evaluation and development of patient outcome questionnaires.

## References

Endoscopy-Assisted Periacetabular Osteotomy
Dean K. Matsuda, M.D., Hal D. Martin, D.O., and Javad Parvizi, M.D.

Abstract: Minimizing soft tissue dissection and improving visualization of vital structures during periacetabular osteotomy (PAO) is of paramount importance to improve patient outcome and minimize complications. The endoscopy-assisted PAO was introduced to accomplish this objective. It involves an initial hip arthroscopy, for treatment of central compartment pathology, followed by a mini-open Bernese periacetabular osteotomy under fluoroscopic and endoscopic guidance, and completed by final dynamic hip arthroscopy to assess acetabular reorientation and fixation and to perform femoroplasty in relation to the new acetabular rim position, if needed. Endoscopy-assisted PAO is used to treat dysplasia or acetabular retroversion in a minimally invasive fashion.

Although less invasive surgery in the form of arthroscopy has been successful in the treatment of femoroacetabular impingement, its success in the treatment of dysplasia has been variable. Some believe that arthroscopy may have a role in the management of patients with borderline dysplasia to perform labral repair and capsular repair or plication. The optimal management of patients with more severe dysplasia should include pelvic osteotomy and acetabular reorientation or supplementation to improve biomechanical deficiencies related to insufficient femoral head coverage. The periacetabular osteotomy (PAO) developed by Ganz et al. maintains the functional integrity of the posterior column, thereby enabling relatively early weight bearing with minimal osteosynthesis. It is arguably the preferred procedure for many patients with symptomatic dysplasia (retroverting PAO), whereas the reverse PAO (anteverting PAO), a variant of the former, has utility for patients with acetabular retroversion. Successful outcomes have been shown in both settings; however, the physiological insult of the procedure on patients is immense, and the procedure is associated with a relatively high rate of complications, in particular sciatic nerve injury. Moreover, large volume of blood loss, lengthy postoperative hospitalization, prolonged rehabilitation, and need for aggressive pain management makes this surgical procedure a substantial undertaking for the patient and the surgeon. Furthermore, some patients may opt for less invasive hip arthroscopy when their degree of dysplasia requires acetabular reorientation, leading to surgical revisions and/or failures. The purpose of this manuscript is to present a technical note and lessons learned from the first endoscopy-assisted PAO (eaPAO).

Surgical Technique
The surgical technique is described in relation to a 38-year-old man with symptomatic left hip dysplasia with lateral center-edge angle of 14 degrees, acetabular index of 22 degrees, and anterior center-edge angle of 12 degrees. Supine hip arthroscopy under general anesthesia with epidural injection was performed on a fracture table (Hana table, Mizuho OSI, Union City, CA) as an initial diagnostic and therapeutic step, followed by mini-open eaPAO and concluding with repeat hip arthroscopy and arthroscopic dynamic testing (Fig 1). Tranexamic acid was administered and sciatic neuromotor monitoring was provided. In the supine position, central compartment arthroscopy was performed with a 70-degree arthroscope via the anterolateral portal under ipsilateral hip distraction. A midanterior working portal was established under arthroscopic guidance. Detected intra-articular pathology was treated (in this case selective
Debridement of a grade 3 chondral flap at the anterior chondrolabral junction. Arthroscopic femoroplasty for coexisting cam femoroacetabular impingement was intentionally deferred until acetabular reorientation was complete.

The periacetabular osteotomy was performed via a dual mini-incision rectus and sartorius sparing approach. Arthroscopic fluid extravasation was minimal and did not obscure or impede the performance of the bony cuts. The first osteotomy was performed using a distal incision (3 to 4 cm) via the modified Hueter approach which permits muscle-sparing dissection of the interval between sartorius and tensor fascia lata. In an effort to avoid the lateral femoral cutaneous nerve, the fascia lata was incised in line with the skin incision followed by blunt dissection around the medial aspect of the tensor fascia lata within its incised aponeurotic sheath. Medial retraction of the sartorius and deeper rectus femoris revealed the reflected head of the rectus femoris as it overlays the hip capsule. The interval between the rectus and the capsule was developed to insert the angled osteotome (Ultra Cuts; DePuy Synthes, West Chester, PA), under the protection of a blunt instrument, to the infracotyloid groove. The position of the osteotome was checked by fluoroscopy before performing the incomplete cut of the ischium. The osteotome was advanced in a cephalad manner to start the cut of the posterior column. Then through a second small incision (3 cm) based on the anterior superior iliac spine, the inner table of the pelvis was exposed. Pubic osteotomy was then performed. Under fluoroscopic guidance, a straight osteotome was inserted into the inner pelvis and positioned medial to the pectineal eminence. Two blunt retractors inserted under the ramus protected the obturator vessels and nerves. Dry endoscopy via the Hueter incision enabled anterior visualization of this osteotomy and the inner table. Final biplanar iliac osteotomy was performed by first imaging the posterior column (60 degree inlet view) using fluoroscopy. During this osteotomy, the sharp tip of the osteotome was endoscopically visualized from the anterolateral portal. Care was taken to avoid penetrating through the outer table of the ilium. During this osteotomy, an endoscopically positioned blunt retractor (switching stick, Smith & Nephew, Andover, MA) via the posterolateral portal protected the sciatic nerve, in case the tip of the osteotome penetrated through (Fig 2). The osteotome was advanced in a caudal direction along the posterior column until it met with the first cut of the ischium in the infracotyloid groove. Once the osteotomy of the posterior column was complete, the vertical cut of the ilium, between the anterior superior iliac spine and the anterior inferior iliac spine, was performed. As often needed, controlled osteoclasis or complete release of the osteotomized acetabular fragment involved a final extension of the ischial osteotomy to connect to the posterior column, directing the angled osteotome cephalad. The latter step was performed without incident under fluoroscopic and endoscopic guidance.

A lamina spreader aided controlled mobilization of the acetabular fragment. Positioning of the acetabular fragment was facilitated with a Schanz screw, used as a toggle stick and as a visual guide to relative orientation. In general, goals were to increase anterolateral coverage, flatten the upsloping sourcil, and medialize the radiographic teardrop. The fragment was reoriented...
first in the coronal plane (abduction increasing lateral coverage), then the sagittal plane (flexion increasing anterior coverage), followed by the axial plane (relative retroversion). Care was taken to avoid inadvertent retroversion from overcorrection, undercorrection, or insufficient medialization of the acetabular teardrop. Initial acetabular reorientation was transiently fixated with K-wires, and anterior-posterior fluoroscopic views showed a significant crossover sign suggesting over-correction of desired relative retroversion (Fig 3). Arthroscopic probing of the offending region with concurrent fluoroscopy revealed that the anterior inferior iliac spine was exaggerating the radiographic crossover sign. The acetabular fragment was repositioned so that anterolateral coverage was increased without excessive retroversion, avoiding focal pincer femoroacetabular or subspine impingement. PAO fixation was performed with 3 antegrade 4.5-mm fully threaded screws (cortex screws, DePuy Synthes) from the iliac wing into the reoriented acetabular fragment without violation of the joint (Fig 4).

Peripheral compartment arthroscopy was performed using incremental femoroplasty as dictated by dynamic arthroscopic testing in relation to the newly positioned anterosuperior acetabular rim (Fig 5). This confirmed maintenance of a perimetric labral fluid seal plus eradication of any coexisting and/or PAO-induced femoroacetabular impingement. Dynamic arthroscopic and fluoroscopic examination provided simultaneous testing and confirmation of stability of the PAO fixation construct (Fig 6). Arthroscopic capsular closure was then done (Fig 7).

The fascia lata was closed, followed by subcutaneous and skin closure. Estimated blood loss was 300 mL and there were no intraoperative or postoperative complications. Intraoperative sciatic monitoring had no significant deficits. A supplemental video shows key steps in the performance of this procedure (Video 1).

Outcome

The patient was discharged home on postoperative day 3 with serum hemoglobin of 8.4 g/dL and acetaminophen for pain control. He remained partial

Fig 3. Intraoperative anteroposterior fluoroscopic image of initial reoriented acetabulum demonstrating large crossover sign above intersection of anterior (red) and posterior (blue) lines. Note K-wires providing transient fixation. Arthroscopy clarified that anterior prominence was caused by anterior inferior iliac spine and not by anterior acetabular rim.

Fig 4. Intraoperative anteroposterior fluoroscopic image of acetabular fragment fixated in a more desirable position with improved anterolateral coverage without pincer or subspine impingement. Note Schanz pin providing acetabular repositioning and fixation with cortical screws. Anterior rim (red line) is medial to the posterior rim (blue line).

Fig 5. Arthroscopic and fluoroscopic (inset) image of left hip from anterolateral portal during femoroplasty after endoscopy-assisted periacetabular osteotomy, enabling optimization of concurrent cam decompression in relation to newly oriented acetabular rim.
weightbearing on the operative leg with double crutches, with progression to full weightbearing at 6 weeks. At 12 weeks, he has minimal pain requiring no medication and is fully ambulatory without upper extremity aids. Postoperative radiographs show improvement of the lateral center-edge angle to 27 degrees, acetabular index to 8 degrees, and anterior center-edge angle to 30 degrees.

**Discussion**

Although 2 cadaveric studies have been published and an endoscopic triple osteotomy has been used in children, we present a technical note and lessons learned from the performance of endoscopy-assisted PAO.

Several advantages are possible with the addition of arthroscopy and endoscopy to the PAO (Table 1). Initial hip arthroscopy permits detection and treatment of significant intra-articular hip pathology that might go untreated without arthroscopy or arthroscopy. Arthroscopy permits limited visualization mainly of the anterosuperior hip and may cause instability with disruption of the reflected head of the rectus femoris. If arthroscopy reveals severe chondral damage, immediate or staged hip arthroplasty may be elected, avoiding unnecessary PAO.

Several complications from PAO may be averted or minimized with endoscopy (eaPAO). The sciatic nerve may be injured during PAO and is particularly at risk during the ischial and posterior column osteotomies. The sciatic nerve could be injured if the osteotome perforates the lateral cortex of ischium and the ilio-ischial junction by as little as 10 mm, and it has poor potential for spontaneous full recovery. Our cadaver work showed the proximity of the osteotome tip during these bone cuts (Fig 8). Although the obturator internus muscle is interposed between the ischium and the sciatic nerve, it would provide minimal protection from a wayward osteotome. Endoscopy of the posterior peritrochanteric region (subgluteal space) without hip distraction enables visualization and mobilization of the sciatic nerve, which may be followed proximally and distally with blunt dissection via switching stick. If more proximal mobilization or neurolysis is required, endoscopic ligation and transection of the crossing vessels from the inferior gluteal artery may be performed. If endoscopy reveals the osteotome tip approaching the sciatic nerve, the osteotome may be redirected and the sciatic nerve may be gently retracted. This case demonstrated the use of an endoscopically placed retractor on the sciatic nerve to mobilize and protect it without compromising nerve activity on neural monitoring.

Inadvertent intra-articular osteotomy may be prevented with the addition of endoscopy to supplement fluoroscopic guidance. The latter is a 2-dimensional representation of a 3-dimensional reality and, as such,
is limited. Central compartment arthroscopy can detect intra-articular violation but, perhaps more importantly, can help guide the boney cuts so as to avoid this complication. Similarly, by avoiding osteotomies too close to the joint, acetabular osteonecrosis may be prevented.

If posterior column discontinuity occurs either from fracture or osteotomy, a major structural advantage to the Bernese PAO is lost. Without endoscopic guidance, the surgeon relies on fluoroscopic imaging via a 60-degree internal or iliac view to visualize the osteotome between the posterior margin of the acetabulum and the posterior aspect of the posterior column.

### Table 2. Pearls of Endoscopy-Assisted Periacetabular Osteotomy

| Consider intraoperative tranexamic acid, hypotensive anesthesia, and sciatic nerve monitoring |
| Use low arthroscopic pump pressure or perform dry arthroscopy/endoscopy |
| View critical ischial and posterior column osteotomies endoscopically via anterolateral portal |
| Endoscopic sciatic nerve mobilization with switching stick or endoscopic sciatic nerve retraction via posterolateral portal |
| View inner table osteotomies with dry endoscopy via mini-open incision used for PAO |
| Assess acetabular reorientation with endoscopic and fluoroscopic guidance |
| If positive crossover sign after acetabular fragment reorientation, arthroscopy can differentiate whether from anterior wall or anterior inferior iliac spine |
| Subsequent acetabular fragment repositioning unless otherwise well oriented in which case focal acetabuloplasty or subsyne decompression may be considered |
| Arthroscopic femoroplasty after fixation of PAO in desired orientation |
| Arthroscopic labral repair (or reconstruction if labral insufficiency) |
| Capsular repair or plication via arthroscopic or mini-open approach (surgeon preference) |

**Table 3. Pitfalls of Endoscopy-Assisted Periacetabular Osteotomy**

| Two experienced surgeons are recommended |
| Fluid extravasation from excessive arthroscopic pump pressure may obscure mini-open visualization for PAO |
| Excessive hip distraction may potentially destabilize PAO construct |

Endoscopy supplements fluoroscopic guidance in this regard.

Arthroscopic dynamic testing after PAO offers several advantages. Magnified visualization of the dynamic interaction of the repositioned acetabular rim with the proximal femur enables detection of coexistent and/or PAO-induced femoroacetabular impingement and assessment of labral function and PAO fixation stability. Arthroscopy clarified the fluoroscopic crossover sign observed on initial acetabular positioning as attributable to the anterior inferior iliac spine rather than the anterior acetabular rim. The former could cause subsyne impingement; the latter, pincer impingement. Combined with fluoroscopic guidance, arthroscopy can alert the surgeon to over- or undercorrection and insufficient fixation of the repositioned acetabular fragment, allowing subsequent repositioning (as in this case), supplemental screw fixation, or seamless acetabuloplasty or subsyne decompression.

We performed and recommend post-PAO arthroscopic femoroplasty rather than femoroplasty during initial (pre-PAO) arthroscopy. By matching femoroplasty with the newly positioned acetabular rim, cam decompression is optimized and labral fluid seal retention is facilitated. Capsular closure is recommended and may be performed via mini-open or, as in this case, an arthroscopic approach based on surgeon experience and preference.

When surveyed, open PAO surgeons had expressed concern that endoscopy might cause arthroscopic fluid extravasation such as to obscure the operative field for PAO (Table 1). This case refuted that assumption. There was minimal fluid extravasation from the intermittent application of arthroscopy and endoscopy with no adverse impact on the operative field of view during eaPAO. Maintenance of low arthroscopic pump pressures and the use of dry arthroscopy/endoscopy with intermittent suction may ensure this.

The other often mentioned concern was that post-PAO arthroscopy might destabilize the fixation construct (Table 2). This case did not support that concern either. Although unnecessary or excessive post-PAO traction should be avoided, arthroscopic femoroplasty, dynamic testing, and capsular repair were performed without traction and did not destabilize acetabular fragment screw fixation. Indeed, eaPAO encourages assessment of the fixation construct and if insufficient, supplemental or alternative osteosynthesis may be added.
Table 4. Lessons Learned From Endoscopy-Assisted Periacetabular Osteotomy

| Endoscopic fluid extravasation is minimal and does not significantly obscure the mini-open operative field of vision. |
| Endoscopically placed retractor can protect the sciatic nerve during critical ischial and posterior column osteotomies. |
| Hip arthroscopy supplements fluoroscopic guidance in positioning of acetabular fragment. |
| Facilitates maintenance of labral fluid seal. |
| Enables optimal cam decompression. |
| Confirms eradication of impingement. |
| Checks stability of endoscopy-assisted periacetabular osteotomy fixation construct. |

Disadvantages of eaPAO include the technical complexity of this surgery (Table 3). The procedure likely requires a team approach with 2 skilled surgeons, whereas the open PAO may be performed with 1. Significant experience in mini-open PAO and in hip arthroscopy in general and posterior peritrochanteric endoscopy in particular are required. Even if a surgeon possesses both skill sets, it is suggested that at least in the early development of this surgery, a surgeon particularly skilled in mini-open PAO collaborate with an experienced arthroscopic surgeon.

eaPAO is a feasible less invasive option to conventional PAO that may improve outcomes and safety in patients with dysplasia (retroverting PAO) or acetabular retroversion (anteverting PAO). Its development exemplifies a beneficial collaboration between open and arthroscopic hip preservation surgeons with valuable lessons learned from such efforts (Table 4). The ultimate goal of eaPAO is to develop a completely endoscopic equivalent, perhaps with robotic subcutaneous navigation, that will make this procedure even less invasive and which, in turn, may decrease the incidence of failed hip arthroscopies for patients with dysplasia and acetabular retroversion.

References


Evaluation of the Hip

Hal D. Martin, DO, Shea A. Shears, RN, BSN, and Ian J. Palmer, PhD

Abstract: The evaluation of the hip has evolved over generations of orthopedic surgeons. A number of diagnostic tests have been described for specific pathologies that include a common base of maneuvers. A consistent hip examination is conducted to select the hip, back, abdominal, neuro-vascular, and neurologic systems and to find any comorbidities that often exist with complex hip pathology. Provided is a comprehensive evaluation of the hip with proposed descriptions of traditional tests along with provocative maneuvers. Through the use of a common set of diagnostic procedures and terminology, there will be improvement in the accuracy of diagnostic exams for determining hip pathology.

Key Words: physical examination of the hip, hip Arthroscopy, femoroacetabular impingement, labral tears, hip pain


The evaluation of the hip has evolved over many generations among orthopedic surgeons and the surgical treatments for hip disorders using arthroscopic and open techniques continue to evolve. A number of diagnostic tests such as: Craig test, Trendelenburg gait, Thomas test, Ober test, Ely test, Pace test, Stinchfield test, Patrick test, McCarthy test, log roll, along with range of motion (ROM) tests have been used for the clinical evaluation of the hip. Table 1 provides a list of diagnostic examination published in the current literature; however, there is variability in the way that hip specialists evaluate and examine their patients. Originally described the flexion adduction internal rotation test (FADIR), also called the “impingement test” by MacDonald et al, which is the most consistently described examination for hip pathology in the current literature. Fitzgerald described an examination using an arcing maneuver from flexion, external rotation (ER) and full adduction to extension with internal rotation (IR) and adduction to diagnose labral tears. Other variations of hip examinations, all which describe the position of testing associated with the presentation of pain are ROM with IR and ER, flexion and internal rotation, maximal flexion with internal rotation and maximal flexion with external rotation, IR with flexion and axial compression, and posterior impingement. Although there is a commonality that forms the basis of these different maneuvers; there is a lack of a consistent technique and standardization among hip specialists. On account of this variability in examination and techniques, there exists a need for enhanced awareness along with improved diagnostic information for the treatment of hip pathology.

The Multicenter Arthroscopy of the Hip Outcomes Research Network has agreed on a common set of diagnostic procedures and techniques for evaluating hip pathology in adults, which provides an international consensus and terminology.

This paper provides common language among examiners in the evaluation of hip pain. A comprehensive evaluation of the hip with proposed descriptions of traditional tests along with provocative maneuvers provided is, which will aid in the accuracy of the diagnosis of hip pathology.

HISTORY

A complete patient history (Table 2) is obtained before the physical examination of the hip. The first factor for consideration of treatment is the age of the patient and the presence or absence of trauma. A description of the present condition is documented including the date of onset, mechanism of injury, pain location, and factors, which increase or decrease the pain. Prior consultations, surgical interventions, and past injuries are documented. Treatments to date such as rest, physical therapy, ice, heat, nonsteroidal antiinflammatories, surgery, injections, orthotics, or the use of support aids must also be recognized. Associated complaints, such as pain in the abdomen or back, numbness, weakness, sit pain, length of time sitting, cough, or sneeze exacerbation help to rule out thoracolumbar issues.

The vascular supply to the femoral head and any possible sources of disruptions are screened including metabolic disorders, such as abnormality of lipids, thyroid, homoeostasis, and clotting mechanisms. The social history of the patient is reviewed to recognize the presence or use of tobacco, alcohol, steroids or altitude issues, which also can affect the blood supply to the femoral head. A history of sports and recreational activities help to determine the type of injury.

Several questionnaires are available providing a quantitative and qualitative description of the patient's functional ability. Questionnaire selection is based upon validity, reliability, patient population, and pathology. The modified Harris Hip Score is the most documented and standardized functional score to date, which is a quantitative score upon pain and function. Other hip scores have been outlined with questionnaires in more specific patient populations such as: Merle d’Aubigné, the Nonarthritic Hip Score, Hip Disability and Osteoarthritis Outcome Score, Musculoskeletal Function Assessment, Short Form 36 (SF-36), and the Western Ontario and McMaster University Osteoarthritis Index. The use of a verbal analog score is also subjectively useful.
TABLE 1. Physical Exam Maneuvers Reported in Current Literature

<table>
<thead>
<tr>
<th>History</th>
<th>Dominant Physical Exam Findings</th>
<th>Radiographic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Klaue et al.&quot;</td>
<td>Compliant of knife-sharp groin pain and sensation of locking in the hip, feeling of “giving way”</td>
<td>FADDIR</td>
</tr>
<tr>
<td>Fitzgerald</td>
<td>Traumatic onset, limited ROM</td>
<td>Dynamic FABER-FADDIR Dynamic FADDIR-FABER</td>
</tr>
<tr>
<td>Petersilge et al.&quot;</td>
<td>Pain w/ambulation, clicking sensation, Traumatic injury</td>
<td>Impingement Test (FADDIR), Extension of hip, Extension w/IR, Apprehension test, Bicycle test. Billopsus snapping</td>
</tr>
<tr>
<td>MacDonald et al.&quot;</td>
<td>Pain w/ambulation, especially after activity, night pain locking/snapping, instability</td>
<td>FADDIR, PRI</td>
</tr>
<tr>
<td>Leung et al.&quot;</td>
<td>Groin pain, night pain, locking</td>
<td>FADDIR, PRI</td>
</tr>
<tr>
<td>Hase and Ueno.&quot;</td>
<td>Limited ROM, GT tenderness</td>
<td>FADDIR, FIR, Scour, Palpation of GT FIR</td>
</tr>
<tr>
<td>Santori et al.&quot;</td>
<td>Sharp intense groin pain</td>
<td>FIR, FADDIR, Abduction Extension</td>
</tr>
<tr>
<td>Eijer et al.&quot;</td>
<td>Painful catching or clicking; pain on prolonged sitting, getting in/out of car; occasional back pain, atrofrra instability</td>
<td>Overall Joint Laxity, Prone extension w/ER, Patrick Test, Aerial distraction</td>
</tr>
<tr>
<td>Philippson</td>
<td>Sharp groin pain</td>
<td>FADDIR, MFIR, MFER</td>
</tr>
<tr>
<td>Suenaga et al.&quot;</td>
<td>Slow onset of pain after minor trauma, exacerbated by excessive demand</td>
<td>FIR, MFER, EMER</td>
</tr>
<tr>
<td>Nivvani et al.&quot;</td>
<td>Sharp groin pain</td>
<td>FADDIR, Posteriorinferior impingement w/ER and extension</td>
</tr>
<tr>
<td>Gunz et al.&quot;</td>
<td>Atraumatic, minor rotational injury, groin pain, generalized hip pain</td>
<td>FADDIR, FIR, ROM FADDIR</td>
</tr>
<tr>
<td>Siebenrock et al.&quot;</td>
<td>Atraumatic, minor rotational injury, groin pain, generalized hip pain</td>
<td>FIR, FADDIR</td>
</tr>
<tr>
<td>Beck et al.&quot;</td>
<td>Atraumatic, minor rotational injury, groin pain, generalized hip pain</td>
<td>FADDIR</td>
</tr>
<tr>
<td>Ito et al.&quot;</td>
<td>Atraumatic, minor rotational injury, groin pain, generalized hip pain</td>
<td>FADDIR</td>
</tr>
<tr>
<td>Kassarjian et al.&quot;</td>
<td>3 Traumatic, 1 Previous Hip Arthroscopy, 2 Confirmed OA</td>
<td>FADDIR</td>
</tr>
<tr>
<td>Beaulé et al.&quot;</td>
<td>3 Traumatic, 1 Previous Hip Arthroscopy, 2 Confirmed OA</td>
<td>FADDIR</td>
</tr>
<tr>
<td>Martin</td>
<td>Trendelenburg, SLR, ROM IR/ER, ROM Abduction, ABDEER, Adduction w/ Flexion, Thomas, McCarthy IR/ER, FABER, Palpation, Log Roll, Heel Strike, FADDIR, LRI, Obers</td>
<td>FADDIR, Log Roll, SLRAR, Restricted ROM, FABER, PRI</td>
</tr>
<tr>
<td>Clohisy et al.&quot;</td>
<td>Hip pain w/ROM</td>
<td>FADDIR</td>
</tr>
<tr>
<td>Martin et al.&quot;</td>
<td>Hip pain w/ROM</td>
<td>FADDIR</td>
</tr>
<tr>
<td>Martin et al.&quot;</td>
<td>Hip pain w/ROM</td>
<td>FADDIR</td>
</tr>
</tbody>
</table>

AP indicates anteroposterior; DDH, developmental dysplasia of the hip; DEXRIT, Dynamic External Rotatory Impingement Test; DIRE, Dynamic Internal Rotatory Impingement Test; ER, External Rotation; FABER, Flexion Abduction External Rotation; FADDIR, Flexion Adduction Internal Rotation; FIR, Flexion Internal Rotation; GT, greater trochanter; IR, Internal Rotation; LRI, Lateral Rim Impingement; MFER, maximal flexion with external rotation; MFIR, maximal flexion with internal rotation; MRA, magnetic resonance arthrography; OA, osteoarthritis; PRI, Posterior Rim Impingement; PSRT, Passive Supine Rotation Test; ROM, range of motion; SLR, Straight Leg Raise; SLRAR, Straight Leg Raise Against Resistance; SLST, Single Leg Stance Phase Test.

THE PHYSICAL EXAMINATION OF THE HIP

A consistent hip examination is conducted to screen the hip, back, abdominal, neurovascular, and neurologic systems and to find any comorbidities that often exist with complex hip pathology. Each examination has a specific way to be conducted and interobserver consistency and practice is one of the most important aspects of the evaluation. The order of the examination should be easy on the patient and flow for the physician. The most efficient order of examination begins with standing tests followed by seated, supine, lateral, and ending with prone tests. The physical examination will be fine tuned and directed...
TABLE 2. Complete Review of Patient History

NAME: ____________________________________________
DATE: ________________
AGE: ________________
EMPLOYMENT: ________________________
REFERRED BY: ________________________
CHIEF COMPLAINT: L HIP  R HIP  OTHER: ________________________
HISTORY OF PRESENT ILLNESS:
- Date of onset
- Traumatic/nontraumatic
- Mechanism of injury
- Pain location
- Pain increased with
- Pain decreased with
- Have you ever been diagnosed with AVN? If yes, do you have a family history of heart disease, stroke, or clotting disorders?
  - Alcohol use
  - Tobacco use
  - Steroid use
  - Labs: Homocysteine
  - Factor V Leiden
  - Lipid profile
  - Thyroid profile
  - Pain a.m./p.m.: popping/locking

TREATMENT TO DATE
- Rest
- Ice
- Heat
- NSAIDS
- PT
- Surgery
- Chiropractic tx
- Injections
- Support (cane, crutch)
- Orthotics

TESTS AND EVALUATIONS:
- MRI
- MRI Arthrogram
- X-rays
- Lab
- Biometrics
- Consults

PAST INJURIES:

LIMITATIONS:
- Sitting: Length of Time able to sit ______
- Getting in or out of car
- Getting in or out of tub
- Sports
- Jogging
- Walking
- Stairs
- Work
- ADL’s
- Household activities

FUNCTION:
- HHS: ______
- VAS: Pain at Rest (0-10): ______
- Pain With Activity: ______

ASSOCIATED
- Back
- L: Left
- R: Right
- Night pain awakening
- Numness
- Weakness

SPORTS AND ACTIVITIES:

GOAL IN TREATMENT:

Review of systems: The review of the constitutional, gastrointestinal, respiratory, cardiovascular, extremities, neurologic, musculoskeletal, psychiatric, skin, and genitourinary systems is unremarkable other than as mentioned in the history of present illness.

ADL indicates activities of daily living; AVN, avascular necrosis; HHS, Harris Hip Score; L, left; PT, physical therapy; R, right; VAS, Verbal Analog Score.

through the review of the history of present illness. To establish international clarification among clinicians, each test is given a descriptive functional title (Table 3).

The Multicenter Arthroscopy of the Hip Outcomes Research Network group identified common trends among hip specialists in the physical examination of the hip.25
TABLE 3. Physical Examination of the Hip Intake Form

<table>
<thead>
<tr>
<th>Gait/Posture:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoulder height:</td>
<td>Equal</td>
</tr>
<tr>
<td>Iliac crest height:</td>
<td>Not equal</td>
</tr>
<tr>
<td>Active Forward Bend:</td>
<td></td>
</tr>
<tr>
<td>Spine:</td>
<td></td>
</tr>
<tr>
<td>• straight</td>
<td>structural</td>
</tr>
<tr>
<td>• scoliosis:</td>
<td>non-structural</td>
</tr>
<tr>
<td>• Recurvatum:</td>
<td>thumb test</td>
</tr>
<tr>
<td>• Lordosis:</td>
<td>elbows</td>
</tr>
<tr>
<td>• Gait:</td>
<td>normal</td>
</tr>
<tr>
<td>• pelvic winkle:</td>
<td>analgie</td>
</tr>
<tr>
<td>• Foot progression angle:</td>
<td>arm swing</td>
</tr>
<tr>
<td></td>
<td>short stride length</td>
</tr>
<tr>
<td></td>
<td>short stance phase</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>• Single Leg Stance Phase Test (Trendelenburg Test):</td>
<td>R</td>
</tr>
</tbody>
</table>

**Seated Examination:**

- **Neurologic Findings:**
  - **Motor:**
  - **Sensory:**
  - **DTR:**
  - **Circulation:**
  - **Skin Inspection:**
  - **Lymphatic:**
- **Straight Leg Raise:**
- **Range of Motion:**

**Supine Examination:**

- **Leg lengths:**
- **ROM:**
  - Flexion:
  - Abduction:
  - Adduction:
- **Hip Flexion Contracture Test (Thomas Test):**
  - FADDIR:
  - DEXRIT:
- **Posterior Rim Impingement Test:**
  - Apprehension Sign:
- **Abdomen:**
- **Adductor Tubercle:**
- **Palpation pubic symphysis/Adductor:**
- **Tinel's – femoral nerve:**
- **FABER (Patrick Test):**
- **Straight Leg Raise Against Resistance (Slichter Test):**
- **Passive Supine Rotation Test (Log Roll Test):**
- **Heel Strike:**

**Lateral Examination**

- **Palpation:**
  - SI joint
  - Iliac crest
  - Greater trochanter
  - ASIS
  - Piriformis
  - Tinel's – sciatic nerve

In the standing position, common tests included gait analysis, single leg stance phase test, and laxity. In the supine position, common tests included ROM of hip flexion, ROM of IR and ER at 90 degree hip flexion, FADDIR, dynamic internal rotatory impingement test (DIR1), dynamic external rotatory impingement test.
### TABLE 3. (continued)

<table>
<thead>
<tr>
<th>G. Max insertion into ITB</th>
<th>Tender</th>
<th>Non-tender</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sciatic nerve</td>
<td>Tender</td>
<td>Non-tender</td>
</tr>
<tr>
<td>Gluteus medius</td>
<td>Tender</td>
<td>Non-tender</td>
</tr>
</tbody>
</table>

**Abductor strength:**
- Tensor Fascia Lata Contracture Test: Grade (1-3)___
- Gluteus Medius Contracture Test: Grade (1-3)___
- Gluteus Maximus Contracture Test: Grade (1-3)___
- Lateral Rim Impingement Test: R + - L + -
- FADDIR Test: R + - L + -

**Prone Examination:**
- Rectus Contracture Test (Ely’s Test): R + - L + -
- Femoral Anteversion Test (Craig’s Test): degrees anteverision

**Palpation:**
- Spinosus processes: + -
- SI joints: R + - L + -
- Bursae ischium

**Specific Tests:**
- Philippson Internal Rotation Test
- McCarthy’s Sign
- Scours
- Foveal Distraction
- Bicycle
- Fulcrum
- Seated Piriformis Stretch Test
- Pace Sign
- ABDEER
- Dynamic Trendelenberg
- Supine abduction external rotation

ASIS indicates anterior superior iliac spine; BP, blood pressure; DEXRIT, Dynamic External Rotatory Impingement Test; DIRT, Dynamic Internal Rotatory Impingement Test; DP, dorsalis pedis; DTR, deep tendon reflexes; ER, External Rotation; FABER, Flexion Abduction External Rotation; FADDIR, Flexion Adduction Internal Rotation; HT, height; L, left; P, pulse; PT, posterior tibialis; R, right; ROM, range of motion; R, RFSP; SI, sacroiliac joint; T, Temperature; WT, weight.

(DEXRIT), palpation, flexion abduction external rotation (FABER), straight leg raise against resistance (SLRAR), muscular strength, passive supine rotation (PSR), and the posterior rim impingement (PRI) test. Common lateral position tests included palpation, passive adduction tests, and abductor strength. In the prone position the femoral anteverision test was commonly conducted. The physical examination that follows is inclusive of these points.

### STANDING EXAMINATION

In the standing examination a general point of pain is noted with 1 finger. The groin region directs a suspicion of intraarticular problem and lateral-based pain is primarily associated with both intraarticular or extraarticular aspects. A characteristic sign of patients with intraarticular hip pain is the “C Sign.” The patient will hold their hand in the shape of a C and place it above the greater trochanter with the thumb positioned posterior and fingers extending to the groin. This finding can be misinterpreted as lateral soft tissue pathology; however, the patient is often describing deep inferior hip pain. Posterior-superior pain requires a thorough evaluation in differentiating hip and back pain.

As the patient stands, the shoulder height (Fig. 1) and iliac crest heights are noted to evaluate leg length discrepancies. Incremental wooden blocks placed under the short side heel, aid in orthotic considerations. General body habitus is assessed and issues of ligamentous laxity are determined by the thumb and middle finger tests and hyperextension of the elbows or knees. Monitoring the spine as the patient bends forward differentiates structural versus nonstructural scoliosis. The degree of lumbar flexion is recorded and side-bending ROM is also useful.

Gait abnormalities often help to detect hip pathology owing to the transfer of dynamic and static load to the ligamentous and osseous structures. A full gait of 6 to 8 stride lengths is observed from behind and the front of the patient. Key points of gait evaluation include foot rotation (internal/external progression angle), pelvic rotation, stance phase, and stride length. The foot progression angle will detect osseous or static rotatory malalignment. The knee and thigh are observed simultaneously to assess any rotatory parameters. A secondary abnormal hip rotation may result from the knee being held in either IR or ER to allow proper patellofemoral joint alignment. This abnormal motion is usually present in cases of severe increased
femoral anteversion precipitating a battle between the hip and knee for a comfortable position thus affecting gait. In cases of a painful gait, the anatomical location of pain is noted and at what point within the gait phase pain is present.

Noting iliac crest rotation and terminal hip extension assesses pelvic rotation. On average, normal gait requires 6 to 8 degrees of hip rotation and 7 to 10 degrees of pelvic rotation, equaling a total rotation of 15 degrees²⁶ (Fig. 2). A pelvic wink is shown by an excessive rotation toward the affected hip, thus producing extension and rotation through the lumbar spine, to obtain terminal hip extension. This winking gait can be associated with articular hip pathology, laxity, or hip flexion contractures, especially when combined with increased lumbar lordosis or a forward-stooping posture. Excessive femoral anteversion, or retroversion, can affect the wink on terminal hip extension, as the patient will try to create greater anterior coverage with a rotated pelvis. Injury to the anterior capsule can also contribute to a winking gait.

A shortened stance phase can be indicative of neuromuscular abnormalities, trauma, or leg length discrepancies. The Abductor Deficient Gait (common nomenclature: Trendelenburg Gait or abductor arch) is an unbalanced stance phase attributed to abductor weakness, or proprioception disruption. The Abductor Deficient Gait may present in 2 ways: with a shift of the pelvis away from the body (“dropping out” of the hip on the affected side), or with a shift of the weight over the adducted leg (shift of the upper body “over the top” of the affected hip). An atalgic gait is characterized by a shortened stance phase on the painful side limiting the duration of weight bearing (a self-protecting limp caused by pain). A short-leg gait is noted by the drop of the shoulder in the direction of the short leg.

The Single Leg Stance Phase Test (traditionally known as the Trendelenburg Test) is conducted on both legs, with
the nonaffected leg examined first to establish a baseline reference for the patient's function. During the Single Leg Stance Phase Test, the patient stands with feet shoulder width apart and then brings 1 leg forward by flexing the leg to 45 degrees at the hip and 45 degrees at the knee. The single leg stance phase position is held for 6 seconds testing the contralateral hip abductor musculature and neural loop of proprioception. Normal dynamic mid-stance translocation is 2 cm²; a pelvic tilt greater than 2 cm constitutes a positive shift. This test is also conducted in a dynamic fashion by some examiners.

**SEATED EXAMINATION**

The seated hip examination consists of a thorough neurologic and vascular examination. Even in apparently healthy individuals the need to check the basics is important including, pulse, deep tendon reflexes, sensation, and inspection of the skin. A straight leg raise test is then conducted by actively extending the knee into full extension, which is helpful in detecting radicular neurologic symptoms.

One of the most important assessments is IR and ER in the seated position (Fig. 1). The seated position ensures that the ischium is square to the table, thus providing sufficient stability at 90 degrees of hip flexion and a reproducible platform for the accurate rotational measurement. Passive IR and ER is carried out gently, and is compared from side to side. Seated rotation ROM is also compared and contrasted to the extended position of the hip. The loss of IR is 1 of the first signs for the possibility of intraarticular disorder. Pathology related to femoracetabular impingement or to rotational constraint from increased or decreased femoral or acetabular anteversion can result in significant side-to-side differences. An increased IR combined with a decreased ER may indicate excessive femoral anteversion and distinguished from hip capsular pathology by radiographic and biometric assessment.

**SUPINE EXAMINATION**

The supine examination begins with the assessment of leg lengths (Fig. 3). Next, passive hip flexion ROM is assessed as both knees are brought up to the chest. The

![FIGURE 3. Details of the supine, lateral and prone examination. Shown: the Dynamic Internal Rotation Test, the Flexion/Adduction/Internal Rotation Test, and the Rectus Contracture Test.](image-url)
pelvic position is carefully observed as the hip may stop early in flexion with the end ROM being predominately pelvic rotation. The Hip Flexion Contracture Test (also known as the Thomas Test) is done by having the patient extend and relax 1 leg down toward the table, while holding the contralateral leg in full flexion. The inability of the thigh to reach the table shows a hip flexion contracture; both sides are examined to compare the differences.

FIGURE 5. DEXRT. A, starting position; (B) dynamic ER with abduction; (C) arthroscopic view of incomplete FAI decompression assessing congruence with dynamic ER; (D) replication of the dynamic exam within the operating theater.
During the course of the supine examination, any pop in this plane can sometimes be related to a snapping iliopsoas tendon. A Fan Test (the patient circumducts and rotates the hip in rotatory fashion) can help delineate the presence of the snapping iliopsoas tendon over the femoral head or the innominate. Many times this will be eliminated with a simultaneous abdominal contraction. A hula hoop maneuver, in which the patient stands and twists, or a bicycle test (conducted in the lateral position), can help to distinguish the pop internally from the external pop of coxa saltans externus owing to the subluxing iliotibial band over the greater trochanter.

The FABER test, conventionally known as the Patrick Test, is helpful in determining hip versus lumbar complaints. Recreational hip pain can be associated with musculotendinous or osseous posterior lateral acetabular incongruence or ligamentous injury. In cases of a coup/contra-coup injury in which the mechanism of injury is initiated posteriorly, there will be a secondarily referred anterior pain.

The DIRI (Fig. 4) is conducted in the supine position and the patient is instructed to hold the nonaffected leg in flexion beyond 90 degree, thus establishing a zero pelvic set point eliminating lumbar lordosis. The examined hip is then brought into 90 degree flexion or beyond and is passively taken through a wide arc of abduction and internal rotation. A positive is noted with recreation of the complaint pain. DIRI can also be carried out in the operating theater for direct visualization of femoral neck and acetabular congruence.

The DEXRIT (Fig. 5) is conducted in the supine position and the patient is instructed to hold the non-affected leg in flexion beyond 90 degree, thus eliminating lumbar lordosis. The hip is then brought into 90 degree flexion or beyond and dynamically taken through a wide arc of abduction and external rotation. A positive test is noted with recreation of pain. DEXRIT can be conducted intraoperatively for direct visualization of femoral neck and acetabular congruence.

Passive abduction and adduction ROM is assessed in the supine position. Palpation of the abdomen is carried out and any tenderness is documented. Abdominal tenderness is differentiated from fascial hernia and/or adductor tendinitis. Resisted torso flexion with palpation of the abdomen will differentiate the fascial hernia from other complaints. Palpation of the adductor tubercle with active testing will detect adductor tendinitis. Common physical exam findings associated with athletic pubalgia include inguinal canal tenderness, pubic crest/tubercle tenderness, adductor origin tenderness, pain with resisted sit-ups or hip flexion, and a tender, dilated superficial ring.

Another useful test is Tinel of the femoral nerve. This test is found to be positive with hip flexion contractures of greater than 25 degrees, as a result of the proximity of the psoas tendon and the femoral nerve. A Heel Strike is carried out by striking the heel abruptly, which if painful, is indicative of some type of trauma or a stress fracture. The PSR test (commonly known as the Log Roll) involves passive IR and ER of the femur, with the leg lying in an extended or slightly flexed position. The PSR test is conducted bilaterally and any side-to-side differences of this maneuver can alert the examiner of the presence of laxity, effusion, or internal derangement. The Straight Leg Raise Against Resistance Test (also known as the Stinchfield Test) is an assessment of hip flexor/psoas strength and a sign of an intrarticular problem by increasing the compressive force across the hip joint or the psoas placing pressure on the labrum. The patient carried out an active straight leg raise, with the knee in extension up to 45 degree, the examiner’s hand is then placed distal to the knee while applying a downward force. A positive test is noted with recreation of the complaint, pain, or weakness.

The PRI test PRI is conducted with the patient at the edge of the examining table so that the examined leg hangs freely at the hip. The patient draws up both legs in to the chest, eliminating lumbar lordosis. The affected leg is then extended off the table, allowing for full extension of the hip, abducted and externally rotated. The PRI test takes the hip into extension assessing the congruence of the posterior acetabular wall and femoral neck. A variation of this test is the Lateral Rim Impingement test.

LATERAL EXAMINATION

The lateral examination begins with the patient on the contralateral side by palpating the areas of the supra-S1 and SI joint (Fig. 3), muscles of abduction, and in particular the origin of the gluteus maximus as it inserts along the lateral border of the sacrum, and the most posterior aspect of the ilium. The next point of palpation is the ischium for detection of avulsions or bursitis. Finally, the piriformis and sciatic nerve are palpated for any sign of tenderness, along with the abductor musculature, which includes the glutei (maximus, medius, and minimus) and tensor fascia lata. An Active Piriformis test is conducted by the patient pushing the heel down into the table, abducting and externally rotating the leg against resistance, while the examiner monitors the piriformis. The Active Piriformis test is similar to Pace sign, which is pain and weakness on resisted abduction and ER of the thigh in the seated position. A set of Passive Adduction Tests (most like Ober Test) is conducted with the leg in 3 positions: extension (Tensor Fascia Lata Contracture Test), neutral (Gluteus Medius Contracture Test), and flexion (Gluteus Maximus Contracture Test). In each position, the hip should adduct down toward the table and any restrictions are recorded. Gluteus medius tension is assessed by relaxation of the iliotibial band with knee flexion. When conducting the Gluteus Maximus Contracture Test, the shoulder is rotated down toward the table with the hip flexed and knee extended. If adduction cannot occur in this position, the gluteus maximus portion is contracted. The gluteus maximus is balanced with the tensor fascia lata anteriorly. A clear delineation of the exact area of restriction will help to direct physical therapy and perirhoeatlatic treatment options. Strength is assessed with any type of lateral-based hip complaint. The gluteus medius strength test is conducted with the knee in flexion to release the iliobial band contribution.

The passive assessment of FADDIR is done in a dynamic manner (depicted in Fig. 3, Lateral Exam). The examiner holds the monitoring hand about the superior aspect of the hip with the lower leg cradled on the forearm with the knee upon the hand. The hip is then brought into flexion, adduction, and internal rotation. Any reproduction of the patient’s complaint and the degree of impingement are noted. FADDIR is commonly conducted as part of the supine assessment. The difference is the position of the pelvis. The supine position eliminates lumbar lordosis, whereas the lateral tests the normal dynamic pelvic
inclusion. Pelvic inclination may affect testing and both positions are helpful in evaluation.

The Lateral Rim Impingement Test is conducted with the hip passively abducted and externally rotated. The examiner cradles the patient's lower leg with 1 arm and monitors the hip joint with the opposing hand. The examiner passively brings the affected hip through a wide arc from flexion to extension in continuous abduction while externally rotating the hip. Reproduction of the patient's pain is scored positive. If the feeling of guarding or instability is present, the test is positive for apprehension, which is not to be confused with coup/coutracoup. The Lateral Rim Impingement Test establishes a functional lumbar lordosis with a clear ability to comfortably monitor sites of impingement, which aids in the separation posterior and lateral points of impingement.

PRONE EXAMINATION

The prone examination (Fig. 3) involves palpation of 4 distinct areas: the supra-SI, SI, glutus maximus origin, and spine (facets). Should the pain be identified in the supra-SI joint region or in about the facet, a lumbar hyperextension test can help to identify the exact location of suspected pain. If this test is positive, the patient can then be placed into a supine position with the knees flexed. If this helps to alleviate the pain, the back should be further evaluated.

The Femoral Anteversion Test (traditionally as Craig Test) will give the examiner an idea of femoral anteversion/retroversion. With the patient in the prone position, the knee is flexed to 90 degree and the examiner manually rotates the leg while palpating the greater trochanter so that it protrudes most laterally. Femoral version is assessed by noting the angle between the axis of the tibia and an imaginary vertical line, which normally is between 10 and 20 degrees. This test will help to identify cases of retroversion. The Rectus Contracture Test (also known as Ely Test) is conducted with the patient in the prone position and the lower extremity flexed toward the gluteus maximus. Any rise of the pelvis or restriction of hip flexion is indicative of a rectus femoris contracture.

SPECIFIC TESTS

McCarthy Test

A maneuver associated with a McCarthy sign, a reproducible pop or click. The McCarthy test is conducted with the contralateral leg held in flexion. The examined hip is brought to 90 degree flexion, then abducted, externally rotated, and extended. The hip is then brought to 90 degree flexion, adducted, internally rotated, and extended. A positive McCarthy sign is helpful in detecting anterior femoroacetabular impingement or a torn labrum.

Scout—Performed in the same manner as DIRI, however, the examiner applies pressure at the knee thereby increasing pressure at the hip joint, helpful in detecting interarticular congruence.

Foveal Distraction Test

Intraarticular pressure is alleviated by gently pulling the leg away from the body as the patient is in the supine position. The relief of pain or recreation of pain will help define extraarticular versus intraarticular pathology.

Bicycle Test

This test was conducted with the patient in the lateral position. The motion of a bicycle pedaling pattern is recreated as the examiner monitors the iliotibial band for the detection of coxa sulcus externus.

Fulcrum Test—The examiner's knee is placed under the patient's knee, acting as the fulcrum. The patient then carries out a straight leg test against resistance.

Seated Piriformis Stretch Test

For patients presenting with sit pain and suspected sciatic nerve problems, the Seated Piriformis Stretch Test is performed in the seated position with the hip at 90 degrees of flexion. The examiner extends the knee and passively moves the flexed hip into adduction with internal rotation while puliating 1 cm lateral to the ischium (middle finger) and proximally at the sciatic notch (index finger). A positive test is the recreation of the posterior pain. Freiberg has described sciatic nerve entrapment by the piriformis and may be entrapped in other ways which is best described as Deep Gluteal Syndrome.

The Abduction/Extension/External Rotation Test

The examination is conducted in the lateral position with the affected leg passively brought into abduction, extension, and ER as forward pressure is applied to the posterior aspect of the hip. Recreation of the patient's pain is a positive test. As with the apprehension test conducted on the shoulder, abduction/extension/external rotation test is helpful in the detection of any type of anterior capsular laxity or injury. Of note, current research suggests that this position specifically releases the teres ligament.

Dynamic Trendelenburg Test

The patient carry out a single leg stance and the examiner applies a slight force or shove to the patient's shoulder (Personal communication Tom Sampson, MD). By introducing this dynamic component to single leg standing, subtle signs of strength or proprioception deficits may be elicited.

Supine Abduction External Rotation Test

This test was conducted in the supine position, the hip is taken into abduction and ER at varying degrees of flexion to extension to distinguish internal derangements, laxity, or impingement (Personal communication Carlos Guanche, MD).

Resisted Sit-up Test—The athletic hernia is described as a condition of a weakened posterior wall of the inguinal canal, which results in chronic pain in the groin that may refer to other surrounding areas and is exacerbated with activity. Common physical exam findings include inguinal canal tenderness, pubic crest/uberchec tenderness, adductor origin tenderness, pain with resisted sit-ups or hip flexion, and a tender, dilated superficial ring.

Pudendal Nerve Block Test

The Nantes criteria include pain in the urogenital area that is increased with sitting and that does not wake the patient at night, and loss of sensation of the genitalia. If these essential criteria are met, a diagnostic anesthetic pudendal nerve block should be carried out and relief of symptoms strongly supports the diagnosis.
### TABLE 4. Physical Examination Findings and Related Pathology

<table>
<thead>
<tr>
<th>History</th>
<th>Dominant Positive Physical Exam Findings</th>
<th>Radiographic</th>
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<tbody>
<tr>
<td>Labral tear</td>
<td>Loss of IR</td>
<td>CAM</td>
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<tr>
<td></td>
<td>FADDIR (ant. tear)</td>
<td>Pincer</td>
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<td></td>
<td>DIRI (ant. tear)</td>
<td>Alpha angle &gt; 50(^\circ) abnormal rotatory alignment</td>
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<td></td>
<td>LRI (sup. tear)</td>
<td>Contrecoup</td>
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<td>FABER (sup. tear)</td>
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<td></td>
<td>PRI (post. tear)</td>
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<td></td>
<td>DEXRIT</td>
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<tr>
<td>FAI CAM</td>
<td>Loss of IR</td>
<td>Reduced Head-Neck offset</td>
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<tr>
<td>Atraumatic</td>
<td>FADDIR</td>
<td>Prominence</td>
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<tr>
<td></td>
<td>DIRI</td>
<td>Alpha &gt; 50(^\circ) Asymmetry</td>
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<td></td>
<td>DEXRIT</td>
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<tr>
<td>Traumatic</td>
<td>Repetitive flexion with internal rotation</td>
<td>Herniation Pit</td>
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<td>MRI or CT - rotatory impingement</td>
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<td>FAI pincer</td>
<td>Loss of IR</td>
<td>Acetabular Retroversion</td>
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<td>Anterior</td>
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<td></td>
<td>DEXRIT</td>
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<tr>
<td>Lateral</td>
<td>Decreased ER</td>
<td>Overhanging lip on acetabulum</td>
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<td></td>
<td>FABER</td>
<td>AI &gt; 5(^\circ)</td>
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<td>DEXRIT</td>
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<td>Posterior</td>
<td>Decreased ER</td>
<td>Coxa Profunda</td>
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<td>PRI</td>
<td>Posterior Rim outside center axis</td>
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<td></td>
<td>FABER (coup-contracoup)</td>
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<tr>
<td>Hip instability</td>
<td>Difficulty</td>
<td>Updoped Acetabular Roof</td>
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<td>Osteous</td>
<td>down stairs/hill “Giving Way” Chronic</td>
<td>AI &gt; 10(^\circ) Cephalad</td>
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<td></td>
<td>pain after excessive activity</td>
<td>Coxa Valga &gt; 145(^\circ)</td>
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<td>Ligamentous</td>
<td>Femoral Version &gt; 30(^\circ)</td>
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<td>Laxity/Rcurvatum of other joints</td>
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<td>In-Toeing Gait</td>
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<td>Ligamentous</td>
<td>Recurvatum/Laxity</td>
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<td>FABER/waist apprehension</td>
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<td>Hyperinstability</td>
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<td>Passive Adduction test</td>
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<td>Muscular complaints</td>
<td>Decreased Joint Space Width (Standing AP)</td>
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<tr>
<td>Chondral lesion</td>
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<tr>
<td>Acute</td>
<td>Hip pain with long standing pathology or OA</td>
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<tr>
<td>Chronic</td>
<td>Decreased IR/ER</td>
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<td>DEXRIT</td>
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<tr>
<td>GT pain</td>
<td>Scour (acute lesion)</td>
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<td></td>
<td>Restricted ROM</td>
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<tr>
<td></td>
<td>Pain with palpation specific to anatomical location</td>
<td>+ Passive Adduction Tests</td>
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<tr>
<td>Snapping hip Psous</td>
<td>“Snap/Pop” Weak Core Strength</td>
<td>Abductor Weakness</td>
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<td>+ Fan test</td>
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<td>Restricted Abd/Add</td>
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<td>+ Bicycle test</td>
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<tr>
<td>IIiobial Band</td>
<td>“Clunk”</td>
<td>Abductor Weakness</td>
</tr>
</tbody>
</table>

ABDEER indicates abduction extension external rotation; AI, acetabular inclination; AP, anteroposterior; CAM, cam-type; DEXRIT, Dynamic External Rotatory Impingement Test; DIRI, Dynamic Internal Rotatory Impingement Test; ER, External Rotation; FABER, Flexion Abduction External Rotation; FADDIR, Flexion Abduction Internal Rotation; FAI, femoroacetabular impingement; GT, greater trochanter; IR, Internal Rotation; LRI, Lateral Rotatory Impingement; OA, osteoarthritis; PRI, Posterior Rim Impingement; PSR, passive supine rotation; ROM, range of motion.

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CONCLUSIONS

The evaluation of the hip has evolved over generations of orthopaedic surgeons. A number of diagnostic tests have been described for specific pathologies that include a common base of maneuvers. Through the use of a common set of diagnostic procedures and terminology, there will be improvement in the accuracy of diagnostic exams for determining hip pathology.

ACKNOWLEDGMENT

The authors thank Aaron M. Smathers, MS, for his assistance in preparing the manuscript.

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Factors associated with the failure of arthroscopic surgery treatment in patients with femoroacetabular impingement: A cohort study

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Received 13 May 2014; accepted 4 September 2014

Abstract

Objective: The aim of this study was to evaluate the association of the anatomical and functional characteristics with therapeutic failure in patients with femoroacetabular impingement, who underwent hip arthroscopy.

Materials and methods: A cohort study was performed on 179 patients with femoroacetabular impingement who underwent hip arthroscopy between 2004 and 2012. The demographic, anatomical, functional, and clinical information were recorded. A logistic regression model and ANCOVA were used in order to compare the described characteristics with the treatment outcomes of the hip arthroscopy.

Results: The median time of follow-up for symptoms was 13 months (8–30), and the mean time of follow-up after surgery was 23.83 ± 9.8 months. At the end of the follow-up 3.91% of the patients were considered as a therapeutic failure. The WOMAC score in pain and functional branches, as well as the total WOMAC score, showed significant differences (p < 0.05). The mean WOMAC score was higher (0–100 with 0 being a perfect score) in the group of patients who failed after surgery as compared with the group who meet the requirements for a successful treatment, 65.9 vs 48.8, respectively (mean difference 17.0; 95% CI; 1.3–32.6; p = 0.033).

Please cite this article as: Martínez D, Gómez-Hoyos J, Márquez W, Gallo J. Factores asociados al fracaso terapéutico de la cirugía arthroscópica en pacientes con choque femoroacetabular: un estudio de cohorte. Rev Esp Cir Ortop Traumatol. 2015;59:112–121.

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Factors associated with the failure of arthroscopic surgery treatment in patients with femoroacetabular impingement

Introduction

In some cases, pain in non-arthritic hips is associated to anatomical alterations of the acetabulum (pincer type deformity), the femoral neck (cam type deformity) or both (mixed deformity), which added to cyclical mechanical loads or lesions caused during physical activity derive in damage to the labrum or cartilage. This condition, known as femoroacetabular impingement (FAA), is probably the main cause of osteoarthritis (OA) in non-dysplastic hips. The association between labral lesions and a history of FAA in 90% of cases has led to early interventions in order to avoid the progression of degenerative changes.

The etiology of the typical anatomical deformities of FAA is still controversial. The theories put forward include evolutionary changes, predisposing diseases, like proximal femoral epiphysiolysis, and genetic factors, among others.

Despite the presence of anatomical deformities typical of FAA, some epidemiological studies have determined that the onset is not associated to symptoms in nearly 4.3% of males and 3.6% of females. The absence of studies which clearly associate OA with asymptomatic FAA is the reason why the current trend is to intervene patients only when they present pain, related or not to physical activity. In 2013, Agricola et al. found an association between OA and an alpha angle over 60°, with a greater association as the measurement increased, and finding the greatest association among patients with 83°. Nevertheless, all the patients in that study were symptomatic, so the scenario of patients with anatomical configurations compatible with FAA but without symptoms and developing OA remains unexplored.

Conservative treatment is currently accepted as the initial intervention for all patients. However, its effectiveness in terms of functional improvement or modification of the natural history of the degenerative changes has not been proven so far. Therefore, surgical treatment in patients with symptoms acquires great relevance in order to alleviate pain, improve functional condition, shorten the return to physical activity and prevent degenerative changes on the labrum and cartilage.

The correction of the alterations described can be carried out through open, arthroscopic or mini-anterior arthroscopy-assisted surgery. Open surgery involves a controlled dislocation of the hip, which makes the procedure technically demanding and, due to factors inherent to the technique, may entail complications such as nonunion of the trochanteric osteotomy, osteonecrosis of the femoral head, heterotopic ossification and persistent weakness of the abductor musculature.

Arthroscopic and assisted mini-anterior treatments avoid the need to dislocate the hip, but they also require maneuvers, like prolonged traction and liquid infusion, that can cause transient neuropraxias and extravasation of fluid to

Conclusion: The poor functional state prior to arthroscopic treatment of femoroacetabular impingement, mainly due to preoperative pain, assessed using the WOMAC scale, is associated with a higher therapeutic failure rate.

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the abdominal cavity in some cases.\textsuperscript{18} Nevertheless, both with the open technique and arthroscopic and assisted procedures, the rates of complications are increasingly low due to the increasing experience of surgeons, as well as an improved selection of patients.\textsuperscript{18}

Recent studies have proven that these techniques have similar rates of effectiveness,\textsuperscript{19,20} with reduction of pain and improvement of function in between 68 and 96% of patients,\textsuperscript{21} but with an advantage for arthroscopic or assisted treatment regarding the rate of return to activity among high-level athletes.\textsuperscript{19} These studies have assessed treatment failure in two ways: through the need for a new surgical procedure in the affected hip and through the use of different scoring scales intended for this purpose.

Some studies of effectiveness have shown as a secondary result that patients with advanced age and OA prior to the procedure were associated with poor results. However, no published studies have determined other anatomical or functional factors related to failure of the surgical treatment, which can reach up to 32% of cases\textsuperscript{21} after controlling for confounding factors. One study demonstrated failure in 12% of patients with no presence of OA,\textsuperscript{21} thus indicating the existence of other characteristics determining failure of arthroscopic treatment, in addition to the previously identified variables.

Elucidating these characteristics would enable a reduction in the frequency of surgical treatment failure, establishing predictive variables which helped to select patients for arthroscopic hip treatment, due to the clarity obtained in terms of patients who would truly benefit from the intervention.

The objective of this study was to evaluate the association of anatomical and functional characteristics with therapeutic failure of arthroscopic surgery in patients suffering FAA.

Materials and methods
We conducted a predictive study which included 179 patients with FAA, who were intervened at Clínica Las Américas (Medellín, Colombia), by one of the authors (WM), between the years 2004 and 2012, to assess the association of anatomical and functional characteristics with therapeutic failure of arthroscopic surgery in patients with FAA.

Subjects
We included patients with ages between 17 and 66 years with a diagnosis of FAA, who underwent arthroscopic hip surgery, with at least 1 year of postoperative follow-up. We excluded patients with a history of congenital or acquired hip disease other than FAA (Perthes disease, hip dysplasia, fracture and epiphysiolysis), those with a prior history of hip surgery and those who presented radiographic findings compatible with hip OA greater than grade i in the Tonnis scale.\textsuperscript{23}

Diagnosis
The diagnosis of FAA was established in patients with hip pain who did not respond to nonsurgical treatment and had positive findings for pincer or cam type FAA.

All patients included presented the typical clinical manifestations and radiographic findings of FAA, which were identified through hip radiographs and arthrography by magnetic resonance.

Hip radiograph
Radiographic findings were determined through anteroposterior projection of the pelvis and axial Johnson projection of the proximal femur, supervised by the same surgeon (WM) and conducted according to the standards recommended by the literature, similarly to the measurement of the alpha angle and center edge angle (CE),\textsuperscript{24} assessing the deformity of the femoral head and acetabular overcoverage, respectively, which in turn determined the type of impingement.

Arthrography by magnetic resonance (arthro-resonance)
The arthrographies were conducted at 3 different centers in the city by similar processes; injection of the intraarticular contrast medium enabled the intraarticular hip components to be delimited, as well as the condition of the labrum and acetabular cartilage to be established. These were interpreted by the radiologists at each of the centers and verified by the surgeon (WM) so as to determine the condition of the structures examined.

Surgical procedure
Arthroscopic hip interventions were conducted by the same surgeon on an outpatient basis, under general anesthesia. In addition, a femoral block was carried out to control postoperative pain. An orthopedic table was used in all cases, with the patient in the supine position and a large perineal post (standard for protected hip traction). The intervened hip was positioned at 25° abduction, extension and neutral rotation. A traction test was conducted prior to creating the portals.

After verifying the arthroscopy equipment and the 30° and 70° lenses (Arthrex\textsuperscript{®}, Florida, USA), as well as the irrigation system, the anterolateral and anterior portals were created using the inside-out technique. The diagnosis of intraarticular lesions was established initially, and then corrected according to their indication.

Anatomical characteristics
The lesions of the joint cartilage and labrum were assessed through arthro-resonance according to the McCarthy classification.\textsuperscript{25} Presence of chondral lesion was determined by stages 3 b and 4 of this classification.

The findings in the arthroscopic procedure, as well as the interventions conducted during the procedure, were considered as exposure variables; the presence of an acetabular cyst, microfractures, chondroplasty, resection or reinsertion of the labrum, osteoplasty, acetabuloplasty and tenotomy of the psoas were verified in the intraoperative records of patients.
The procedures were conducted by the same surgeon (WM) in all cases.

**Functional characteristics**

The scores of the Western Ontario and McMaster Universities (WOMAC) scale in its total LK3.0 version and the different domains, validated for Spanish, were considered to determine the condition of the affected hip prior to the arthroscopic procedure.\(^\text{25}\) The overall result of this scale was scored from 0 to 100. In the WOMAC scale, a result of 0 is the best possible and 100 is the worst possible.

The scale was applied to patients by one of the authors (WM), between 1 and 4 weeks prior to the surgical procedure. Although the validation was conducted in patients with OA, who were excluded from our study, familiarity with this scale and the similar performance of other scales used to assess functionality among young patients, such as the modified Harris hip score (MHHS), non-arthritis hip score (NAHS) and hip disability and osteoarthritis outcome score, made the WOMAC scale an adequate option for the evaluation of these patients.

**Follow-up**

Follow-up was started on the same date the arthroscopic procedure was performed, until the final assessment of the condition of each patient. All patients were monitored for at least 1 year and no additional controlled interventions were carried out during this period. All invasive procedures conducted on the involved hip were approved by patients. The final evaluation verified the presence of a new surgical procedure on the involved hip and other important clinical and sociodemographic characteristics through an instrument designed for this purpose. This questionnaire was completed through personal interviews, e-mail or telephone, between March 2012 and February 2013.

The outcome measured was failure of the arthroscopic treatment of the affected hip, defined as: (1) need for a new arthroscopic procedure, and (2) open surgery of the hip, or both.

When indicated, open surgery was conducted by a different surgeon, after consultation with the surgeon who conducted the arthroscopies (WM). The revisions of arthroscopies were always conducted by the same surgeon, author of this article. The indication was persistence of pain or limitation of movement.

**Statistical analysis**

A sample size of 123 subjects was calculated, taking into account that exposure factors would be present in 25% of the subjects suffering failure of the arthroscopic treatment, an OR of 3.8, 95% confidence interval (CI), a 3:1 ratio and a power of 70%. The software package Epidat version 4.1, of the Pan American Health Organization (PAHO), was used for the analysis.

The description of the nominal variables was conducted through proportions, and of the quantitative variables through means and medians, according to the previously established type of distribution.

The differences in quantitative variables between patients who did or did not suffer failure of the arthroscopic treatment were evaluated using the Student t test or the Mann–Whitney U test, depending on the type of distribution. The chi squared test of independence for categorical variables or the Fisher exact test for dichotomous variables were used to evaluate the association of variables included with the presence of failure of the arthroscopic treatment.

We conducted a binomial logistic regression analysis to evaluate the association between the anatomical characteristics and the presence of failure of the arthroscopic treatment. We adjusted the model for age and gender, presenting the results in OR and their respective 95% CI. The association between the functional variables and the outcome was evaluated through analysis of covariance (ANCOVA) after verifying the statistical assumptions. We obtained the mean scores in the different categories of the WOMAC scale, adjusted by age and gender according to the result of the arthroscopic treatment (failure versus success).

The analyses were carried out with the software package SPSS, version 21.0, and with a level of statistical significance of 5%.

**Results**

Out of a total of 232 patients who underwent hip arthroscopy between January 2004 and February 2012, we included 179 patients who fulfilled the criteria defined and who had a full follow-up. A total of 32 patients were excluded; 28 of them due to some grade of hip arthritis prior to the procedure, 1 due to prior fracture of the involved hip and 2 due to avascular necrosis.

Out of the 179 patients included and with a full follow-up, 69 were evaluated through a telephone survey, 78 through a personal interview and 32 by e-mail. It was not possible to contact 21 patients (10.5%), so they were considered as losses for the study (Fig. 1). The final scores in the WOMAC scale were not taken into consideration in the final analysis of results.

Out of the patients included, 3.91% presented failure of the treatment. This corresponded to 7 patients, of which 3 presented pincer type, 3 cam type and 1 mixed. A total of 35.2% were males, the mean ± standard deviation values for age were 43.7 ± 10.4 years, for BMI 23.8 ± 4.2 kg/m², and for overall score in the WOMAC scale prior to the procedure 50.7 ± 19.1. The majority of patients were from a medium-high socioeconomic background, represented by levels 4 and 5, 23.3 and 30.5%, respectively. Regarding laterality of impingement, it appeared on the right side in 40.6% of cases, on the left side in 48.3% and was bilateral in 11% of patients. Depending on the type of impingement, 44.9% of subjects presented cam type, 13.5% presented pincer type and 41.5% presented a mixed type.

The median time of evolution of the symptoms was of 13 months (P25–P75: 8–30) and the mean time of postoperative evolution was 23.8 ± 9.89 months. Regarding the radiographic characteristics of impingement, we found alpha angles and CE angles with mean values of 59.9 ± 6.39° and 36.6 ± 8.02°, respectively.
Table 1a  Description of the demographic and clinical characteristics according to the result of arthroscopic surgery obtained among patients with femoroacetabular impingement.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Result of treatment</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Failure (n = 7)</td>
<td>Mean</td>
<td>%</td>
<td>SD</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>39.00</td>
<td>13.11</td>
<td>43.92</td>
</tr>
<tr>
<td>Gender (males)</td>
<td></td>
<td>28.5</td>
<td>35.4</td>
<td>1.00a</td>
</tr>
<tr>
<td>Laterality</td>
<td></td>
<td>42.8</td>
<td>40.5</td>
<td>0.622</td>
</tr>
<tr>
<td>Right</td>
<td></td>
<td>57.1</td>
<td>47.7</td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td></td>
<td>0.0</td>
<td>11.7</td>
<td></td>
</tr>
<tr>
<td>Time of evolution of symptoms</td>
<td></td>
<td>18.50</td>
<td>29.74</td>
<td>31.96</td>
</tr>
<tr>
<td>Time of postoperative evolution (months)</td>
<td>30.64</td>
<td>13.4</td>
<td>23.56</td>
<td>9.78</td>
</tr>
<tr>
<td>Type of impingement</td>
<td></td>
<td>42.8</td>
<td>48.2</td>
<td>0.053</td>
</tr>
<tr>
<td>Cam</td>
<td></td>
<td>42.8</td>
<td>12.2</td>
<td></td>
</tr>
<tr>
<td>Pincer</td>
<td></td>
<td>14.2</td>
<td>39.5</td>
<td></td>
</tr>
<tr>
<td>Mixed</td>
<td></td>
<td>0.0</td>
<td>0.9</td>
<td>0.213</td>
</tr>
<tr>
<td>Socioeconomic level</td>
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<td>57.1</td>
<td>17.1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>0.0</td>
<td>9.9</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>0.0</td>
<td>9.9</td>
<td></td>
</tr>
<tr>
<td>3</td>
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<td>9.9</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>0.0</td>
<td>9.9</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>0.0</td>
<td>9.9</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>0.0</td>
<td>9.9</td>
<td></td>
</tr>
<tr>
<td>Education</td>
<td></td>
<td>0.0</td>
<td>0.9</td>
<td>0.753</td>
</tr>
<tr>
<td>Illiterate</td>
<td></td>
<td>14.2</td>
<td>6.3</td>
<td></td>
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<tr>
<td>Incomplete primary</td>
<td></td>
<td>0.0</td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td>Complete primary</td>
<td></td>
<td>14.2</td>
<td>18.9</td>
<td></td>
</tr>
<tr>
<td>Complete secondary</td>
<td></td>
<td>28.5</td>
<td>15.3</td>
<td></td>
</tr>
<tr>
<td>Technical or vocational</td>
<td></td>
<td>42.8</td>
<td>54.9</td>
<td></td>
</tr>
<tr>
<td>Professional</td>
<td></td>
<td>0.0</td>
<td>0.9</td>
<td>0.753</td>
</tr>
<tr>
<td>Previous treatments</td>
<td></td>
<td>14.2</td>
<td>33.3</td>
<td>0.160</td>
</tr>
<tr>
<td>Analgesics</td>
<td></td>
<td>42.8</td>
<td>12.6</td>
<td></td>
</tr>
<tr>
<td>Infiltrations</td>
<td></td>
<td>0.0</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td></td>
<td>42.8</td>
<td>52.2</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td></td>
<td>0.0</td>
<td>0.0</td>
<td>&lt;0.001b</td>
</tr>
<tr>
<td>Postoperative treatments</td>
<td></td>
<td>100.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Open surgery</td>
<td></td>
<td>0.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>New arthroscopy</td>
<td></td>
<td>0.0</td>
<td>9.9</td>
<td></td>
</tr>
<tr>
<td>Infiltrations</td>
<td></td>
<td>0.0</td>
<td>90.0</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td></td>
<td>0.0</td>
<td>90.0</td>
<td></td>
</tr>
</tbody>
</table>

a Fisher exact test.
b Statistical significance <0.05.

No differences were observed in the clinical and sociodemographic characteristics of patients included in the study, with the exception of presence of interventions subsequent to treatment, where the performance of a new arthroscopic procedure was more prevalent among the failure group (Tables 1a and 1b).

Out of the anatomical characteristics (radiographic and those observed and corrected during the arthroscopic procedure), osteochondroplasty was associated to the therapeutic failure, even after adjusting for age and gender (OR = 0.07; 95% CI, 0.01–0.4; p = 0.004) (Table 2).

The mean preoperative WOMAC score was higher among the failure group compared to the success group in the domains of pain and functional capacity after adjusting for age and gender. For the pain domain, the mean value was 15.4 in the failure group compared to 10.7 in the success group (difference of 4.6; 95% CI, 1.3–7.9; P = 0.007) and for functional capacity 49.1 compared to 34.4, respectively.
Factors associated with the failure of arthroscopic surgery treatment in patients with femoroacetabular impingement

Table 1b  Description of the demographic and clinical characteristics according to the result obtained after arthroscopic surgery in patients with femoroacetabular impingement.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Result of the treatment</th>
<th></th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Failure (n=7)</td>
<td>Success (n=172)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>%</td>
<td>SD</td>
</tr>
<tr>
<td>Preoperative assisted physical therapy</td>
<td>42.8</td>
<td>41.4</td>
<td>1.00</td>
</tr>
<tr>
<td>Postoperative assisted physical therapy</td>
<td>28.5</td>
<td>27.9</td>
<td>1.00</td>
</tr>
<tr>
<td>Posture at work</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sitting</td>
<td>42.8</td>
<td>59.4</td>
<td></td>
</tr>
<tr>
<td>Standing</td>
<td>57.1</td>
<td>36.9</td>
<td></td>
</tr>
<tr>
<td>Crouching</td>
<td>0.0</td>
<td>2.7</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>0.0</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>Previous physical activity</td>
<td>85.7</td>
<td>60.3</td>
<td>0.24</td>
</tr>
<tr>
<td>Previous competitive activity</td>
<td>14.2</td>
<td>32.4</td>
<td>0.43</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>59.43</td>
<td>67.28</td>
<td>0.07</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>1.63</td>
<td>1.67</td>
<td>0.25</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>22.35</td>
<td>23.94</td>
<td>0.21</td>
</tr>
<tr>
<td>Internal snapping hip</td>
<td>28.5</td>
<td>9.3</td>
<td>0.14</td>
</tr>
<tr>
<td>Retroversion</td>
<td>14.2</td>
<td>6.9</td>
<td>0.41</td>
</tr>
<tr>
<td>Inginal pain</td>
<td>100.0</td>
<td>98.8</td>
<td>1.00</td>
</tr>
<tr>
<td>Sitting pain</td>
<td>100.0</td>
<td>97.6</td>
<td>1.00</td>
</tr>
<tr>
<td>Pain when entering or exiting a car</td>
<td>85.7</td>
<td>93.6</td>
<td>0.39</td>
</tr>
<tr>
<td>Block</td>
<td>14.2</td>
<td>2.3</td>
<td>0.18</td>
</tr>
<tr>
<td>Locking</td>
<td>0.0</td>
<td>23.2</td>
<td>0.35</td>
</tr>
<tr>
<td>Pain with rotational movement</td>
<td>100.0</td>
<td>95.3</td>
<td>1.00</td>
</tr>
<tr>
<td>Logroll</td>
<td>100.0</td>
<td>73.2</td>
<td>0.19</td>
</tr>
<tr>
<td>Impingement test</td>
<td>100.0</td>
<td>96.5</td>
<td>1.00</td>
</tr>
<tr>
<td>Signs of apprehension</td>
<td>0.0</td>
<td>2.9</td>
<td>1.00</td>
</tr>
<tr>
<td>Associated tendinitis</td>
<td>28.5</td>
<td>6.9</td>
<td>0.09</td>
</tr>
<tr>
<td>‘‘C’’ sign</td>
<td>100.0</td>
<td>97.6</td>
<td>1.00</td>
</tr>
<tr>
<td>Cross over</td>
<td>14.2</td>
<td>12.2</td>
<td>1.00</td>
</tr>
<tr>
<td>Alpha angle (degrees)</td>
<td>54.14</td>
<td>60.23</td>
<td>0.14</td>
</tr>
<tr>
<td>Center edge (degrees)</td>
<td>38.57</td>
<td>36.57</td>
<td>0.52</td>
</tr>
<tr>
<td>Trainee surgeon</td>
<td>14.2</td>
<td>4.6</td>
<td>0.30</td>
</tr>
<tr>
<td>Neuropraxia of the pudendal nerve</td>
<td>14.2</td>
<td>6.4</td>
<td>0.39</td>
</tr>
</tbody>
</table>

* Fisher exact test.

Table 2  Comparison between the anatomical findings and the procedures conducted based on the results of arthroscopic surgery obtained among patients with femoroacetabular impingement.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Result of treatment</th>
<th>Raw OR</th>
<th>Adjusted OR</th>
<th>95% CI of the adjusted OR</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Failure (n=7)</td>
<td>Success (n=172)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>%</td>
<td></td>
<td>Inferior</td>
<td>Superior</td>
</tr>
<tr>
<td>Lesion of the acetabular cartilage</td>
<td>14.3</td>
<td>40.1</td>
<td>0.2</td>
<td>2.1</td>
<td>0.200</td>
</tr>
<tr>
<td>Chondroplasty</td>
<td>14.3</td>
<td>17.4</td>
<td>0.78</td>
<td>0.78</td>
<td>0.8</td>
</tr>
<tr>
<td>Resection of labrum</td>
<td>14.3</td>
<td>33.1</td>
<td>0.33</td>
<td>0.37</td>
<td>0.369</td>
</tr>
<tr>
<td>Reinserction of labrum</td>
<td>85.7</td>
<td>60.5</td>
<td>3.92</td>
<td>3.7</td>
<td>0.231</td>
</tr>
<tr>
<td>Osteoplasty</td>
<td>42.9</td>
<td>89.0</td>
<td>0.93</td>
<td>0.07</td>
<td>0.391</td>
</tr>
<tr>
<td>Acetabuloplasty</td>
<td>57.1</td>
<td>47.7</td>
<td>1.46</td>
<td>1.96</td>
<td>0.304</td>
</tr>
<tr>
<td>Tenotomy of the psoas</td>
<td>28.6</td>
<td>11.0</td>
<td>3.22</td>
<td>2.5</td>
<td>0.315</td>
</tr>
</tbody>
</table>

OR: odds ratio.
OR adjusted by age and gender.
* Statistical significance <0.005.
Table 3  Comparison of the preoperative score in the WOMAC scale according to the results of arthroscopic surgery obtained among patients with femoroacetabular impingement.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Result of treatment</th>
<th>Difference of means</th>
<th>95% CI of the difference in means</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Failure ($n=7$)</td>
<td>Success ($n=172$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WOMAC pain</td>
<td>Mean TE</td>
<td>Mean TE</td>
<td>4.64</td>
<td>0.007$^a$</td>
</tr>
<tr>
<td>WOMAC rigidity</td>
<td>15.4 1.6</td>
<td>10.7 0.3</td>
<td>1.31 7.97</td>
<td></td>
</tr>
<tr>
<td>WOMAC function</td>
<td>3.8 0.9</td>
<td>3.6 0.1</td>
<td>-0.16 2.03</td>
<td>0.838$^b$</td>
</tr>
<tr>
<td>WOMAC total</td>
<td>49.1 5.9</td>
<td>34.4 1.1</td>
<td>2.69 26.59</td>
<td>0.017$^d$</td>
</tr>
<tr>
<td></td>
<td>65.9 7.7</td>
<td>48.8 1.5</td>
<td>1.36 32.68</td>
<td>0.033$^d$</td>
</tr>
</tbody>
</table>

TE: typical error.

*Statistical significance <0.05, means adjusted by age and gender.

Figure 1  Algorithm showing the process of patient inclusion.

Patients undergoing hip arthroscopy: 232

Patients with exclusion criteria: 32

Patients eligible for participation in this study: 200

Patients lost during follow-up: 21

Patients included in the study: 179

Failure of the treatment: 7

Success of the treatment: 172

(difference of 14.6; 95% CI, 2.6–26.5; $P=0.017$). The mean preoperative WOMAC total score was also higher among the failure group compared to the success group, 65.9 versus 48.8, respectively (difference of 17.0; 95% CI, 1.3–32.6; $P=0.033$) (Table 3).

Discussion

The main finding of our study was the association between the scores in the preoperative WOMAC scale (in the domains of functional capacity, pain and overall score) and the failure of arthroscopic treatment in patients with FAA. Patients in whom the treatment failed had higher scores in the WOMAC scale than those in whom the treatment was successful.

To date, there are no reports in the literature of studies finding an association between high scores in the WOMAC scale and a poor subsequent arthroscopic result. Nevertheless, the study conducted in 2010 by Gedouin et al. revealed that patients with radiographic findings compatible with hip OA obtained higher scores in the WOMAC scales and worse postoperative results. As in our study, the differences in the pre- and postoperative scores between patients in whom the treatment failed or was successful were statistically significant. In 2012, Philippon et al. published a study on patients older than 50 years, in whom the modified Harris hip score (MHHS) was used before and after surgery to measure the results of the intervention. After adjusting by days of evolution of the lesion and by gender, the study reported that preoperative scores lower than 50 in the MHHS were associated to the need for total hip joint replacement.

In our study we did not find an association between the anatomical characteristics, specifically those related to the arthroscopic procedure, and the result of the treatment. Within the anatomical characteristics we included repairs and modelings to guarantee hips which were as similar as possible to a normal hip. On the other hand, a study conducted in 2012 compared 2 cohorts of patients with pincer type and mixed FAA, one undergoing resection and debridement of the labrum and the other undergoing repair, using the MHHS, a quality of life questionnaire (SF-12) and an analog visual scale (VAS) for pre- and postoperative pain, and found statistically significant differences in some of these scores: MHHS ($p=0.01$), SF-12 ($p=0.41$) and VAS ($p=0.04$) favoring the labral repair group. Follow-up of these patients lasted for 3.5 years and it is worth noting that the results were not adjusted for any confounding factors.

Prior to this work, a German study conducted in 2009 evaluated the performance of a minimally invasive approach through NAHS and described in detail the surgical procedure conducted on patients. This included 100 hips with a mean follow-up of 54 months. Like in our study, labral reinsertion was not correlated with the NAHS scores ($87 \pm 11$ versus $82 \pm 19$, $p=0.13$) at the end of the follow-up period.
Another German study, which assessed the usefulness of a minimally invasive approach, proceeded according to the findings in patients with all types of FAA. The authors measured the results through the WOMAC scale and the Oxford hip index after a mean follow-up of 15 months. The Oxford index showed an improvement from 34.3 ± 9.8 points prior to the procedure to 16.3 ± 11.0 points after it, whilst the WOMAC scale varied from 60.8 ± 23.1 points to 84 ± 15.1 points at the time of the last assessment. This study did not evaluate the specific characteristics of the arthroscopic procedure.

In 2000, a prospective study with a follow-up period of 2 years found an association between the time of onset of pain and poor results in hip arthroscopy. It is worth noting that this work evaluated patients undergoing hip arthroscopy regardless of the baseline diagnosis and that the subsequent assessment was carried out using the Harris scale, which is not the same as the one used in our work. This study also reported an association with patient age, unlike our results, which showed no significant differences between the ages of patients in whom the treatment failed or succeeded. Findings differing from ours have also been reported by other studies, where patients over 40 years of age were associated with worse postoperative outcomes, like the grade of acetabular lesion and femoral head deformity.

Other studies have found an association between established hip OA and poor postoperative results. Due to the consistency of this association evaluated in other studies, we decided to exclude these patients to avoid any confusion bias that this variable could cause. Another factor that has been associated to poor postoperative results is greater cartilage damage; however this association was not observed in our study.

It is important to highlight that the literature contains no evidence of an association between the interventions conducted in the arthroscopic procedure and failure of treatment. In our study we found no association between microfractures, chondroplasty, resection and reintroduction of the labrum, acetabuloplasty and tenotomy of the psoas and the result of treatment; however, osteoplasty showed an association with better treatment results.

The WOMAC scale is a valuable tool for the functional assessment of patients with hip pathologies; it has widespread international recognition and has been translated and validated in various countries, including Spain and Peru. This widespread recognition enables its use for preoperational approximation, despite the fact that its original development was conducted on patients with arthritic hips. The scores should be correlated with the clinical symptoms of patients and we must bear in mind that its original aim was not specific for clinical hip conditions.

The WOMAC scale comprises 3 domains of great importance in quality of life of patients and carrying out activities of daily life. This enables physicians to identify the main needs and ailments of patients requiring intervention for their daily lives. Based on the results of this study, the systematic application of this scale to patients with FAA candidates for hip arthroscopy will enable physicians to identify with greater accuracy those patients who would benefit from this procedure and offer different alternatives to subjects with high scores in the overall WOMAC scale and, specifically, in the functional capacity domain, taking into account other clinical and social characteristics to guarantee that the treatment selected fulfills the expectations.

Bearing in mind the results of our study, we suggest paying greater attention to the functional and pain characteristics of patients, since these are the domains with greater contributions to the scale. It appears that placing greater emphasis on these variables would enable better patient discrimination and detection of those with high or low probabilities of success after arthroscopic treatment.

Limitations

The main limitation of our study lied in the loss of some follow-up variables, despite complying with the estimated sample size. The follow-up losses corresponded to 10.5% of the sample and we acknowledge that they could influence the final estimation of results. However, there were no differences between included and lost patients. The varying characteristics of our population made the retrieval of all patients for subsequent evaluation more laborious, and even impossible in some cases, despite the efforts to this effect. The lack of agreement in the literature regarding the definition of treatment failure, associated to an absence of scales validated in our medium which enabled a better assessment of the surgical outcome of patients, hindered the evaluation of results and patient prognoses. Further efforts should be aimed toward subsequent development.

The low frequency of the outcome led to difficulties for the statistical methods employed in the comparisons. Nevertheless, this could be explained by the experience of the treating surgeon, who has improved his technique over the years, thus leading to highly satisfactory results in the majority of patients. A proof of this is the low frequency of neuropaxia of the pudendal nerve (6.7%), one of the most common complications in this procedure. On the other hand, despite the low frequency, the outcome evaluated was objective and defined treatment failure with no risk of varying interpretations by patients and examiners.

Further studies are required in order to identify the associations with other variables which were not considered in this work, so as to establish eligibility criteria for arthroscopic treatment among patients with FAA.

Conclusions

A poor functional condition prior to arthroscopic treatment of FAA, mainly as regards preoperative pain assessed by the WOMAC scale, was associated to a higher rate of therapeutic failure.

Level of evidence

Level of evidence III.

Ethical responsibilities

Protection of people and animals. The authors declare that this investigation adhered to the ethical guidelines of the Committee on Responsible Human Experimentation, as well
as the World Medical Association and the Declaration of Helsinki.

Confidentiality of data. The authors declare that they have followed the protocols of their workplace on the publication of patient data.

Right to privacy and informed consent. The authors declare having obtained written informed consent from patients and/or subjects referred to in the work. This document is held by the corresponding author.

Conflict of interest

The authors have no conflict of interests to declare.

References

Factors associated with the failure of arthroscopic surgery treatment in patients with femoroacetabular impingement

The Function of the Hip Capsular Ligaments:
A Quantitative Report

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Douglas P. Beall, M.D., and Bryan Kelly, M.D.

Purpose: Our purpose was to analyze the anatomy and quantitative contributions of the hip capsular ligaments. Methods: The stabilizing roles of the medial and lateral arms of the iliofemoral ligament, pubofemoral ligament, and ischiofemoral ligament were examined in 12 matched pairs of fresh-frozen cadaveric hips (6 male and 6 female hips). The motion at the hip joint was measured in internal and external rotation through ranges of motion from 30° flexion to 10° extension along a neutral swing path. The motion was standardized by use of frame stabilization and motion tracking. Results: There is a clear and consistent ligamentous pattern within the hip corresponding to a distinct function and contribution to internal and external rotation. On releasing the ischiofemoral ligament, the greatest gain in range of motion was that of internal rotation. The largest increase of motion by releasing the pubofemoral ligament was observed in external rotation, especially during extension. The release of the medial and lateral arms of the iliofemoral ligament each gave the greatest increase of motion in external rotation, with the lateral arm release providing more range of motion in flexion and in a neutral position. The lateral arm release also showed a significant motion increase in internal rotation, primarily in extension. Conclusions: The ischiofemoral ligament controls internal rotation in flexion and extension. The lateral arm of the iliofemoral ligament has dual control of external rotation in flexion and both internal and external rotation in extension. The pubofemoral ligament controls external rotation in extension with contributions from the medial and lateral arms of the iliofemoral ligament. Together, these findings can have significant clinical applications. Clinical Relevance: When abnormal muscular and osseous pathology can be eliminated as a cause of instability or restrictive range of motion, the understanding of the independent functions of the hip ligaments will aid in defining accurate assessment and nonsurgical and arthroscopic treatment techniques. Key Words: Hip—Ligaments—Flexion—Extension—Internal rotation—External rotation.

The hip is a unique joint that possesses both mobility and stability because of its anatomic configuration. A portion of the hip’s stability may be attributed to the strong, dense articular capsule of the hip. The capsule has a cylindrical sleeve-like shape and proximally inserts both anteriorly and posteriorly along the periphery of the acetabulum outside the labrum. Distally, the capsule attaches to the femur anteriorly along the intertrochanteric line, but posteriorly, it has an arched free border that only partially covers the femoral neck. Most of the fiber are longitudinally oriented, except for the circular fiber of the zona orbicularis located posteriorly and inferiorly. Together, these osseous and ligamentous structures and the musculotendinous components help to characterize and constrain the dynamic movements of the hip. It is known that peak contact forces are 2 to 3 times the body weight in level walking, well over 7 times during stair climbing, and over 8 times during stumbling. The hip is, therefore, not only important in the transfer of weight and energy between the
appendicular and axial skeleton but is crucial in the execution of lower-limb motion such as walking, running, jumping, and kicking.\textsuperscript{1,7} Despite its importance in everyday maneuvers, the hip is less understood than other large joints such as the shoulder and the knee. The hip joint’s stability and range of motion may be compromised in many ways. Traumatic dislocation of the hip joint is uncommon because of the strength and stability of the joint, but the hip may be dislocated posteriorly when the hip is flexed adducted, and medially rotated during a traumatic event such as a motor vehicle accident. Anterior dislocations may result from a violent injury that forces the hip into extension, abduction, and lateral rotation.\textsuperscript{8} Children are most susceptible to dislocation because of their shallow acetabulum.\textsuperscript{4,9} Congenital dislocation of the hip is much more common.\textsuperscript{8,10} In children 10% to 24% of athletic injuries are hip-related, and 5% to 6% of adult sports injuries originate in the hip and pelvis.\textsuperscript{7,11} External rotation of the hip during golf or martial arts tends to push the femoral head anteriorly, and over time, this may lead to focal anterior capsular laxity and stretching of the iliofemoral ligament. Subsequent joint instability and labral tears in the anterosuperior region of the acetabulum may follow. A labral tear leads to reduction in the joint seal that helps to hold the femoral head in place using negative pressure, and increased translation of the femoral head may result. The increase in hip joint flexibility required by athletes involved in such sports as ballet, ice skating, and gymnastics may lead to generalized ligamentous laxity and result in symptoms of hip instability. Direct blows to the greater trochanter in sports such as football or hockey may lead to many injuries including isolated labral tears and chondral injuries. In addition to trauma, these athletes can have overuse-type hip injuries.\textsuperscript{4} An understanding of the structure and function of the hip capsular ligaments can be of potential value when engaged in the process of diagnosis and treatment of patients presenting with hip pain.

Given the difficult in definin the exact structure and function of the hip ligaments, controversy and discrepancy surround the current structural descriptions and functional theories. In perhaps the most complete and in-depth study of the hip, Fuss and Bacher\textsuperscript{12} anatomically describe the hip ligaments differently than every other source. They describe the iliofemoral ligament as consisting of 3 bands, whereas all others depict 2. They portray the ischiofemoral ligament as also consisting of 3 bands, 1 of which attaches to the lesser trochanter, whereas no other sources describe this structural anatomy. Similar discrepancies are found in the number of bands contributing to both the pubofemoral ligament and the ligamentum teres. Finally, some investigators illustrate the orbicularis ligament as encircling the entire femoral neck, whereas others report only a posterior contribution.\textsuperscript{1-4,8,12-19} There are at least as many incongruities concerning the function of these ligaments. Fuss and Bacher divide the function of their 3 iliofemoral bands into 5 categories, none of which coincides with the “restricting-adduction” described by Crowninshield et al.\textsuperscript{20} Furthermore, Fuss and Bacher divide the function of their 3 ischiofemoral bands into 4 categories, different from any other author.\textsuperscript{1-5,8,12,15,17-22} The contribution of the ligamentum teres is said to be “minimal” or to have “no role whatsoever” by most,\textsuperscript{4,8,10,12,14} but others believe it “contributes significantly to the stabilization of the hip.”\textsuperscript{13} These many inconsistencies only add to the uncertainty in treating hip-related pathologies.

The lack of a clear and specific description of the function and anatomy of the hip capsular ligaments warranted the development of this investigational study. The purpose, therefore, is to provide a surgically and clinically useful description of the origin and insertion of each primary hip ligament for the direct analysis of the percent contribution of each ligament in the control of internal and external rotation. It is hypothesized that the medial and lateral arms of the iliofemoral ligament, the pubofemoral ligament, and the ischiofemoral ligament both have a specialized restrictive function to internal and external rotation that is unique to the specific range of motion within a neutral swing path.

**METHODS**

Twelve fresh-frozen human cadaveric hips (mean age, 62 years) were dissected, leaving the ligamentous structure of the pelvis and hips intact. Two were excluded from the study because of severe arthritis and artificial hardware. All musculature was removed to expose the underlying hip capsular ligaments. The ligaments that were found included the iliofemoral ligament, pubofemoral ligament, ischiofemoral ligament, ligamentum orbicularis, and ligamentum teres femoris. All were cleaned and left in situ so that careful examination of their exact origin, insertion, and course could be defined and documented. Once the skeletonization was completed, radiographic and manual examinations of the hip, pelvis, and spine were conducted to ensure no occult pathologic state existed. If any specimen showed signs of arthrosis or osseous
pathology, as well as decreased mobility, signs of surgical interventions, or clearly detectable crepitation or deformities, then it was excluded from the study. All specimens were also radiographically checked for femoral and acetabular anteversion and cam and pincer lesions, the center edge and neck-shaft angles were measured, and McKibbin’s index was calculated. The hips with an abnormal McKibbin’s index of greater than 60 or less than 20 were eliminated from this study to establish a foundation for the individual ligamentous restraint under normal osseous geometric conditions.

Each specimen was then placed in a lateral position, and 2 rods were positioned perpendicularly and drilled through the T12 or L1 vertebra and set with Ilizarov osseous fixation (Fig 1). The pelvis was also stabilized by fixing the iliac wing to a dissection stand and table mount (Fig 1). The femur was reamed and cut at midshaft. Intramedullary rod fixation of the distal femur was performed and held in place by screwing a set screw perpendicularly into the femur (Fig 1). The femoral rod was inserted through a vertical plane grid that was used to assess the hip joint’s range of motion. Measurement marks representing specific angles of 10° in extension, 0° neutral, and 15° and 30° in flexion were placed on the vertical plane grid. This range of motion correlates to that of the average walking step. For each femoral location along the swing path, the degrees of external and internal passive rotation were measured with a goniometer. A total of 3 independent measurements were made at each location. Any measurement greater than 1 SD away from the mean was disregarded from the study, and thus an additional measurement would be recorded in its place. Internal and external rotation measurements were taken with completely intact ligaments to serve as our baseline measurements. After these range-of-motion values were attained, sequential ligamentous cutting was performed. The hips were guided through the slotted grid for each ligamentous group, and external and internal rotation angles were measured. The hip capsular ligaments were removed in the following order: (1) medial arm of the iliofemoral ligament, (2) lateral arm of the iliofemoral ligament, (3) pubofemoral ligament, and (4) ischiofemoral ligament. The medial arm of the iliofemoral ligament was cut at the base proximal to its insertion along the distal intertrochanteric line with care taken not to disturb any portion of the other ligaments (Fig 1).

The lateral arm was cut at the 12-o’clock position, proximal to its insertion at the anterior greater trochanteric ridge. The pubofoemoral and ischiofemoral ligaments were cut in a similar manner so as to include the entire ligaments but nothing more. The ischiofemoral ligament was cut posterior to 12 o’clock, proximal to its insertion. Finally, a 2-cm labrum resection was made at the 1-o’clock position in a longitudinal fashion between the medial arm of the iliofemoral and pubofoemoral ligaments, where most acetabular labral tears occur.

After all of the external ligaments of the hip capsule were resected, a clear examination of the ligamentum teres was performed. As with the other ligaments, the anatomic appearance was carefully recorded. After all measurements were made, data analysis with analysis of variance was performed on each specimen along with an independent variable analysis.

**RESULTS**

Our first goal with this study was to anatomically describe the gross structure of the hip capsular ligaments. The medial arm of the iliofemoral ligament was observed to originate between the anterior-inferior iliac spine (AIIS) and the iliac portion of the acetabular rim and transverse nearly vertically downward. Its insertion was consistently noted to be on a bump, or knob, located on the distal intertrochanteric line. The name of this structure was not found in our research. The lateral arm originates superior to the medial arm, closer to the AIIS, and traverses more horizontally along the neck of the femur, covering the orbicular ligamentous fiber running perpendicular to the lateral arm at its distal portion. The lateral arm of...
the iliofemoral ligament inserts on the anterior greater trochanteric crest (Fig 2A).

The pubofemoral ligament was noted to resemble a sling, running inferior to the medial arm of the iliofemoral ligament, medial and inferior to the iliopectineal eminence, originating at the pubic portion of the acetabular rim and the obturator crest of the pubic bone and attaching distally to the femoral neck. Fibers from the pubofemoral ligament blend with the medial arm of the iliofemoral ligament. The sling of the pubofemoral ligament was also noted to wrap inferiorly around the neck of the femur and insert inferior to the ischiofemoral ligament along the posterior intertrochanteric crest. The ischiofemoral ligament originates at the ischial portion of the acetabular rim and crosses the hip capsule in 2 horizontal bands. The superior band spirals superolaterally, arching across the femoral neck to blend with the zona orbicularis fibers and inserts medial to the anterosuperior base of the greater trochanter. The inferior band inserts more posteriorly, medial to the base of the greater trochanter along the posterior intertrochanteric crest (Fig 2B).

When the hip was in internal rotation (Tables 1 and 2, Fig 3) and the medial arm of the iliofemoral ligament was severed, no notable change was observed. However, when the lateral arm of the iliofemoral was cut, an increase of 5° was seen in all positions except 30° flexion. Similar to the medial arm, when the pubofemoral ligament was resected, no significant change was noted. When the ischiofemoral ligament was cut, the amount of internal rotation allowed doubled throughout the entire swing path of the femur. Therefore, the

| Table 1. Mean Internal and External Rotation After Release of Corresponding Ligament |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|
|                                | 30° Flexion     | 15° Flexion     | 0° Neutral      | 10° Extension   |
|                                | IR   | ER    | IR   | ER    | IR   | ER    | IR   | ER    |
| All intact                     | 21.60| 37.70 | 17.63| 33.17 | 14.73| 25.47 | 10.53| 15.40 |
| Med Ilio                       | 22.13| 41.93 | 17.93| 38.77 | 16.47| 32.47 | 11.57| 26.07 |
| Lat Ilio                       | 25.13| 49.17 | 23.47| 47.80 | 22.03| 43.17 | 20.57| 37.97 |
| Pubo                           | 25.90| 50.33 | 23.00| 46.20 | 21.53| 45.37 | 18.87| 45.60 |
| Ischio                         | 48.70| 52.56 | 47.56| 50.11 | 45.78| 51.63 | 45.30| 51.22 |

NOTE. Figures 3 and 4 are visual representations of Table 1. Abbreviations: IR, internal rotation; ER, external rotation; Med Ilio, medial arm of iliofemoral ligament; Lat Ilio, lateral arm of iliofemoral ligament; Pubo, pubofemoral ligament; Ischio, ischiofemoral ligament.
ischiofemoral ligament was observed to be the most significant restrictor of internal rotation. Of note, the lateral arm of the iliofemoral ligament is also a principal contributor to the hip’s stability in internal rotation. Furthermore, its contribution increases as the femur moves from flexion to extension along a neutral swing path. Thus the lateral arm limits internal rotation most in extension.

The summary of external rotation (Tables 1 and 2, Fig 4) illustrates the contributions of both the medial and lateral arms of the iliofemoral ligament. The lateral arm was observed to have a greater contribution in all locations along the neutral swing path except for extension. A minimum increase of 7° was noted with release of the lateral arm. No change was observed for the pubofemoral ligament along the entire neutral swing path concerning internal rotation. Similarly, no notable change was seen in external rotation when the pubofemoral ligament was removed, except for in extension. Without ligamentous restraints, the hip subluxated anteriorly at 48° of external rotation. In addition, with the anterior labrum transected, the stability of the hip in either internal or external rotation is severely diminished.

The ischiofemoral ligament’s contribution to the stability of the hip in internal rotation is clearly seen (Table 3, Fig 5). Also observed here is the lateral arm of the iliofemoral ligament’s restriction to internal and external rotation in extension. The greatest inhibitor to external rotation in extension appears to be the medial arm of the iliofemoral ligament. The pubofemoral ligament’s main restriction is external rotation in extension.

<table>
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<tr>
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<th>30° Flexion</th>
<th>15° Flexion</th>
<th>0° Neutral</th>
<th>10° Extension</th>
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<tr>
<td></td>
<td>IR</td>
<td>ER</td>
<td>IR</td>
<td>ER</td>
</tr>
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<td>Ischio</td>
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</table>

Abbreviations: IR, internal rotation; ER, external rotation; Med Ilio, medial arm of iliofemoral ligament; Lat Ilio, lateral arm of iliofemoral ligament; Pubo, pubofemoral ligament; Ischio, ischiofemoral ligament.

**Table 2.** Ninety-Five Percent Confidence Intervals for Mean Values Given in Table 1

**Figure 3.** Summary of internal rotation of hip ligaments through ranges of motion from 30° flexion to 10° extension along a neutral swing path. The greatest increase in internal rotation was seen after transection of the ischiofemoral ligament (far right segment of graph). The amount of internal rotation doubled after this ligament was destabilized. The lateral arm of the iliofemoral ligament was also noted to contribute to the stability of the hip in internal rotation (with this contribution increasing as the hip moves from flexion to extension).

**Figure 4.** Summary of external rotation of hip ligaments through ranges of motion from 30° flexion to 10° extension along a neutral swing path. It should be noted that the slope of the line increases (representing more external rotation) as each ligament is subtracted. The graph illustrates the contribution of the iliofemoral ligament and is the main restrictor of external rotation in flexion. The lateral arm has a greater contribution than the medial arm in all locations except for in extension. The pubofemoral ligament also has an important contribution in extension and is the main restrictor in extension.
tension. It should be noted that as the femur moves from flexion to extension, the potential range of motion to be gained increases greatly, suggesting that the hip rests in a looser state when in flexion.

The contribution of each ligament’s removal toward the total range of motion was also determined (Table 4, Fig 6). The greatest contribution to internal rotation in all degrees of flexion and extension was the ischiofemoral ligament, accounting for more than 60% contribution. An additional 12% to 30% contribution to internal rotation was determined to be the lateral arm of the iliofemoral ligament. For external rotation in all degrees of flexion and extension, both the lateral and medial arms of the iliofemoral ligament accounted for over 50% contribution. The pubofemoral ligament provided very little contribution (<5%) to internal rotation. However, the percent contribution of the pubofemoral ligament to external rotation increased to 10% to 20% from 30° flexion to neutral and provided its greatest contribution, of 34%, to external rotation in extension.

**DISCUSSION**

To develop a surgically and clinically useful description of the hip capsular ligaments, the origin and insertion of 4 major ligaments were defined in 10 human cadaveric hips. The iliofemoral ligament was found to consist of 2 bands, the medial arm and the lateral arm. The medial arm originates between the AIIS and the iliac portion of the acetabular rim, and the lateral arm originates superior to the medial arm, closer to the AIIS. Insertion of the medial arm was determined to be on a bump, or knob, structure located on the distal intertrochanteric line. Insertion of the lateral arm was determined to be on the anterior greater trochanteric crest. The pubofemoral ligament origin was determined to be at the pubic portion of the acetabular rim and the obturator crest of the pubic bone. The pubofemoral ligament resembled a sling that wrapped inferiorly around the femoral neck and blended with the medial arm of the iliofemoral ligament. Insertion of the pubofemoral ligament was along the posterior intertrochanteric crest, inferior to the ischiofemoral ligament. The ischiofemoral ligament originated at the ischial portion of the acetabular rim and was noted to contain 2 horizontal bands, the superior band and the inferior band. The superior band

**TABLE 3.** Percent Change in Internal and External Rotation After Ligament Release

<table>
<thead>
<tr>
<th></th>
<th>30° Flexion</th>
<th>15° Flexion</th>
<th>0° Neutral</th>
<th>10° Extension</th>
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<tr>
<td></td>
<td>IR</td>
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<td>ER</td>
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<td>Pubo</td>
<td>93.14</td>
<td>5.82</td>
<td>107.39</td>
<td>7.66</td>
</tr>
<tr>
<td>Ischio</td>
<td>19.21</td>
<td>15.53</td>
<td>16.99</td>
<td>20.05</td>
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NOTE. The amount of change observed after each ligament removal was of special interest in analyzing the data. Figure 5 provides the visual complement of Table 3. (It should be noted that each percent change was calculated in reference to the previous range of motion. For example, an increase from 10° to 18° represents an 80% change.)

Abbreviations: IR, internal rotation; ER, external rotation; Med Ilio, medial arm of iliofemoral ligament; Lat Ilio, lateral arm of iliofemoral ligament; Pubo, pubofemoral ligament; Ischio, ischiofemoral ligament.

**Figure 5.** Summary of amount of change observed after each ligament removal. The contribution to hip stability by the ischiofemoral ligament (Ischio) in internal rotation (IR) should be noted. Both the lateral arm (Lat Ilio) and medial arm (Med Ilio) of the iliofemoral ligament provide restriction to IR in extension. The Lat Ilio also provides a major contribution to external rotation (ER). The primary restrictor of ER in extension is the Med Ilio. The pubofemoral ligament (Pubo) has the overall least amount of change; however, its greatest contribution is to restrict ER in extension. This graph also illustrates a greater degree of laxity when the hip is in flexion because the percent change of all of the ligaments is less in flexion.
arched across the femoral neck, blending with the fiber of the zona orbicularis, and inserted medial to the anterosuperior base of the greater trochanter. Insertion of the inferior band was more posterior, medial to the base of the greater trochanter along the posterior intertrochanteric crest.

The ischiofemoral ligament was noted to be the most significant restrictor of internal rotation. This accurately correlates with the qualitative description given by many other investigators.\(^1,2,8,12,15,18,19\) Concerning external rotation, our finding also agree with past qualitative descriptions concerning the contributions of both the medial and lateral arms of the iliofemoral ligament.\(^2,12,18,22\) It was also observed that the hip naturally internally rotates 20° in extension. The removal of these 4 major ligaments of the hip revealed that the greatest gains in internal and external range of motion occur in extension. This affirm that the hip rests in a looser state when in flexion and is, therefore, at a greater risk for injury when in this position.\(^2\)

The quantitative contributions of the hip capsular ligaments have yet to be analyzed. This study quantitatively describes the stabilizing roles of the medial and lateral arms of the iliofemoral ligament, pubofemoral ligament, and ischiofemoral ligament in internal and external rotation of the hip through range of motion from 30° flexion to 10° extension, which is the range of motion involved in normal activities. Because a quantitative report on the hip capsular ligaments has yet to be presented, our approach was based on recent work performed in the shoulder.\(^25\)

The clinical applications regarding the loss of rotation, both internal and external, are found with many pathologic conditions existing in the hip. The separation of osseous, musculotendinous, and ligamentous causes is important to prescribing proper diagnosis and treatment strategies. Understanding of the ligamentous contribution in minimally invasive techniques may assist in more favorable outcomes. A clear dialectic of both function and anatomy will produce the opportunity for advancing understanding of the capsular plication, thermal capsulorrhaphy, capsulotomy, or therapy to re-establish more normal ranges of motion for improved kinematic motion. Leaving the lateral arm loosely closed during both arthroscopic and open surgery for femoral acetabular impingement aids in establishing a more normal range of motion when loss of internal rotation is found.

### Table 4. Percent Contribution of Each Ligament to Internal and External Rotation

<table>
<thead>
<tr>
<th></th>
<th>30° Flexion</th>
<th></th>
<th>15° Flexion</th>
<th></th>
<th>0° Neutral</th>
<th></th>
<th>10° Extension</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IR</td>
<td>ER</td>
<td>IR</td>
<td>ER</td>
<td>IR</td>
<td>ER</td>
<td>IR</td>
<td>ER</td>
</tr>
<tr>
<td>All intact</td>
<td>7.52</td>
<td>27.58</td>
<td>7.09</td>
<td>33.96</td>
<td>12.29</td>
<td>28.49</td>
<td>7.10</td>
<td>28.96</td>
</tr>
<tr>
<td>Med Ilio</td>
<td>17.90</td>
<td>44.32</td>
<td>17.19</td>
<td>36.09</td>
<td>22.09</td>
<td>34.36</td>
<td>33.26</td>
<td>27.03</td>
</tr>
<tr>
<td>Lat Ilio</td>
<td>12.08</td>
<td>15.90</td>
<td>11.20</td>
<td>20.62</td>
<td>2.17</td>
<td>21.59</td>
<td>0.60</td>
<td>35.22</td>
</tr>
<tr>
<td>Pubo</td>
<td>69.45</td>
<td>13.55</td>
<td>71.69</td>
<td>10.37</td>
<td>70.50</td>
<td>17.29</td>
<td>65.60</td>
<td>9.77</td>
</tr>
<tr>
<td>Ischio</td>
<td>7.52</td>
<td>27.58</td>
<td>7.09</td>
<td>33.96</td>
<td>12.29</td>
<td>28.49</td>
<td>7.10</td>
<td>28.96</td>
</tr>
</tbody>
</table>

**NOTE.** The percent contribution of each ligament, with the visual complement in Fig 6, is shown. We believed that these data also needed to be analyzed to counter any misleading data given by the percent change. For example, an increase from 2° to 6° was represented by a 200% change in the previous method; however, concerning the total contribution to the range of motion, this 4° is of minor weight.

**Abbreviations:** IR, internal rotation; ER, external rotation; Med Ilio, medial arm of iliofemoral ligament; Lat Ilio, lateral arm of iliofemoral ligament; Pubo, pubofemoral ligament; Ischio, ischiofemoral ligament.

![Summary of %Contribution](image1)

**Figure 6.** Summary of contribution of each ligament’s removal toward total range of motion. The graph illustrates that the ischiofemoral ligament (Ischio) shows the greatest contribution to restriction of internal rotation (IR), with the lateral arm of the iliofemoral ligament (Lat Ilio) being the second most important contributor. The iliofemoral ligament, both the medial arm (Med Ilio) and the Lat Ilio together, provides more than half of the contribution to external rotation (ER) in all degrees of flexion and extension. The contribution by the pubofemoral ligament (Pubo) to IR is very small; however, its greatest contribution is to ER, particularly in extension.
The limitations of this study include analysis of 4° of freedom and the ligament cutting order. Future studies should assess the bony geometry in relation to the ligamentous contribution to comprehensively appreciate the synergy existing between both the acetabulum and proximal femur in 6° of freedom. Random removal of the ligaments would distinctly verify that our results were independent of cutting sequence; however, we intentionally removed the ligaments in a distinct order to give a greater power analysis. Lastly, on the basis of our observation with all ligaments cut, a define function of the teres was noted. Therefore future studies should include the function of the ligamentum teres with a random cutting order and 6° of freedom.

CONCLUSIONS

The ischiofemoral ligament controls internal rotation in flexion and extension. The lateral arm of the iliofemoral ligament has dual control of external rotation in flexion and both internal and external rotation in extension. The pubofemoral ligament controls extension in flexion and both internal and external rotation. Together, these findings can have significant clinical applications.

REFERENCES

Function of the Ligamentum Teres in Limiting Hip Rotation: A Cadaveric Study


Purpose: The purpose of this cadaveric study was to evaluate the function of the ligamentum teres (LT) in limiting hip rotation in 18 distinct hip positions while preserving the capsular ligaments. Methods: Twelve hips in 6 fresh-frozen pelvis-to-toes cadaveric specimens were skeletonized from the lumbar spine to the distal femur, preserving only the hip ligaments. Hip joints were arthroscopically accessed through a portal located between the pubofemoral and iliofemoral ligaments to confirm the integrity of the LT. Three independent measurements of hip internal and external rotation range of motion (ROM) were performed in 18 defined hip positions of combined extension-flexion and abduction-adduction. The LT was then arthroscopically sectioned and rotation ROM reassessed in the same positions. A paired sample t test was used to compare the average internal and external hip rotation ROM values in the intact LT versus resected conditions in each of the 18 positions. P < .0014 was considered significant. Results: A statistically significant influence of the LT on internal or external rotation was found in 8 of the 18 hip positions tested (P < .0014). The major increases in internal and external rotation ROM occurred when the hip was in 90° or 120° of flexion. Conclusions: The major function of the LT is controlling hip rotation. The LT functions as an end-range stabilizer to hip rotation dominantly at 90° or greater of hip flexion, confirming its contribution to hip stability. Clinical Relevance: Ruptures of the LT contribute to hip instability dominantly in flexed hip positions.

The morphologic characteristics and anatomic location of the ligamentum teres (LT) in the hip joint suggests that it has a contribution to hip stability. However, the function of the LT in hip stabilization has been debated since the 19th century and is still controversial. There is a lack of information regarding the function of this ligament in limiting hip motion in different hip positions. This fact is relevant because hip instability is increasingly being considered an element in abnormal joint kinematics, labral tears, and hip pain.

Previous studies tested the LT function with the hip capsular ligaments removed, although these ligaments have a fundamental role in hip stabilization. A string model study reproducing the LT excursion in various hip positions found this ligament to have the greatest excursion when the hip was externally rotated in flexion and internally rotated in extension. A cadaveric study reported that the LT stabilizes the femoral head inferiorly as the hip joint is moved into a combined position of flexion and abduction. Another study tested the influence of the LT in limiting flexion-extension and abduction-adduction while preserving the hip capsular ligaments and reported that the LT had a modest effect in limiting hip adduction. The study did not test the influence of the LT in hip rotation. However, the morphologic features of the origin and insertion of the LT indicates that this ligament becomes tight with hip rotation.

An association between LT tears and labral tears has been described and may be related to the increased strain within the labrum caused by increased rotation range of motion (ROM). Ruptures of the LT have also been related to femoroacetabular impingement and hip

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The authors report the following potential conflict of interest or source of funding in relation to this article: H.M. receives support from Pivot Medical and Smith & Nephew. Smith & Nephew supplied the cadaveric specimens and laboratory resources for this study.

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© 2014 by the Arthroscopy Association of North America
http://dx.doi.org/10.1016/j.arthro.2014.04.087

instability.\textsuperscript{15,17} There is a lack of studies testing the function of the LT in limiting hip rotation with preservation of the capsule function. The purpose of this cadaveric study was to evaluate the function of the LT in limiting hip rotation in 18 distinct hip positions with the influence of the capsular ligaments. The hypothesis of this study was that transection of the LT would increase internal and external rotation ROM in 18 hip positions.

**Methods**

**Specimens**

Twelve hips in 6 fresh-frozen pelvis-to-toes cadaveric specimens were skeletonized from the lumbar spine to the distal femur, preserving the hip ligaments. The specimens were thawed to room temperature before the experiments. Eight hips were from male donors and 4 hips were from female donors. The average age of donors was 72.3 years (range, 56 to 87 years) at the time of death. Each specimen was positioned with the pubic symphysis on the same horizontal plane as both anterior superior iliac spines, securing the pelvis with holding pins (Fig 1). Fluoroscopic and physical examinations of the hip, pelvis, and spine were performed to ensure no occult pathologic state existed. Exclusion criteria comprised deformities that restricted motion—such as signs of arthrosis, gross cam deformity, coxa profunda or protrusio, osseous pathologic processes, or surgical intervention—as well as an abnormal McKibbin’s index greater than 60 or less than 20.\textsuperscript{18} All hips were submitted to 3 cycles of mobilization to maximal extension, flexion, abduction, and adduction. A 4.5-mm cannula and an arthroscopic probe were inserted lateral to the pubofemoral ligaments and medial to the iliofemoral ligaments, adjacent or through the communication between the psoas bursa and hip joint (Fig 2). A 70° arthroscope was used without irrigation for the arthroscopic examination of each specimen, which was completed under manual distraction of the hip, assessing dynamically the integrity of the LT and cartilage of the acetabulum and femoral head (Video 1, available at www.arthroscopyjournal.org). The LT was intact in all specimens.

**Measurement and Hip Positions**

A frame was constructed to hold the lower extremity in each measurement position while allowing unobstructed hip rotation (Fig 3). After the arthroscopic examination, 3 independent measures of internal ROM and 3 of external ROM were made in 18 different hip positions using a standard goniometer technique,\textsuperscript{19} with a limb of the goniometer positioned vertically and the other aligned with the tibial tuberosity and anterior border of the tibia (Fig 4). The hip positions consisted of a combination of abduction-adduction (25° abduction, 0° abduction-adduction, and 10° adduction)
and extension-flexion (10° extension, 0° flexion-extension, and 30°, 60°, 90°, and 120° of flexion). Each of the 18 measurement positions was confirmed with standard and bubble goniometers. The order of positioning in the sagittal plane was alternated so that 6 hips were initially positioned at 10° extension and ended in 120° flexion, whereas the other 6 hips were initially at 120° flexion and ended in 10° extension. Positioning in the frontal plane was done in a consistent order: 25° abduction to 10° adduction.

After these measures were completed, the joint was again arthroscopically inspected for abnormalities, confirming the integrity of the LT. Arthroscopic scissors were inserted adjacent to the arthroscope through the same portal and the LT was then cut (Video 1, available at www.arthroscopyjournal.org). The measurements were repeated in the 18 hip positions as previously described. A total of 216 measurements were performed in each hip: 108 before cutting the LT and 108 after cutting the LT. Next, the internal and external hip rotation ROM with the LT intact was compared with the internal and external rotation after the resection of this ligament for each of the 18 hip positions. All hip rotation maneuvers were performed by a single examiner and all measurements were performed by another single examiner. The hip capsule was intermittently irrigated with saline throughout the experiment in all specimens. After ROM testing, the hip joint was opened to confirm the section of the LT and assess the labrum. No labral tear was identified on the superior/extra-articular surface of the labrum, with normal relations between the labrum and femoral head. Smaller than 1-cm intrasubstance degenerative tears were found in the inner/articular surface of the labrum in most hips. Finally, the femoral and acetabular version of each specimen was measured.

Reliability Analysis
Reliability of the internal and external rotation measurements was assessed in 2 ways. First, after all the measurements were taken in the first specimen, the 2 hips were repositioned in neutral flexion-extension. Measurements of internal and external rotation were repeated in adduction, neutral abduction-adduction, and abduction using the technique previously described. The reliability assessing our precision with repositioning and repeated measurement was good, with an intraclass correlation coefficient (ICC [2,1]) of 0.89 and standard error of measure of 2°. The minimal detectable difference (MDD) of the measurement technique was quantified by multiplying the standard error of measure by \( \sqrt{2} \) and constructing a 95% confidence interval.20 The MDD\(_{95} \) was found to be ±6°. Second, an ICC (2,1) was calculated using the first and third measurements of internal and external rotation in each of the 18 positions in the 12 specimens.
Excellent test-retest reliability was identified with an ICC value of 0.99.

**Statistical Analysis**

The averages of the 3 measures of internal and external rotation in each of the 18 positions were used for analysis. Thirty-six paired t tests were performed comparing ROM with the LT intact and nonintact conditions. Alpha was set at 0.05 and adjusted with the Bonferroni correction to 0.0014 to prevent type I error associated with the 36 comparisons.

**Results**

The average internal and external ROM values in the 18 positions for the intact and nonintact LTs are presented in Figs 5 and 6, respectively. An increase in internal or external rotation ROM was observed in all hip positions after the LT was resected, with a greater than 6° increase detected in 11 of the 18 positions. The LT significantly influenced internal or external rotation ROM, or both, in 8 of the 18 hip positions tested ($P < .0014$). Of the 8 positions, 6 encompassed $90^\circ$ or $120^\circ$ of hip flexion. Internal rotation was limited in 5 positions, external rotation was limited in 5 positions, and both were limited in 2 positions (Table 1).

Regarding the version of the acetabulum and femoral neck measured after tests were completed, the mean version of the femoral neck was $11.7^\circ$ (95% confidence interval, 8.81° to 14.68°) and the mean acetabular version was $14.5^\circ$ (95% confidence interval, 11.66° to 17.33°).

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**Fig 5.** Comparison of internal rotation with the ligamentum teres (LT) intact (dark columns) and after cutting the LT (light columns) in 18 hip positions. (Abd, abduction; Add, adduction; Ext, extension; Flex, flexion; *, significant $P < .0014$.)

**Fig 6.** Comparison of external rotation with the ligamentum teres (LT) intact (dark columns) and after cutting the LT (light columns) in 18 hip positions. (Abd, abduction; Add, adduction; Ext, extension; Flex, flexion; *, significant $P < .0014$.)
Furthermore, the effects of the LT in limiting rotation were more evident when the hip was flexed at 90° and 120° (Table 1).

A previous cadaveric study also reported a stabilization function of the LT when the hip was placed in more than 90° of flexion, more specifically in a squat position.8 Testing 8 hip specimens, that study reported that the LT prevented femoral head anteroinferior subluxation when hips were, on average, in 100° of flexion and 20° of abduction. A string model study has also shown the LT to have the greatest excursion when the hip was externally rotated in flexion.8 These findings may be particularly important in individuals engaged in activities requiring high degrees of flexion and external rotation, e.g., dance, ballet, wrestling, martial arts, baseball, and playing goal in hockey. The LT may be even more important in individuals with capsular laxity and osseous risk factors for instability,8,22 particularly when a hypoplastic anteroinferior acetabular wall predisposes to hip instability.8 The LT function should also be considered in the pathogenesis of femoroacetabular impingement. The levering mechanism associated with the impingement in flexion may lead to inferior hip instability23 in patients without restraining bone morphologic characteristics. Considering that the LT stabilizes the hip joint in flexion, tears of

Discussion

The present study supports a stabilization function for the LT in the hip when capsular ligaments are preserved. A statistically significant influence of the LT on internal or external rotation was found in 8 of the 18 hip positions tested (P < .0014). Although the sample size may have influenced the statistical significance, an increase in internal or external rotation was observed in all hip positions after the LT was resected. There was a trend for the LT contribution in limiting rotation as the degree of hip flexion increased. This observation is logical considering that the medial and lateral arms of the iliofemoral ligament become lax in hip flexion.11 Furthermore, the effects of the LT in limiting rotation were more evident when the hip was flexed at 90° and 120° (Table 1).

Previously, testing 8 hip specimens, that study reported that the LT prevented femoral head anteroinferior subluxation when hips were, on average, in 100° of flexion and 20° of abduction. A string model study has also shown the LT to have the greatest excursion when the hip was externally rotated in flexion.8 These findings may be particularly important in individuals engaged in activities requiring high degrees of flexion and external rotation, e.g., dance, ballet, wrestling, martial arts, baseball, and playing goal in hockey. The LT may be even more important in individuals with capsular laxity and osseous risk factors for instability,8,22 particularly when a hypoplastic anteroinferior acetabular wall predisposes to hip instability.8 The LT function should also be considered in the pathogenesis of femoroacetabular impingement. The levering mechanism associated with the impingement in flexion may lead to inferior hip instability23 in patients without restraining bone morphologic characteristics. Considering that the LT stabilizes the hip joint in flexion, tears of
the LT may be caused by femoroacetabular impingement or may contribute to hip joint degeneration and instability. Concomitant tears of the labrum and LT tears have been reported\(^\text{14,15}\) and may be related to the influence of the LT in the pathogenesis of femoroacetabular impingement. The increased hip rotation in the case of LT deficiency may also explain the association with labral tears caused by increased strain in the labrum.\(^\text{16,24}\)

The present study also found the LT to limit internal rotation when the hip was in 0° of flexion and in 10° of adduction. This finding is in agreement with a previous study performed in a string model with plastic bones.\(^\text{8}\) This function of the LT may be important in activities such as golf, soccer, and kicking in American football, which embrace movements with the hip in extended and adducted positions.

Another study investigated the influence of the LT in restricting hip motion after its arthroscopic section in cadavers.\(^\text{13}\) Hip flexion-extension and adduction-abduction ROM was tested in 7 hips before and after LT resection. The authors reported no significant change on the flexion-extension ROM and a modest increase of 3.5° on abduction-adduction motion. However, the authors did not test the influence of the LT in hip rotation and used uniplanar mobilization of the hip.

In addition to limiting hip motion, other relevant functions have also been suggested for the LT. A nociception proprioception function of the LT is indicated by the presence of free nerve endings in this ligament.\(^\text{25,26}\) The LT may also restrict the lateralization of the femoral head, which would be particularly important in dysplastic hips with increased shearing forces.\(^\text{27,28}\) This function is comparable to the inferior stabilization effect of the LT, especially in hip flexion, abduction, and external rotation,\(^\text{9}\) in which the floor of the acetabulum would represent the roof.

The uncertainty regarding the LT function reflects the variable importance given by different authors. The most used technique for open surgical treatment of femoroacetabular impingement includes disruption of the LT.\(^\text{29}\) Additionally, excision of a hypertrophic LT was traditionally performed in open reduction of hip dysplasia in pediatric patients.\(^\text{30,31}\) However, other authors have considered the importance of the LT in hip function and its maintenance in children with hip dysplasia.\(^\text{27,28}\)

The major strength of the present study includes assessment of the LT function while preserving other hip ligaments, in which the influence should be considered in a practical in vivo scenario. Another strength is the inclusion of a broad spectrum of 18 hip positions from hip extension to 120° of flexion. This diversity of hip positions reproduces the variable position assumed by the hip in daily and physical activities.

**Limitations**

This biomechanical cadaveric study presents a number of limitations. First, all soft tissue superficial to the hip capsule ligaments was removed from the specimens. These structures offer stability to the hip joint and influence ROM, particularly in an in vivo scenario with dynamic muscular action. Nevertheless, if the soft tissues were preserved, significant damage to the capsular ligaments would be necessary to evaluate and section the LT. Second, the donors were 56 to 87 years at the time of death. The difference in biomechanics of younger ligaments could affect the relative interaction between the LT and the capsular ligaments. Third, the tests were performed without reproducing the weight-bearing forces, which could also influence the ROM and function of the LT. Additionally, maximal internal and external rotation of the hip was performed manually without an objective control of the applied force. However, given the results of the reliability analyses and the accuracy of the measurements in this study, varying amounts of force applied by the examiner did not seem to be problematic. Finally, an electronic tracking system could assist in positioning and measuring hip motion. Although a sophisticated measurement system might add more precision to the measurements, the MDD value of ±6° seems clinically relevant.

**Conclusions**

The major function of the LT is controlling hip rotation. The LT functions as an end-range stabilizer to hip rotation dominantly at 90° or greater of hip flexion, confirming its contribution to hip stability.

**References**


Function of the ligamentum teres during multi-planar movement of the hip joint

Benjamin R. Kivlan · F. Richard Clemente · RobRoy L. Martin · Hal D. Martin

Received: 28 March 2012 / Accepted: 28 July 2012 / Published online: 11 August 2012 © Springer-Verlag 2012

Abstract

Purpose The purpose of this study was to describe the orientation of the ligamentum teres and quantify the limb position when the ligamentum teres reached its endpoint during a simulated squat position in human cadavers.

Methods Dissection of eight (4 male; 4 female) cadavers resulted in the complete removal of all soft tissue attachment of the femur to the acetabulum, leaving only the ligamentum teres intact. The limb was then moved into combined flexion and abduction of the hip joint to simulate a deep squat position until a ligamentous endpoint of the ligamentum teres was achieved. The orientation of the ligamentum teres in relation to the femoral head was described and the position of the limb relative to the sagittal plane (flexion) and frontal plane (abduction) was quantified. The mean, standard deviation, 95 % confidence intervals, and standard error of the measurement were calculated for the observed angles.

Results Multi-planar movement of flexion and abduction moved the ligamentum teres into an anterior/inferior position relative to the femoral head and prevented the femoral head from anterior/inferior subluxation. The ligamentum teres endpoint was obtained at a combined average position of 100.6° (range 94°–112°; SD 5.5°; 95 % CI 96°–105°) and 20.0° (range 12°–32°; SD 7.0°; 95 % CI 14°–26°) flexion and abduction angle.

Conclusions The ligamentum teres formed a “sling-like” structure to support the femoral head inferiorly as the hip joint was moved into a combined position of flexion and abduction that resembled a squat position. The results help to define a possible role of the ligamentum teres in hip joint stability and possible mechanisms of injury.

Keywords Ligament · Instability · Hip joint · Range of motion

Introduction

Tears of the ligamentum teres are commonly found in athletes undergoing hip arthroscopy [4], particularly in patients with femoroacetabular impingement [17]. While ligamentum teres pathology is becoming more recognized, there remains continued debate regarding the mechanical function of the ligamentum teres and its role in stabilization of the hip joint [1–3, 5, 7, 8, 10, 15, 16, 18].

A recent study investigating the function of the ligamentum teres discovered that the ligamentum teres may contribute to hip joint stability during squatting movements [15]. This conclusion was based on a biomechanical model, operative findings, and patient report. The biomechanical model of the hip joint found that a position combining hip flexion and abduction that resembles the position of the limb during a squat caused the ligamentum teres to lengthen to its greatest anatomical length. Subjects with complete ligamentum teres ruptures were also noted to have laxity during dynamic arthroscopic assessment as the
hip was moved into a position of combined hip flexion and abduction. Additionally, 100 % of subjects with complete ligamentum teres ruptures and osseous risk factors for decreased hip joint stability self-reported instability when squatting [15].

Although these findings suggest the ligamentum teres may provide hip joint stability during squatting movements, cadaveric confirmation of such a role has not been thoroughly investigated. Changes in isolated sagittal and frontal plane motion of the hip joint on human cadavers after resection of the ligamentum teres with the capsuloligamentous structures intact have been studied [7]. There were no significant differences found in total hip flexion, extension, or abduction ranges of motion (ROM) between hip joints with intact and those with a resected ligamentum teres. Although these findings indicate that the ligamentum teres may not limit single plane motion beyond that produced by capsuloligamentous structures, it remains unknown if the ligamentum teres offers stability to the hip joint when isolated in a multi-planar position of the hip joint.

The primary purpose of this study was to describe in cadaveric specimens the orientation and potential function of the ligamentum teres during simulated squatting movements which places the hip joint in a combined position of abduction and flexion. The examination was performed in the absence of all other possible soft tissue stabilizing structures of the hip joint.

Materials and methods

Eight embalmed Caucasian cadavers (4 male; 4 female) with a lifespan between 72 and 89 years were utilized for this study. Dissection of the cadavers resulted in the complete removal of all soft tissue attachment of the femur to the acetabulum, leaving only the ligamentum teres intact (Fig. 1).

Observation of ligamentum teres

While observing the ligamentum teres, the limbs were moved through combinations of flexion and abduction of the hip joint to simulate a squatting movement. This observation revealed a unique combined position of flexion and abduction that produced the greatest visible tension on the ligamentum teres and resisted inferior subluxation of the femoral head. Any greater or lesser component of either motion failed to produce the same maximal visible tension of the ligamentum teres. At this unique multi-planar position, the visible tension on the ligamentum teres could also be palpated as resistance to motion of the femur. We operationally termed this position the ligamentous endpoint. This palpable tension (ligamentous end feel) could only be discerned at a specific position of combined flexion and abduction.

Limb position at the endpoint of ligamentum teres

A single cadaver hip was examined by two investigators. With the cadaver lying supine, the primary investigator moved the limb into flexion-abduction until the ligamentous endpoint was achieved. A second investigator measured the flexion and abduction angles of the limb at the endpoint position. To measure the flexion angle, an inclinometer calibrated to the horizontal plane was placed on the mid-sagittal plane of the distal 1/3 of the thigh. For abduction measurements, a second inclinometer calibrated to the vertical plane was placed on the lateral aspect of the distal 1/3 of the thigh. Flexion and abduction measures were taken once the hip joint was moved into the endpoint position of combined flexion and abduction.

The same two investigators repeated this initial assessment of the ligamentous endpoint position 20 times with a 30 s interval between trials. This was done to examine the variation between measurements. The remaining seven hips were then examined by the same two investigators for three trials with 30 s separating each assessment. The average of the three measures determined the endpoint position of the ligamentum teres.

Statistical analysis

Mean, standard deviation, 95 % confidence intervals, and standard error of the measurement were calculated for sagittal plane position (flexion angle) and frontal plane position (abduction angle) at the endpoint of the ligamentum teres. To determine the variability of the measurements, the 20 consecutive assessments performed on the
single cadaver were examined using a co-efficient of variance.

To ensure the eight specimens were not being altered by movement testing, data plots of the three trials used to examine endpoint position were descriptively examined for the flexion and abduction angles. In addition, the mean flexion angle measured on trial one, two, and three were compared with a repeated measures ANOVA. A second ANOVA was used to examine the mean abduction measurements. Alpha was 0.05 for all analyses. Data analysis was performed using a commercially available statistical software package (SPSS 17.0; Chicago IL, USA).

Results

Quantitative description of endpoint position

The assessment of endpoint position on the single cadaver demonstrated good consistency with a co-efficient of variance for abduction at 3.8 % and flexion angle at 6.7 %. Repeated testing of endpoint position on all eight cadavers demonstrated no significant difference between the three trials for either the flexion or abduction angles and no trend of increasing values with increased trial number was seen by examining data plots.

The endpoint position of ligamentum teres excursion during multi-planar movement was achieved at a mean combined flexion-abduction angle of 100.6°–20.0°. Mean, standard deviation, 95 % confidence intervals, and standard error of the measurement for the endpoint position of ligamentum teres excursion during multi-planar movement relative to sagittal plane (flexion) and frontal plane (abduction) position of the hip joint is reported in Table 1.

Descriptive observation of endpoint position

The ligamentous endpoint of the ligamentum teres oriented the ligamentum teres in a unique functional position. In all cadavers, the ligamentum teres was moved into an anterior/inferior position relative to the femoral head as it reached the endpoint position (Figs. 2, 3). At the end point, the ligamentum teres functioned as a sling, providing support for the head of the femur which directly opposed inferior subluxation of the femoral head. This unique functional position for the ligamentum teres was both visible and palpable by the examiner in each cadaver.

Discussion

The most important finding of the present study was that moving the hip joint into flexion-abduction placed the ligamentum teres in a position that provides anterior and inferior stabilization of the hip joint. The ligamentous endpoint determined for the ligamentum teres resembled the position of the hip joint when performing a squat. From the endpoint position the ligamentum teres formed a “sling-like” structure that supported the femoral head inferiorly and prevented anterior/inferior subluxation of the hip joint. This finding correlated with previous work that noted the ligamentum teres may be an important contributor to hip stability during squatting movements [15].

Previous investigators suggest that the ligamentum teres acts to stabilize the hip joint when the capsuloligamentous structures are on slack, in the combined position of flexion-adduction-lateral rotation [1, 10, 18]. Other investigators have suggested that the ligamentum teres limits hip adduction, but have failed to demonstrate a clinically important change in the amount of adduction available at the hip joint after resection of the ligamentum teres [7, 8]. Radiologic evidence suggests that the ligamentum teres becomes tight during lateral rotation of the hip joint [5]. The results of the current study found the ligamentum teres stabilizes the inferior aspect of the hip joint during the combined motion of flexion-abduction of the hip joint on a human model.

The results of the study may have clinical relevance in defining potential mechanisms of injury to the ligamentum teres. The ligamentum teres reached maximal tension during a combined movement of flexion and abduction. Common daily activities involving squatting [13], or athletic movements such as cutting and changing direction [11] place the hip joint in a position of combined flexion-abduction that may place repetitive strain on the ligamentum teres at its endpoint position. Clinicians should recognize that squatting type movements that place the ligamentum teres at its endpoint could weaken and eventually result in a tear to the ligament.

The findings of the current study also help to explain the association of ligamentum teres tears to other pathologies of the hip joint, specifically femoroacetabular impingement and instability. Patients with femoroacetabular impingement

Table 1

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Range</th>
<th>Standard deviation</th>
<th>95 % confidence interval</th>
<th>Standard error of the measure</th>
</tr>
</thead>
<tbody>
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<td>Sagittal plane</td>
<td>100.6</td>
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<td>5.5°</td>
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<tr>
<td>(flexion angle)</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Frontal plane</td>
<td>20.0</td>
<td>11.7°–32.3°</td>
<td>7.1°</td>
<td>5.8°–34.2°</td>
<td>2.8°</td>
</tr>
<tr>
<td>(abduction angle)</td>
<td></td>
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</tr>
</tbody>
</table>
are characterized by abnormal osseous morphology of the femur (cam type impingement) or acetabulum (pincer type impingement) [9]. During the combined movement of flexion-abduction, boney abutment of the femoral head–neck junction against the acetabular rim may cantilever the femoral head inferiorly [6]. This may place additional strain on the ligamentum teres as it forms a sling-like support to the inferior aspect of the hip joint [15]. These findings may have clinical significance as it explains a potential mechanism by which patients with a diagnosis of femoroacetabular impingement may incur ligamentum teres injury.

Further, patients with hip instability often have osseous insufficiency of the acetabulum [2, 15]. With the absence of boney support to stabilize the inferior aspect of the hip joint, patients may rely on the ligamentum teres to provide stabilization beyond its physiologic limits [15, 16]. The results of the current study raise additional questions regarding the potential mechanisms of injury to the ligamentum teres that are worthy of further investigation.

There are a number of factors that should be considered when interpreting the results of this study. First, all soft-tissue constraints to the hip joint other than the ligamentum teres were removed from the specimens. These structures offer stability to the hip joint and influence range of motion [14]. However, the capsuloligamentous structures of the hip joint have been shown to be on slack when the limb is placed in flexion [14]. Further, ligamentum teres deficient patients examined under anesthesia exhibited instability when moved through an arc of flexion and abduction of the hip joint [15]. This would suggest that the capsuloligamentous structures alone do not stabilize the hip joint when moving into a squat position. The results of the current study indicate that the ligamentum teres may offer stability to the hip joint when the capsuloligamentous structures are insufficient.

Another limitation of the study was that the endpoint position relative to the transverse plane was not quantified. An attempt was made to replicate the mechanics of a squat position and maintain the limb in neutral rotation until the endpoint position was determined. A biomechanical model of the ligamentum teres has suggested that lateral rotation increased the excursion when combined with flexion and abduction [15]. To include measurement of rotation, a 3-dimensional motion analysis system must be used. This could be a focus of future research.

The order in which the hip joint was moved during multi-planar movement testing could also have impacted the endpoint position. In reproducing a deep squat position that has been associated with hip instability in patients with ligamentum teres deficiency [15] a unique position of flexion-abduction in each specimen was found that produced a ligamentous endpoint. Theoretically, there may be other combined positions that could demonstrate tension through the ligamentum teres. Statistical analysis of the results, however, clearly indicated the combination of hip flexion and abduction consistently reproduced an endpoint position for the ligamentum teres for each specimen as demonstrated by a low standard error of the measure and co-efficient of variance.

Another consideration is that the use of embalmed cadavers may have altered tissue characteristics of the ligamentum teres and influenced the endpoint position [12]. Embalming fluid and dehydration of tissue specimens can alter plasticity of soft tissue structures, perhaps leading to lower endpoint limb position values. These factors, however, do not change the novel position of the ligamentum teres observed during movement testing in 100 % (8/8) of specimens.

Finally, there could be concern that repeated testing stretched the ligamentum teres and allowed greater excursion of the ligamentum teres before an endpoint position was achieved in later trials. The results of the
repeated measures ANOVA indicated no significant difference between trials and no trend of increasing range of motion at the endpoint position with increasing numbers of trials was observed by examining data plots. Therefore, we concluded that stretching of the ligamentum teres with repeated testing was not an influential factor on the results of our study.

Conclusions

The results of the current study suggest that the ligamentum teres has the potential to provide stabilization to the hip joint during multi-planar movement of flexion and abduction. It was discovered that the ligamentum teres formed a “sling-like” structure to support the femoral head inferiorly as the hip joint was moved into multi-planar movement that resembled a squat. The knowledge gained by this study may help in understanding the role of the ligamentum teres to hip joint stability and the possible mechanisms of injury.

Acknowledgments The authors would like to recognize Dr. David Somers for his efforts in critical review and editing of the manuscript.

Conflict of interest The authors declare that they have no conflict of interest.

References

**Hip Injuries in the Overhead Athlete**

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INTRODUCTION

The overhead athlete has been an area of interest in sports medicine, especially as it relates to shoulder and elbow pathology. However, hip pathology associated with acetabular labral tears is an area gaining interest. Advancements in hip arthroscopy have identified femoroacetabular impingement (FAI) and instability as potential contributors to labral and chondral pathology.\textsuperscript{15, 23, 24, 26, 29, 32} This review will focus on the mechanics associated with overhead sports, including baseball, football, lacrosse and tennis, and discuss how these athletes may be at risk for a labral-chondral injuries related to FAI and instability.

Overhead activities are similar in that the athlete uses torque generated from the feet, hips, and trunk to develop high velocity movements in the upper extremity. Whether the activity involves throwing a baseball, throwing a football, shooting a lacrosse ball, or hitting a tennis ball, hip rotation is a critical component of the movement pattern. Generally the overhead athlete begins by establishing forward momentum using a shuffle step or “crow-hop” to move their body in a parallel fashion toward the target. Here the athlete may “wind up” rotating the upper torso away from the target. The dominant or back leg will accept a majority of weight, as the athlete initiates a step towards the target with the non-dominate or lead leg. The stride moves both lower extremities into hip abduction and external rotation. Once the lead leg strides forward and contacts the ground it accepts weight to act as a fulcrum by which the trunk and upper body will rotate. Acceleration is further developed as the back leg pushes the body towards the target with the pelvis rotating forward in relation to the lead leg. Forward rotation of the pelvis will cause the lead hip to internally rotate and adduct. As acceleration progresses forward toward the target, momentum will continue to increase flexion, internal rotation, and adduction of the lead hip,
with extension, external rotation, and abduction of the back hip. The distribution of body weight will advance onto the lead leg as the overhead activity follows through to the end of the movement. Obviously the pattern outlined above will vary depending on the overhead sport and the specific activity within the sport. For example when throwing a baseball, a fielder will have different mechanics than a pitcher. However the movement patterns in overhead sports are similar enough, whether it is baseball, football, lacrosse, or tennis, to consider how the biomechanics could lead to labral-chondral injuries.

**Mechanisms of Labral Tears**

Mechanical impingement and instability of the femoroacetabular joint are noted causes of labral and chondral pathology.\(^4,24,26,32\) Understanding FAI and instability is important if we are to recognize how athletes participating in overhead activities maybe at risk for intraarticular pathology. While there is an increased awareness of labral tears, FAI, and instability, the prevalence of these pathologies has not been well defined. A retrospective review found 55% of patients with chronic hip pain had an arthroscopically confirmed labral tear.\(^{19}\) The prevalence of labral tears as diagnosed by magnetic resonance imaging (MRI) arthrogram have ranged between 22% and 96%, depending on the population being studied.\(^{16,21,22}\) The most common location for labral and chondral damage is at the anterior-superior margin. This area of the labrum has been shown to be particularly vulnerable as it has less elasticity and tolerance to compressive forces than other sections the labrum.\(^{31}\) Anterior-superior acetabular cartilage damage often occurs concurrently with anterior-superior labral tears.\(^3,4\) Abnormalities of the proximal hip joint are usually associated with labral-chondral pathology. A study found 95% of patients with an arthroscopically identified labral tear had clinical signs of FAI.\(^6\) Because the femoral-head neck
and acetabular deformities can vary, the prevalence FAI is difficult to define. It was noted that 78% patients with unilateral hip pain had cam-type FAI bilaterally with 42% having an associated acetabular deformity.¹

**Femoroacetabular Impingement**

The two main classifications of FAI are cam and pincer type impingement.¹¹ Although their morphology are different they often occur together.⁴ Cam impingement results from an abnormal bump, thickening, and/or loss of femoral-head neck offset. This boney deformity can be localized anteriorly, superiorly, posteriorly, inferiorly, or any combination of these locations to include a circumferential loss of the femoral head-neck offset.¹⁰ The labrum will be susceptible to injury when compressed by the cam deformity. Cam FAI is also thought to cause sheer forces which could lead to acetabular cartilage damage.² The specific location of injury will depend upon the location of the deformity and the direction the hip is moved. Cam deformities are most often found at the anterior-superior head-neck junction.¹² Biomechanically, a cam deformity at the anterior-superior femoral head-neck junction will compress the anterior-superior labrum during hip internal rotation with flexion and adduction. Head-neck deformities that are located superiorly can cause superior labral lesions with hip abduction. Posterior head-neck deformities can cause posterior-superior labral lesions with hip external rotation in extension. Also an inferior-medial cam lesion will impinge the anterior labrum during straight plane flexion. Since cam deformities may not be isolated to one specific location, a combination of movements may result in the greatest approximation of the cam deformity with the acetabulum and labrum causing labral-chondral damage across multiple regions.
While cam type impingement involves the femoral head-neck junction, pincer impingement results form an acetabular deformity. Pincer impingement can be further described as focal or global overcoverage of the femoral head by the acetabulum. Superior focal overcoverage is most common and is a result of the anterior and superior acetabular rim extending laterally over the femoral head. This deformity will cause the femoral head-neck junction to abut the anterior-superior labrum particularly when the hip is in a positioned of internal rotation, abduction, and flexion. Excessive acetabular retroversion is also a type of focal overcoverage that results in anterior overcoverage but posterior under coverage of the femoral head. Because of the anterior overcoverage, internal rotation of the hip in 30-60° of flexion will cause the head-neck junction to come into contact with anterior-superior labrum. Focal overcoverage could also result from excessive acetabular anteversion. Here posterior overcoverage will cause the head-neck junction to abut the posterior-superior labrum when the hip is externally rotated in extension. Coxa profunda and protusio are two types of acetabular deformities that cause global overcoverage. Coxa profunda is defined radiographically when the tear-dropped shaped acticular surface of the acetabulum lies medial to the ilioischial line from an anterior-posterior view. Protrusio refers to a medialization of the femoral head position within the acetabulum. Depending of the severity of the overcoverage labral damage from compression may occur in multiple locations with combinations of joint movements. Additionally, acetabular deformities can cause ‘counter-coup’ cartilage and/or labral lesions in a location opposite to the labral compression when the femoral head is levered out of the acetabulum.

In addition to cam and pincer type FAI, mechanical impingement may be caused by rotational deformities of the femur in the transverse plane. The femoral head-neck is normally rotated
15°-20° anteriorly. When the femoral head-neck is rotated less than 15°, decreased antversion is said to be present. True femoral retroversion is noted when the femoral head-neck is rotated posteriorly. When angle of antversion is decreased the anterior-superior head-neck junction will be closer to the anterior rim of the acetabulum. Therefore the anterior-superior labral may be at risk for compression from the femoral head-neck junction with movements that incorporate hip internal rotation in 30-60° of flexion. Femoral head-neck rotation greater than 15° anteriorly it is referred to as excessive femoral anteversion. When anteversion is greater than 30° the posterior head-neck junction is closer to the posterior rim of the acetabulum. Therefore the posterior-superior labrum is at risk for injury with movements that incorporate external rotation in extension. Femoral rotational deformities can also cause ‘counter-coup’ cartilage and/or labral lesions in a location opposite to the labral compression when the femoral head is levered out of the acetabulum. Also, related to femoral head neck deformities, coxa valgum or varum may also lead to abnormal loading the superior labrum and contribute to labral-chondral pathology.

**Instability**

Labral pathology can also be caused by atraumatic instability, with or without mechanical impingement. Focal rotational instability in the hip is defined as a localized laxity of select ligamentous and capsular structures. The injury pattern of the shoulder known to occur in the throwing athlete can be used to understand the issues of focal rotational instability of the hip. It is well documented, the biomechanics of throwing leads to progressive laxity of the anterior capsule in the shoulder. Similarly, excessive repetitive forceful hip rotation can contribute to focal rotational instability. The most common injury pattern is repetitive forceful hip external
rotation beyond the limit of normal motion leading to iliofemoral ligament laxity. Although less common, excessive internal rotation could potentially lead to ischiofemoral ligament laxity. Forces that may lead to instability are known to occur during overhead athletic activities that require rapid acceleration and deceleration in conjunction with rotation of the hip.\textsuperscript{25,27} In the presence of instability that results from the laxity, abnormal loading of the anterior-superior labrum can occur resulting in subsequent labral-chondral damage.\textsuperscript{25,31}

Boney deformities may also contribute to instability. A shallow acetabulum resulting from dysplasia, as noted by a center edge (CE) angle less than 23°, is the most recognized deformity that can contribute to instability. Other osseous risk factors for instability include a neck shaft angle greater than 140° and acetabular index (AI) less than 13°. Inferior acetabulum insufficiency (IAI) may also be a potential risk factor for instability. With IAI the acetabulum resembles a teardrop where the lateral limb lies in close proximity of the medial limb and appears vertical on standing anterior-posterior pelvic X-ray. (FIGURE 1) The instability with IAI is most apparent when the hip is abducted, flexed, and externally rotated. Rotation deformities of the femur and acetabulum in the transverse plane may also lead to excessive loading of capsuloligamentous structures.\textsuperscript{30} Femoral and acetabular anteversion may stress the anterior structures with activities that require hip external rotation. Likewise femoral and acetabular retroversion may stress posterior capsuloligamentous structures with activities that require hip internal rotation.

\textbf{Trauma}
A study of the hip in elite level athletes found that sports requiring axial and torsional forces through the hips may predispose them to intra-articular pathologies.\textsuperscript{18} The labrum, because of its function to distribute weight bearing forces will be susceptible to traumatic injury from the shearing forces that occur with overhead activities. This type of labral injury would be similar to that described in the mechanism for meniscal tears in the knee. However, isolated labral tears that result from trauma are not common as tears are usually associated with FAI and instability.

The labrum is critical to joint stability and if damaged from trauma and/or impingement the pathology associated with instability could be accelerated. The labrum works to enhance stability of the hip joint in two ways. First, it acts as a buttress to mechanically prevent excessive joint movement and enhance the congruency of the femoral head and acetabulum. Secondly, it establishes a seal, maintaining the negative intra-articular joint pressure.\textsuperscript{8, 34} Therefore, the capsuloligamentous structures will be placed under abnormally high stress when a tear comprises the labrum’s ability maintain joint stability. This additional stress could exacerbate the symptoms associated with instability and place greater demands on the dynamic neuromuscular stabilizers of the hip. Poor neuromuscular control of the hip and lumbopelvic regions as well as deviations from normal transverse plane orientation (anteversion or retroversion) of the acetabulum and femur may lead to progression of this process. As this process progresses the severity of the labral tear and complaints of instability could worsen. In overhead sports where the hip is subject to higher physiologic demands, neuromuscular control is a crucial component of joint stability and function. As dynamic stability of the hip is compromised, weight-bearing forces will be unevenly distributed, potentially leading to the progression of labral pathology.\textsuperscript{10} A summary of
the labral tear and rotational instability location and potential associated deformity is present in Table 1.

**DISCUSSION**

The mechanics of overhead sports, particularly throwing a baseball, throwing a football, shooting a lacrosse ball, and hitting a tennis ball, may increase the potential for labral tears associated with FAI and instability. The axial and torsional forces under loading may further predispose overhead athletes to traumatic labral pathology. The positional requirements and movement patterns for the athlete involved in overhead sports incorporate movements that could cause the boney deformities associated with FAI to abut the labrum leading to injury. Additionally, these movement patterns require excessive rotation that could lead to rotational instability. During different phases of an overhead activity the labrum and capsuloligamentous structures will be at risk for injury.

Over head activities begin by establishing forward momentum with the lead leg striding forward. Particularly as it relates to baseball, the movement pattern a pitcher uses to stride forward may put them at risk for injury. During the “wind-up” phase a pitcher will move their lead leg through open-chain adduction-internal rotation to abduction-external rotation through an arc of flexion toward the intended target. (FIGURE 2) The athlete is at a potential risk for labral impingement during this motion, especially in the presence of an anterior-superior cam deformity, excessive acetabular retroversion, femoral retroversion, global acetabular overcoverage, and superior focal acetabular overcoverage. With striding forward, abduction and external rotation will occur in both the lead and back hips. (FIGURE 3) The potential for injury
with this movement pattern include posterior-superior impingement in both hips. The risk factors for this type of impingement include posterior-superior cam, excessive acetabular anteversion, excessive femoral anteversion, global overcoverage, and superior focal acetabular over coverage.

Striding forward is critical to developing forward momentum. Depending on the sport and specific activity the athlete will obtain varying degrees of abduction and external rotation. For example the stride length is greater when throwing a baseball compared to football. As the stride distance increases hip abduction and the likelihood of lateral rim impingement with superior labral lesions will also increase. Also, the back hip is performing this movement under compressive and shear forces that may result in additional stress to the labrum and articular surfaces. These types of forces can result in traumatic type injuries.

In addition to striding forward, acceleration is developed with the pelvis rotating forward in relation to the lead leg. As the pelvis rotates forward the lead hip will move into internal rotation and adduction with trunk and hip flexion occurring as the movement progresses forward. (FIGURE 4) Hip flexion, internal rotation, and adduction will put individual at risk for anterior-superior impingement as the head-neck junction approximates the anterior-superior rim of the acetabulum. As noted above the risk factors for this injury include anterior-superior cam, excessive acetabular retroversion, femoral retroversion, global overcoverage, and superior focal acetabular over coverage. These risk factors may be especially evident in those with a loss of hip internal rotation range of motion. As the trunk and pelvis accelerate forward the back hip continues to externally rotate and abduct combined with extension. As external rotation increases the likelihood of anterior rotational instability also increases. The risk factors for anterior rotational instability include a shallow acetabulum, excessive acetabular anteversion, and
excessive femoral anteversion. Capsular laxity may be evident in those with increased hip external rotation range of motion when compared to the opposite side. Those with signs of general ligament laxity and neuromuscular deficits leading to poor lumbo-pelvic control may be at greater risk for instability. Hip external rotation and extension will also increase the risk for posterior impingement and contra-coup anterior-superior impingement as the head-neck junction approximates the posterior rim of the acetabulum. As the hip is forced into external rotation and extension, the femoral head may be counter-levered against the posterior rim, driving it forward with a subsequent contra-coup lesion of the anterior-superior labrum. Risk factors for posterior impingement include posterior cam, excessive acetabular anteversion, excessive femoral anteversion, and global overcoverage. Activities that require greater external rotation, such during a fore-hand tennis stroke, may be at greater risk for these injuries. (FIGURE 5)

During the follow-through phase the distribution of body weight is moved predominantly onto the lead or non-dominant side with increases in flexion, internal rotation, and adduction. During a forceful activity, the player may drag or even lift the back foot indicating the weight has shifted entirely onto the lead lower extremity. (FIGURE 6) As the lead leg the hip moves into internal rotation, flexion, and adduction, there is greater risk for anterior-superior impingement as mentioned previously. Additionally, sports that require excessive hip internal rotation may be at risk for posterior rotation instability when the risk factors of a shallow acetabulum, excessive acetabular retroversion, and femoral retroversion are present. Lacrosse is an example when excessive internal rotation may occur. (FIGURE 7) The amount of internal rotation will depend on foot position of the lead leg and whether the foot is in an open position (externally rotated), pointing towards the target in a parallel fashion, or in a closed position (internally rotated) that is
more perpendicular to the target. As the distribution of body weight advances entirely onto the lead hip, additional stress to the labrum and articulating surfaces could result traumatic type injuries.

While deformities such as FAI and laxity can be linked to intra-articular hip problems, the abnormal mechanics caused by these deformities may lead to abnormal movement patterns in the torso and upper extremity. Although upper extremity injuries are more common than hip injuries, pathological stress on the torso, shoulder, and elbow may be a result of poor hip mechanics in overhead activities. In a study examining pitching mechanics, it was found that shoulder and elbows forces were significantly linked to pelvic rotation. The importance of generating forward momentum by the lower extremity in throwing has been documented. If the optimal stride distance and lead leg foot placement does not occur because of decreased strength, restricted range of motion, pain, and/or apprehension in the lead or back hip, an overhead athlete will not be able to properly generate torque form pelvis and lower extremity. With pitching it was noted that leg drive was found to correlated to wrist velocity and be responsible for approximately half of the throwing velocity. Similarly, more than half of the energy produced in a tennis serve is generated from the trunk and legs. If this leg drive does not occur the upper extremity may be responsible for generating a greater proportion of forces required for the overhead activity. Strength of the hip flexors, extensors, and abductors have all been noted to be important in pitching. Particularly, hip abductor strength is required in the back leg to generate forward momentum as well as for proper stabilization when the weight is primarily distributed on this leg. Hip pathology can be associated with decreased hip abductor strength and if the muscles around the hip are not functioning properly, there may be increase stress on shoulder
and elbow. A loss of normal hip motion may also require compensations that lead to pathology in the torso and upper extremity. Decreased internal rotation range of motion in the lead hip was linked to low back problems in athletes participating in tennis.³⁶ A study in athletes playing baseball found that hip rotation range of motion was less in back leg in those with history of shoulder pathology.²⁸ A loss of internal rotation could limit the ability of the hip to absorb stress during follow-through. This may put greater stress on the shoulder.²⁸ The link between hip pathology, changes in movement pattern, and injury risk in the torso, shoulder, and elbow will require further study.

CONCLUSION

While overhead sports are commonly linked with injuries of the upper extremity, there has become a greater awareness of injuries to the hip. Many of the common movements associated with throwing a baseball, throwing a football, shooting a lacrosse ball, and hitting a tennis ball place high demands on the hip and put the overhead athlete at risk for injury. Particularly labral-chondral lesions related to FAI and rotational instability.
REFERENCES


Table 1: Labral Tear and Rotational Instability Location with Potential Associated Deformity

<table>
<thead>
<tr>
<th>Anterior-Superior Labral Tear</th>
<th>Superior Labral Tear</th>
<th>Posterior-Superior Labral Tear</th>
<th>Anterior Rotational Instability</th>
<th>Posterior Rotational Instability</th>
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<tr>
<td>Anterior-Superior cam</td>
<td>Superior cam</td>
<td>Posterior-Superior cam</td>
<td>Excessive Acetabular Anteversion</td>
<td>Excessive Acetabular Retroversion</td>
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<td>Inferior-Medial cam</td>
<td>Coxa Varum</td>
<td>Excessive Acetabular Anteversion</td>
<td>Excessive Femoral Anteversion</td>
<td>Excessive Femoral Retroversion</td>
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<td>Excessive Acetabular Retroversion ‘counter-coup’</td>
<td>Shallow Acetabulum</td>
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<td>Excessive Acetabular Anteversion ‘counter-coup’</td>
<td>Superior Focal Acetabular Overcoverage</td>
<td>Excessive Femoral Anteversion</td>
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<tr>
<td>Instability</td>
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</table>
Figure 7. Excessive hip internal rotation, seen with shooting a lacrosse ball, may increase the risk for posterior rotation instability as well as anterior-superior impingement.

Figure 1. Radiograph depicting inferior acetabulum insufficiency (IAI) with the acetabulum resembling a vertical teardrop.
Figure 2. The “wind-up” phase with the lead leg moving through open-chain adduction-internal rotation to abduction-external rotation through an arc of flexion.
Figure 3. Striding forward requires abduction and external rotation occurring in both the lead and back hips.

Figure 4. Acceleration phase of throwing with lead hip moving into internal rotation and adduction and the back hip continuing into external rotation, abduction, and extension.
Figure 5. Activities that require greater external rotation, such during a fore-hand tennis stroke, may increase the risk for anterior rotational instability and posterior impingement.

Figure 6. The follow-through phase with increasing in flexion, internal rotation, and adduction on the lead or non-dominant side.
<table>
<thead>
<tr>
<th>Lead Leg (Non-Dominant)</th>
<th>Movement</th>
<th>Potential Injury</th>
<th>Risk Factors</th>
</tr>
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</table>
| Wind-up                 | Adduction-internal rotation to abduction-external rotation through an arc of flexion | Anterior-Superior Impingement | • Cam deformity  
• Coxa profunda |
| Cocking                 | Abduction and External Rotation | Posterior-Superior Impingement | • Superior Cam Deformity  
• Coxa profunda |
| Acceleration            | Flexion, Internal Rotation and Adduction | Anterior-Superior Impingement | • Cam deformity  
• Femoral Retroversion  
• Acetabular Retroversion |
| Follow-Through          | Internal Rotation, Flexion, and Adduction | Anterior-Superior Impingement | • Cam deformity  
• Femoral Retroversion  
• Acetabular Retroversion |

<table>
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<th>Trail Leg (Dominant)</th>
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<th>Risk Factors</th>
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</table>
| Wind-up             | Abduction and External Rotation | Superior Impingement  
• Focal Rotary Instability | • Superior Cam Deformity  
• Laxity  
• Neuromuscular deficits |
| Cocking             | External Rotation, Abduction and Extension | Focal Rotary Instability  
• Contra-Coup Anterior-Superior Impingement  
• Posterior Impingement | • Laxity  
• Neuromuscular Deficits  
• Femoral Anteversion  
• Coxa Profunda |

Table 3. Pathomechanics of Labral Tears in Throwing
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<td>Superior Impingement</td>
<td>Superior Cam Deformity</td>
</tr>
<tr>
<td></td>
<td>Internal Rotation, Adduction, Flexion</td>
<td>Anterior-Superior Impingement</td>
<td>Cam deformity, Femoral Retroversion, acetabular Retroversion</td>
</tr>
<tr>
<td></td>
<td>Internal Rotation in flexion and adduction</td>
<td>Anterior-Superior Impingement</td>
<td>Cam deformity, Femoral Retroversion, acetabular Retroversion</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trail Leg (Dominant)</th>
<th>Movement</th>
<th>Potential Injury</th>
<th>Risk Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Internal Rotation with flexion and adduction</td>
<td>Anterior-Superior Impingement</td>
<td>Anterior Cam deformity, Laxity, neuromuscular deficits, hip dysplasia, femoral anteversion, coxa profunda</td>
</tr>
<tr>
<td></td>
<td>Abduction and External Rotation</td>
<td>• Superior Impingement, • Focal Rotary Instability</td>
<td>Focal Rotary Instability, Contra-Coup Anterior-Superior Impingement, posterior Impingement</td>
</tr>
<tr>
<td></td>
<td>External Rotation, Abduction and Extension</td>
<td>Anterior-Superior Impingement</td>
<td>Contra-Coup Anterior-Superior Impingement, posterior Impingement</td>
</tr>
<tr>
<td></td>
<td>Extension</td>
<td>Anterior-Superior Impingement</td>
<td>Contra-Coup Anterior-Superior Impingement, posterior Impingement</td>
</tr>
</tbody>
</table>

**Table 4** Pathomechanics of Labral Tears in Batting
HIP INJURIES IN BASEBALL
Ben Kivlan, PT, SCS, OCS, CSCS; RobRoy Martin PhD, PT, CSCS; Hal D. Martin, DO; Bryan T. Kelly, MD

INTRODUCTION

The throwing athlete has been a long studied topic in the area of sports medicine. Because of the high prevalence of upper extremity injuries in baseball, interests have focused mostly on the elbow and shoulder. To date there has been little information directed to the study of lower extremity injuries in baseball. Recently, there has been an increased awareness of hip injuries, particularly acetabular labral tears, and the impact these injuries have on athletes. Notably, some of the most recognizable professional athletes in baseball have sustained acetabular labral tears requiring arthroscopic hip surgery. The attention on these athletes has further increased awareness and raised growing concern regarding risk factors and causes of these injuries.

McCarthy et al12 studied intra-articular injuries of the hip in elite level athletes. Their study concluded that sports requiring axial and torsional forces through the hips may predispose athletes to intra-articular pathologies. Therefore athletes participating in baseball appear to be vulnerable to such injuries.12, 14 According to Major League Baseball (MLB) sources, 9 MLB players underwent arthroscopic procedures for intra-articular hip pathology between November 2008 and 2009. Of these 9 nine players there were 4 infielders, 2 catchers, one outfielder and one pitcher.

While case descriptions of baseball players acquiring intra-articular hip pathology have been reported, there is limited explanation of the pathomechanics leading to injury. What is less understood is how the biomechanics of the hip during common baseball specific movement patterns may contribute to intra-articular injuries of the hip. Specifically, we need to consider how the positional requirements and mechanics of throwing, batting, and fielding could possibly lead to intra-articular hip pathology. The purpose of this paper is to outline mechanism of injury for labral tears of the hip joint and relate these potential causes to physical demands imposed on the athletes playing baseball.

MECHANISMS OF LABRAL INJURIES

The emergence of advanced imaging and minimally invasive surgical techniques has allowed us to discover a new appreciation for non-traumatic and overuse pathologies to the hip joint. Hip arthroscopy allows for visual inspection, identification, and new treatment options for intra-articular injuries, including labral tears. The pathogenesis of labral pathology is believed to be commonly rooted in either mechanical impingement or instability of the femoroacetabular joint. Understanding the common mechanisms of labral pathology is important if we are to recognize how athletes participating in baseball are at risk.

Femoroacetabular Impingement
Femoroacetabular Impingement (FAI) often precedes an injury to the labrum. It was noted that 95% of patients with labral tears had clinical signs of FAI.\(^2\) Therefore it is not coincidence that the morphological characteristics found in FAI are also present in patients with labral pathology.\(^8\) Efforts to explain FAI have lead to classifying the impingement based on aberrant anatomy of the proximal hip joint. The two main classifications of FAI are generalized into cam or pincer type impingement.

**Cam Impingement**

Cam impingement is thought to originate from an abnormal bump or thickening of the femoral head-neck junction. A cam deformity may be defined as a loss of the femoral head-neck offset that can be localized anteriorly, superiorly, posteriorly, inferiorly, or any combination of these locations. This includes a circumferential loss of the femoral head-neck offset. Cam deformities are most often found in the anterior-superior head-neck junction.\(^7\) Injury to the labrum will occur as the boney deformity abuts the labrum, with the location of injury dependent upon the location of the deformity and the direction the hip is moved. Table 1 describes the movements that may cause impingement with the corresponding location of the cam deformity.

The most common location for labral and acetabular cartilage damage is at the anterior-superior margin. Since cam deformities may not be isolated to one specific location, a combination of movements may result in the greatest approximation of the deformity with the labrum and acetabulum. Biomechanically, the combined movements that approximate the anterior-superior femoral head-neck and the anterior-superior labrum are internal rotation and abduction. The addition of flexion will further accentuate the impingement. Cam deformities in other locations may also create anterior-superior impingement depending on the movement pattern of the hip. Anterior-inferior cam deformities may come into contact with the anterior-superior labrum when the hip is first flexed, then adducted and internally rotated. The anterior-superior labrum may also be susceptible to injury and this area of the labrum may have less elasticity and tolerance for compressive forces than other sections the labrum.\(^6\)

**Pincer Impingement**

Pincer impingement of the femoroacetabular joint is caused by abnormalities to the acetabulum. The primary causes of pincer impingement may either be from retroversion of the acetabulum or from an abnormally deep acetabulum also known as coxa profunda. In a retroverted acetabulum, the anterior acetabular rim extends more laterally, creating an abutment with the anterior femoral head-neck junction especially in positions of internal rotation, abduction, and flexion. Coxa profunda creates a global overcoverage of the femoral head. Thus impingement of the labrum due to coxa profunda may occur in multiple positions that may affect a wide spectrum of combined joint movements.

Cam and Pincer impingement are common in the fact each may create mechanical damage to the labrum and articular cartilage. The mechanisms however are different, but not necessarily mutually exclusive from one another. Beck et al.\(^1\) found that most patients may have varying degrees of both types of impingement. Additional causes of mechanical impingement may exist as the result of rotational deformities of the femur in the transverse plane. The femoral head is normally rotated 15° anteriorly. When the femoral head is rotated less than this it is termed retroversion. In this condition, the anterior superior head-neck junction is closer to the anterior
rim of the acetabulum. The anterior-superior labral lesion can result as the labrum is compressed by the femoral head-neck junction with movements that incorporate internal rotation. When the femoral head is rotated more than 15º anteriorly it is called anteversion. In the presence of femoral anteversion the posterior head neck junction is closer to the posterior rim of the acetabulum. Anteversion may put the posterior labrum at risk for injury with movements that incorporate external rotation.

Instability
Atraumatic instability, with or without mechanical impingement, may also be a contributing factor leading to hip pathology and pain. Focal rotational instability is defined as a localized laxity of select ligamentous and capsular sturctures. Excessive repetitive forceful hip rotation is believed to contribute to focal rotational instability. The most common injury pattern is excessive external rotation leading to iliofemoral ligament laxity. These forces are known to occur during athletic activities that require rapid acceleration and rotation of the pelvis as described in golf, ballet, martial arts, and hockey, as well as baseball. In the presence of instability, abnormal loading of the anterior-superior labrum can occur resulting in subsequent labral damage.

The labrum is critical to joint stability and damage to the labrum from FAI may further increase the symptoms of instability. The labrum works to enhance stability of the hip joint in two ways. First, it acts as a buttress to mechanically prevent excessive joint movement and enhance the congruency of the femoral head and acetabulum. Secondly, it establishes a seal that creates negative intra-articular joint pressure that is an important contributor stability of the hip joint. When a labral tear occurs the ability of the labrum to maintain joint stability is compromised and the capsuloligamentous structures will be under additional stress, possibly perpetuating the instability. Poor neuromuscular control of the hip and lumbopelvic regions as well as transverse plane rotational deformities of the acetabulum and femur may contribute to issues related to focal rotational instability.

LOWER BODY MECHANICS IN BASEBALL

A detailed description of the lower body mechanics during baseball is important to understanding the underlying causes of hip injury. This section will describe the biomechanics of common baseball specific skills and is summarized in Table 2.

Lower Body Mechanics of Throwing
The phases of throwing can be divided into wind-up/cocking, acceleration, and follow-through.

Wind-up/Cocking phase
The act of throwing a baseball begins in the lower extremity. The initial steps of throwing begin with the player establishing forward momentum to propel the ball forward. This may start by a shuffle step or a “crow-hop” by the player to set his feet and begin moving toward a target. In pitching, the player may initiate a backward step of the contra-lateral leg during a “wind-up” that precedes the propulsion of the dominant leg in an effort to establish greater velocity of the ball. The player starts the throwing motion facing perpendicular to the intended target, with the head,
shoulders, and hips parallel to the direction of the target. The dominant or back leg accepts a majority of the weight as the player initiates a step towards the target with the non-dominates or lead leg. The gluteal muscles of the dominant leg move the leg into abduction, external rotation and extension. The lead leg the same time will move through open-chain addition-internal rotation to abduction-external rotation through an arc of flexion toward the intended target. Simultaneous abduction of both legs occurs with striding, as the separation of the feet or stride length is nearly doubled from the initial stance position. Stride length is an important factor in the development of a mature throwing pattern and a key determinant of ball velocity. The trunk remains perpendicular to the target as the hips and pelvis rotate towards the target. This rotational movement helps to store elastic energy in preparation to propel the ball forward. The lead lower extremity contacts the ground, assuming an externally rotated position as the lead foot is pointed in the direction of the throw. The cocking phase is complete as the lead foot comes into contact with the ground.

**Acceleration**
Both lower extremities remain in contact with the ground to form a stable base that allows the upper trunk and extremity to propel the ball forward. Once foot contact has been made with the lead lower extremity, a quick and dramatic weight shift occurs. The lead lower extremity accepts the weight and acts as a fulcrum by which the trunk and upper body rotate as the entire body works to accelerate the dominant arm through the throwing motion. Acceleration is again initiated in the lower body as the pelvis rotates forward in relation to the lead leg. Rotation of the pelvis causes extension of the dominant leg as the hip returns to neutral rotation and pivots towards the target. The pelvis will continue to rotate forward causing the lead hip to move into internal rotation and abduction. Hip Flexion will occur as the trunk flexes and rotates in preparation for the release of the ball.

**Follow-through**
After ball release the momentum of the forces generated to propel the ball towards the target increase hip flexion, internal rotation and abduction of the lead hip. During the follow-through phase the distribution of the body weight is moved predominantly onto the lead or non-dominant side. During a forceful throw the player may drag or even lift off the foot of the back or dominant leg indicating the weight shift has moved entirely onto the lead lower extremity. Eccentric muscle activity occurs to reverse the actions of the acceleration phase. In the shoulder, studies show high muscle recruitment patterns among scapular retractors (mid trap and rhomboids) as well as the entire rotator cuff and latissimus dorsi to decelerate the arm. A similar mechanism must exist to decelerate the trunk and lower body. Presumably, the hamstrings, gluteus maximus, and external rotators of the hip as well as the trunk extensors such as the erector spinae, quadratus lumborum, and multifidus activate in an eccentric fashion to decelerate the trunk and conclude the sequence of throwing.

**Lower Body Mechanics during Batting**
The phases of batting can be broken down into three distinct phases that are similar to those described in throwing. Similar to throwing there is a preparatory phase, an acceleration phase and
a follow-through phase. Each has a specific function and purpose in the swing sequence as well as distinct kinematic and biomechanical properties.

Prepatory phase
Stance
The stance is unique and definable to the individual player and is variable between each player. There are, however, general characteristics or commonalities that may describe the start position or the batting stance of the athlete. The player in general starts in a position with shoulders, trunk, and hips perpendicular to the pitcher with the head rotated to view the pitcher. Weight is distributed with a slight favor towards the dominant or back leg. The trunk remains erect with slight forward lean and upper trunk rotation towards the dominant side. The knees and hips vary in the degree of flexion based on individual preferences.

Coiling
The swing sequence begins with a shift of weight away from the pitcher and onto the back leg. This is accompanied by a subtle rotation of the upper torso and pelvis towards the dominant side in an effort to ‘pre-load’ the trunk in preparation acceleration during the swing phase. This action of coiling is done in an effort to store elastic energy to be used to increase power during the acceleration phase.

Acceleration
The acceleration begins with lift off of the lead leg and transfer of weight onto the dominant side. The total force placed on the dominant lower extremity slightly exceeds body weight. Because shear forces (forces measured parallel to the ground) were included in the estimation of total force it allows values of total force transmitted through the lower extremity to be greater than body weight. The non-dominant or lead leg strides toward the target. The average stride length is 380% the width of the hips. By striding nearly 4 times the width of the hips, both femoroacetabular joints move towards end range of abduction. As the lead lower extremity contacts the ground the pelvis rotates 28º around the axis of the trunk. A rapid weight transfer ensues as the lead foot contacts the ground. Total force of the dominant leg reduces from 102% to 58% body weight and increases to 123% on the lead lower extremity. Powered by the gluteal muscles, the dominant hip abducts and externally rotates in the closed chain and is aided by knee extension of the lead leg which creates a rigid lever and fulcrum by which the pelvis rotates. This coupling of movement creates rapid acceleration at a maximum angular velocity of 714º/sec of the pelvis toward the pitcher.

Follow-through
The high angular velocity generated to power the swing is carried over after the ball has been struck. The follow-through phase in hitting can be described similarly to those found in pitching. Thus the lead leg is carried into maximum of internal rotation as the rotation of pelvis around the axis of the trunk is estimated at 83º. Because the lead leg is positioned in a “closed” or internally rotated position, it may require greater internal rotation of the lead leg when compared to throwing. The dominant leg returns to a more neutral rotation as it faces anteriorly during the follow-through, but continues to remain in extension. Another difference between the throwing and batting mechanics at this stage is the distribution of weight across the two lower extremities.
In batting mechanics, there is more even distribution of weight through the follow-through phase that results in a more balanced finish position.18

Fielding and Running the bases
Running the bases and fielding entail similar movement patterns characterized by short, explosive lateral movements. The starting position or “ready” position varies among athletes and their specific position. However, most baseball players assume a “ready” position that begins with the trunk and hips flexed, slight abduction, and neutral rotation of the hips. Running the bases and fielding the baseball involves a quick, lateral movement described as a cross-over step which initiates movement towards the target. The purpose of this movement is to quickly orient the body in the desired direction of running. This requires a strong push-off from abductors of the leg farthest from the ball or the base with simultaneous adduction of the lead leg to initiate the cross-over step. These combined efforts rotate the pelvis toward the intended direction in which the player chooses to run. Pelvic rotation is the resultant efforts of the lead leg moving primarily into adduction with internal rotation and extension, and the trailing leg powering into abduction, extension, and external rotation followed by a rapid hip flexion moment that carries trailing leg in front of the lead leg to begin a normal running sequence.

Position specific considerations should be made in describing potential kinematic causes of hip pathology. A catcher has the most extreme and distinguishable lower body mechanics compared to other position players. The catcher’s stance requires the hips to assume an extreme of flexion combined with external rotation and abduction. In extreme flexion, the anterior and inferior femoral head-neck junction approximates the anterior superior margin of the acetabulum. In slight abduction, the approximation of the femoral-head neck junction may be further exaggerated. Defining the fielding characteristics of specific position players is unique to the position and the individual. Infielders perform more of their defensive duties fielding balls from the ground. Thus, their position may require greater hip flexion and wider stances, placing the hips in greater abduction compared to outfielders. Pitchers will be performing higher repetitions of maximal force throws. The wind-up of the pitching motion requires greater range of motion and demands on the passive stabilizers of the femoroacetabular joint. Since trunk flexion is positively correlated with velocity of the ball during throwing, there is greater potential for anterior superior impingement stress with more forceful throws. Consider the throwing mechanics of a pitcher compared to a second-baseman. The pitcher is utilizing the entire body to generate maximum velocity of the ball, whereas the second-baseman may be trying to make a quicker throw. There is no time to wind-up for the second-baseman and his mechanics may leave him in a more erect position of the trunk, making the stresses on the hip very different. Because of the variability of kinematic variables within the individual and their fielding position, it is difficult to assume the biomechanics and physiological demands of a baseball player are all the same. Thus defining the pathomechanics for hip injury should take into consideration the specific demands of each position and the variability that exists between individual players.

IMPLICATIONS TO INJURY
It is important to recognize the susceptibility of the hip joint to intra-articular pathology of the hip in relation to the mechanics described during sport specific movement patterns. This section will examine the implied mechanisms of labral injury during baseball specific skills. Tables 3 and 4 summarize this information relative to the phases of throwing and batting.

**Femoroacetabular Impingement**

Based on the mechanics of throwing and batting the follow-through phase may put the lead hip at the most risk for injury resulting from FAI. As mentioned previously, internal rotation of the hip approximates the anterior-superior femoral head-neck junction with the anterior-superior margin of the acetabulum and labrum. The anterior-superior portion of the labrum is vulnerable to impingement with the presence of an anterior superior cam deformities as well as those with femoral retroversion and/or acetabular retroversion. These risk factors may be evident in those with a loss on internal rotation. With both throwing and batting, the lead leg resists the linear displacement of the pelvis moving toward the target and provides a stable fulcrum by which the pelvis and torso develop rotational torque. The lead leg thus creates a posteriorly directed force through the femoroacetabular joint to drive the leading ilium posterior, thus invoking a rotation of the pelvis. The pelvic rotation rapidly moves the lead leg towards end range of internal rotation combined with flexion and adduction during the acceleration and follow-through phases of throwing and batting. This is emphasized in batting mechanics where the rotation of the hip at foot contact is more “closed”, resulting in greater internal rotation of the lead leg to accommodate the rapid pelvic rotation. Thus the lead lower extremity may be particularly vulnerable to intra-articular pathology in the presence of a cam deformity, femoral retroversion, and/or acetabular retroversion.

Superior impingement of the labrum is possible during the early phases of throwing and batting as well as during lateral running tasks. This occurs as the athlete strides in the direction of their target. These movements require both extremities to move towards end range of abduction. As the hip moves into abstraction, contact of the superior femoral head-neck junction with the superior acetabular margin may occur. The trail leg is performing this movement under compressive and shearing loads that may result in additional stress to the articulating surfaces of the hip. With superior cam deformities and coxa profunda, the likelihood of impingement increases during the stride sequence of baseball specific movements.

**Posterior impingement/Contra-Coup Lesion**

The dominant leg may also be susceptible to posterior impingement in movements that combine external rotation and extension. External rotation as described in the initial stages of throwing and batting could cause posterior labral lesions as the head-neck junction approximates the posterior rim of the acetabulum. This would be exaggerated and more likely in individuals with femoral anteversion and/or coxa profunda. Positions of external rotation and extension cause impingement at the posterior and superior labrum with corresponding degradation of the articular surface of the femoral head. As the hip is forced into further external rotation and extension, during the acceleration phase of throwing and batting, the femoral head may be counter-levered against the posterior rim, driving it forward. This movement causes posterior-inferior impingement with a subsequent contra-coup lesion of the anterior-superior labrum as the femoral head is forced anteriorly.
Focal rotational instability

Repetitions of forceful rotation in the extremes of motion make the labrum vulnerable to pathology as a result of focal rotational instability. The dominate leg may be particularly susceptible to focal rotational instability during baseball movements. The mechanisms of injury to the hip joint are often compared to the shoulder. In the shoulder, repetitions of throwing lead to micro-instability of the capsulolabral structures. Based on the current understanding of hip mechanics, a similar mechanism may exist for the development of hip pathology of the dominant lower extremity in baseball athletes. The anterior capsulolabral structures, specifically the iliofemoral ligament, are subjected to repetitive stresses into external rotation with abduction during the preparatory and acceleration phases and extension during the follow-through phases of throwing and batting. The iliofemoral ligament has broad attachments to the anterior-superior margin of the acetabulum and labrum. Repeated tensile stresses through the ligament may ultimately contribute to redundancy of the iliofemoral ligament and indirect mechanical loading to the anterior-superior labrum. The anterior-superior region of the labrum may be particularly susceptible to compressive and tensile loads. Redundancy of the ligament and damage to the labrum makes the joint vulnerable to instability.

Failure of the passive stabilizers of the hip may place greater demands on the dynamic or neuromuscular stabilizers of the hip. In athletics where joints are subject to higher physiologic demands, neuromuscular control is a crucial component of joint stability and function. Thus failure of the neuromuscular mechanisms that promote joint stability may increase force that could injure the capsulolabral and labrum. As dynamic stability of the hip is compromised, weightbearing forces are unevenly distributed, leading to the progression of labral pathology and ultimately accelerated degeneration of the joint surfaces.

In the presence of anterior capsuloligamentous laxity one would expect to find greater total range of motion and asymmetry of joint external rotational movements of the dominant leg. In a study on 41 collegiate and high school baseball players, external rotation of the dominant leg was significantly greater than that of the lead leg and had greater total rotational motion as well. However, Ellenbecker et al. examined hip range of motion in professional baseball pitchers and did not find significant difference between sides for internal or external range of motion. According to their research, however, 42% of the pitchers displayed an external rotation asymmetry greater than 10°, but a tendency of the dominant or non-dominant side was not present. Laudner et al. supported these findings and noted external rotation range of motion discrepancies did not exist between the dominant non-dominant limbs. In comparing pitchers to position players, Laudner et al. found that the only significant finding was a decrease of hip internal rotation among pitchers. The difference was approximately a 3 degree loss of internal rotation, and may seemingly have little clinical significance. Generally it seems that asymmetrical hip range of motion in baseball players is not a normal finding. Asymmetry in rotational motion may be an indicator of hip pathology particularly as it relates to the loss of internal rotation with FAI and an increase in external rotation range of motion with focal rotational instability.
CONCLUSION
While baseball is a sport that is commonly linked with overuse injuries of the upper extremity, there is greater awareness of injuries to lower extremity. Many of the common sport specific movements and skills seen in baseball players place high demands on the hips, pelvis and lower trunk. As more evidence of etiological causes and mechanical factors contributing to intra-articular hip pathology emerges, there is a greater understanding of the influence of these demands on labral pathology of the hip joint. Exploring the biomechanics of baseball specific movements shows vulnerability of both lower extremities to stresses strongly associated with intra-articular hip pathology. By understanding these aspects, physicians, trainers, coaches and rehabilitation specialists may develop better preventative and post-injury interventions to diagnose, treat, and prevent hip injuries in baseball players. This paper reviews the biomechanical contributors to intra-articular hip injuries in baseball players, and provides a theoretical construct and review of the literature that identifies vulnerability to injury. It also identifies a need for further research studies to quantify these factors in relation to pathomechanics and the incidence of hip pathology among baseball athletes.

REFERENCES


### Table 1. Cam Deformity Location and Corresponding Position of Impingement

<table>
<thead>
<tr>
<th>Location of cam Deformity</th>
<th>Hip Motion Causing Impingement</th>
</tr>
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<tbody>
<tr>
<td>Anterior</td>
<td>Internal Rotation in 30-60º of flexion</td>
</tr>
<tr>
<td>Superior</td>
<td>Abduction</td>
</tr>
<tr>
<td>Posterior</td>
<td>External Rotation in extension</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Preparatory</th>
<th>Throwing</th>
<th>Batting</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Non-Dominant (Lead Leg)</strong></td>
<td>Wind-up: Wind-up may include a backward step followed by a leg kick into varying flexion, adduction, and internal rotation of the hip. Position players do not have the time to perform a windup.</td>
<td>Stance: Varied preferences unique to individual. Generally, hip is in slight flexion (30), abducted and in neutral rotation.</td>
</tr>
<tr>
<td></td>
<td>Stride (all players): Open chain move through open-chain adduction-internal rotation to abduction-external rotation through an arc of flexion.</td>
<td>Stride: In preparing to swing, the lead leg deweights in preparation to stride towards the ball. This is followed by open-chain abduction and external rotation while in slight flexion.</td>
</tr>
<tr>
<td><strong>Dominant (Trailing Leg)</strong></td>
<td>Accepts 100% of body weight as gluteal muscles push into abduction with slight extension and external rotation.</td>
<td>Accepts 100% of body weight as gluteal muscles push into abduction with slight extension and external rotation.</td>
</tr>
<tr>
<td><strong>Acceleration</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Non-Dominant (Lead Leg)</strong></td>
<td>Foot contact at 5° “closed” (internally rotated from the line of the target)</td>
<td>Foot contact at a more “closed” poison of 61° (internally rotated from the line of the pitched ball)</td>
</tr>
<tr>
<td></td>
<td>Accepts 100% of weight</td>
<td>Accepts a majority of the weight.</td>
</tr>
<tr>
<td></td>
<td>Becomes stable pillar to create fulcrum for rapid forward pelvic rotation.</td>
<td>Becomes a firm pillar which helps drive lead ilium posterior to aid in the rapid acceleration of pelvis.</td>
</tr>
<tr>
<td></td>
<td>Hip moves into closed-chain internal rotation and flexion.</td>
<td>Hip moved into closed-chain internal rotation and adduction.</td>
</tr>
<tr>
<td><strong>Dominant (Trailing Leg)</strong></td>
<td>Drives into extension and towards neutral hip rotation as rapid weight shift on the lead leg occurs.</td>
<td>Drives into extension and towards neutral hip rotation as rapid weight shift on the lead leg occurs.</td>
</tr>
<tr>
<td><strong>Follow-Through</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Non-Dominant (Lead Leg)</strong></td>
<td>In forceful throws, momentum carries into further internal rotation, flexion, and adduction as deceleration of the body occurs.</td>
<td>Pelvic rotation continues to carry into maximum internal rotation with flexion and slight adduction.</td>
</tr>
<tr>
<td><strong>Dominant (Trailing Leg)</strong></td>
<td>Complete weight shift off the dominant side.</td>
<td>Weight shift almost entirely transferred off the leg as it assumes a maximally extended position with slight internal rotation.</td>
</tr>
</tbody>
</table>
History and physical examination of the hip: the basics

Hal David Martin & Ian James Palmer
History and physical examination of the hip: the basics

Hal David Martin · Ian James Palmer

Abstract The history and physical examination of the hip is the key component for evaluation of patients presenting with hip pain. As our understanding of the anatomy and biomechanics of the normal hip vs the pathologic hip advances, the physical examination progresses as well. As with the shoulder and knee examinations, there are critical steps that form the basis of the examination of the hip joint. This hip examination contains 21 steps, which compares well with the shoulder 20 step exam and the knee 33 step exam. Consideration should be given for the hip as comprised of 4 layers: the osseous, capsulolabral, musculotendinous, and neurovascular. The hip represents the link between the upper body and lower body, therefore the fifth layer, the kinematic chain, plays an essential role in treatment recommendations. A clinical evaluation of the hip that incorporates this multifactor thought process will lead to an accurate diagnosis in a timely manner. This paper is a description of the 21 core examinations of a standardized clinical evaluation of the hip.

Keywords History · Symptoms · Layers · Hip physical exam · Hip clinical examination

Introduction

The history of the patient is first obtained prior to the physical examination of the hip. A complete history should consider all hip layers, including the kinematic chain. Key aspects for the consideration of treatment include patient age, the date of onset, presence or absence of trauma, and mechanisms of injury [1]. Date of onset, or duration of symptoms, can help determine treatment efficacy [2]. Absence of trauma may suggest degenerative disease or a predisposition to injury, whereas a history of trauma may indicate a treatable problem [3]. Pain characteristics along with the presence or absence of popping will aid in the determination of intra-articular vs extra-articular causes. It is also necessary to identify related symptoms of the spine, abdomen, and lower extremity, primarily referred knee pain. A history of night pain, sit pain, weakness, numbness, or paraesthesia in the lower extremity may suggest neural compression, which may occur in the lumbar spine or within the subgluteal space [4].

In addition, the following items must documented: previous consultations; surgical interventions; past injuries; childhood or adolescent hip disease; ipsilateral knee disease; history of inflammatory arthritis; and risk factors for osteonecrosis. Factors related to the patient’s social history that can affect the blood supply to the femoral head are reviewed and family medical history is also taken into account. Clearly define any treatments to date and obtain a detailed account of current functional limitations. A history of sports and recreational activities can help determine the type of injury and also guide the treatment, considering the patient’s goals and expectations.

Quantification of hip pain, function, and severity of symptoms can be obtained by 1 or more questionnaires. The modified Harris Hip Score [5] (HHS) is the most documented and standardized functional score to date, which is a quantitative score based on pain and function. Other hip scores have been used for more specific patient populations such as; Merle d’Aubigné [6] (MDA), the Non-Arthritic Hip Score [7] (NAHS), Musculoskeletal Function Assessment [8] (MFA), Short Form 36 [9] (SF-36), and the Western Ontario and McMaster University Osteoarthritis Index (WOMAC) [10]. The MAHORN (Multicenter Arthroscopy of the Hip Outcomes Research Network) Group has validated the International Hip Outcome Tool (iHOT-33) [11]. Developed through an international multicenter study, the iHOT-33 is a self-administered questionnaire with a target population of active adult patients with hip pathology. While
the iHOT-33 was developed for research purposes, a short form (iHOT-12) [12] was also described for use in routine clinical practice. The use of a verbal analog score is also useful for the quantification of pain at rest and pain with activities.

Patient goals and realistic expectations of treatment are discussed. Patients may differ from surgeons regarding the issues they feel are important when considering treatment outcomes [13]. Communication and understanding are important for obtaining an accurate history. Presented in Table 1 are the key items for the history evaluation.

<table>
<thead>
<tr>
<th>Key points of patient history</th>
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<tbody>
<tr>
<td>Age</td>
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<tr>
<td>Date of onset</td>
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<tr>
<td>Trauma</td>
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<tr>
<td>Popping/locking</td>
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<tr>
<td>Treatment to date</td>
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<tr>
<td>Limitations</td>
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<td>Associated complaints</td>
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Table 1

The physical examination of the hip

The 21 step physical examination of the hip (Table 2) is a comprehensive assessment of 4 distinct layers: osteochondral; capsulolabral; musculotendinous; and neurovascular. A consistent hip examination is performed quickly and efficiently to find the comorbidities that coexist with complex hip pathology.

Table 2

<table>
<thead>
<tr>
<th>Twenty-one step physical examination of the hip</th>
</tr>
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<tbody>
<tr>
<td>Standing</td>
</tr>
<tr>
<td>1. Gait</td>
</tr>
<tr>
<td>2. Single Leg Stance Phase Test</td>
</tr>
<tr>
<td>3. Inspection</td>
</tr>
<tr>
<td>Seated</td>
</tr>
<tr>
<td>4. Neurovascular/Reflex</td>
</tr>
<tr>
<td>5. ROM</td>
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<tr>
<td>Supine</td>
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<tr>
<td>6. Palpation</td>
</tr>
<tr>
<td>7. ROM</td>
</tr>
<tr>
<td>8. Hip Flexor Contracture Test</td>
</tr>
<tr>
<td>9. DIRI</td>
</tr>
<tr>
<td>10. DEXRIT</td>
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<tr>
<td>11. FADDIR</td>
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<tr>
<td>12. FABER</td>
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<tr>
<td>13. Dial Test</td>
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<tr>
<td>Lateral</td>
</tr>
<tr>
<td>14. Palpation</td>
</tr>
<tr>
<td>15. Strength</td>
</tr>
<tr>
<td>16. Passive Adduction Tests</td>
</tr>
<tr>
<td>17. Lateral Rim Impingement Test</td>
</tr>
<tr>
<td>18. Posterior Rim Impingement Test</td>
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<tr>
<td>19. Apprehension Test</td>
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<tr>
<td>Prone</td>
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<tr>
<td>20. Rectus Femoris Contracture Test</td>
</tr>
<tr>
<td>21. Femoral Version Test</td>
</tr>
</tbody>
</table>

Fig. 1 Standing evaluation. a and b Shoulder and iliac crest heights are examined with the patient with dynamic loading of the hip joint in the standing position. c As the patient bends forward at the trunk, spinal alignment is palpated. d The degree of trunk flexion is noted in full flexion. e Laxity of the thumb. f Recurvatum of the elbow. g The single leg stance phase test is performed bilaterally and observed from behind and in front of the patient. The patient flexes the hip and knee at 45° and hold this position for 6 seconds.
by assessing the hip, back, abdominal, neurovascular, and neurologic systems. Loose-fitting clothing about the waist is helpful for exposure and patient comfort. Documentation of the exam by an assistant on a standardized written form aids in accuracy and thoroughness. The use of a common language and specific technique for each examination test will eliminate multi-clinical discrepancy and improve reliability. The MAHORN (multicenter arthroscopy of the hip outcomes research network) Group outlined the common tests that form the basis of a multilayered hip evaluation.

Standardization enhances the physical examination reliability and the most efficient order of examination begins with standing tests followed by seated, supine, lateral tests, and ending with prone tests.

Standing examination

A general location of pain is noted by the patient pointing with 1 finger will usually help direct the examination. The groin region may be indicative of an intra-articular problem. Lateral-based pain may be associated with intra- or extra-articular aspects. A characteristic sign of patients with intra-articular hip pain is the “C Sign”. The patient will hold his or her hand in the shape of a C and place it above the greater trochanter, with the thumb positioned posterior to the trochanter and fingers extending into the groin. Posterior-superior pain requires the differentiation of hip and back pain. Bilateral shoulder and iliac crest heights in the standing position are compared to evaluate leg length discrepancies. Trunk bending (side-to-side and forward) is performed to evaluate the lumbar spine and to differentiate structural from nonstructural scoliosis. General body habitus and joint laxity are easily assessed in the standing examination.

Gait abnormalities often help detect hip pathology and the kinematic chain. The patient is taken to an area large enough to observe a full gait of 6 to 8 stride lengths. The key elements of gait evaluation include foot progression angle, pelvic rotation, stance phase, and stride length. The following abnormal gait patterns can be associated with hip pathologies: winking gait with excessive pelvic rotation in the axial plane; abductor deficient gait (Trendelenburg gait or abductor lurch); antalgic gait with a shortened stance phase on the painful side; and short leg gait with dropping of the shoulder in the direction of the short leg.

The single-leg stance phase test (Trendelenburg test) is performed during the standing evaluation of the hip. The single-leg stance phase test is performed bilaterally, with the non-affected leg examined first, to establish a baseline. A positive is noted if the pelvis drops toward the non-bearing side or shift of more than 2 cm toward the bearing (affected) side, which may indicate that the abductor musculature is weak or the neural loop of proprioception is disrupted on the bearing side. Trunk inclination for the bearing (affected) side is also noted in a positive single leg stance test. This assessment is performed in a dynamic fashion by some examiners.

Seated examination

The seated hip examination consists of a thorough vascular, lymphatic, and neurologic examination, which are performed even in apparently healthy individuals. Vascular and lymphatic...
assessment includes the posterior tibial pulse, any swelling of the extremity, and inspection of the skin. The neurologic evaluation includes sensibility, motor function, and deep tendon reflexes (Patellar and Achilles). The presence of radicular neurologic symptoms is detected by the straight leg raise test, performed by passively extending the knee into full extension.

The seated position provides a reproducible platform for the assessment of hip internal and external rotation (Fig. 2a and b). The ischium is square to the table at 90° of hip flexion. Values of hip rotation measured in different positions (seated, prone, supine) can be compared for an assessment of ligamentous vs osseous abnormality. Passive internal and external rotation is performed until a gentle endpoint is obtained and compared bilaterally. Proper hip function requires sufficient internal rotation and there should be at least 10° of internal rotation at the midstance phase of normal gait [18], but less than 20° is abnormal. Excessive femoral anteversion may be indicated by increased internal rotation combined with a decreased external rotation.

Supine examination

The supine examination begins with the inspection of leg length discrepancy. Tenderness with palpation is documented for the abdomen, pubic symphysis, and adductor tubercle. Differentiation of isolated adductor tendinitis and sports hernia may be made by a resisted sit-up torsos flexion.

Hip ranges of motion are recorded for passive abduction, adduction, and flexion. Bring both of the patient’s legs into flexion (knees to chest, Fig. 3a) and note the pelvic position because the hip may stop early in flexion resulting in pelvic rotation to achieve end range of motion. With both legs in flexion, the pelvis is in a zero set-point (eliminating lumbar lordosis) important for the Hip Flexion Contracture Test (Thomas test). The patient holds 1 knee to their chest and passively moves the contralateral leg into extension (Fig. 3b). Inability for the back of the thigh to reach the table indicates the presence of contracture and patients with hyperlaxity or lumbar spine hyperlordosis can result in a false-negative. In patients with hyperlaxity or connective tissue disorders, the zero set point can be established with an abdominal contraction. The dial test is an assessment of capsular laxity. It includes passive internal rotation of the leg, followed by releasing the leg and allowing it to external rotate. External rotation of more than 45°, relative to vertical, is a positive test [19].

Hip joint vs sacroiliac joint pain is detected by the flexion, abduction, external rotation test (FABER), historically known
as the Patrick test (Fig. 3c). The leg is placed in Fig. 4 position with the knee in flexion and hip in flexion, abduction, and externally rotation so that the ankle rests on the contralateral thigh. Ipsilateral or contra-lateral sacroiliac discomfort may be felt. Re-creation of hip pain can be associated with posterior femoroacetabular impingement, ligamentous injury, or trochanteric pathologies.

Several tests exist for the assessment of femoroacetabular congruence, instability, or intra-articular pathology. Ganz originally described the flexion, adduction, and internal rotation test [20], and McCarthy later described the dynamic assessment of the femoroacetabular congruence and relationship to the labrum [21].

The dynamic internal rotatory impingement (DIRI) test is the assessment of anterior femoroacetabular congruence (DIRI). The zero set-point of the pelvis must be obtained by the patient holding the contralateral leg in flexion. The hip is dynamically taken in a wide arc from abduction/external rotation to flexion, adduction, and internal rotation (Fig. 4a and b). Re-creation of the complaint pain is a positive result. Note the degree of flexion that causes impingement, which helps determine the degree, type, and location of anterior impingement. The Scour test is performed in the same manner as DIRI, while applying pressure at the knee to increase pressure on the hip joint.

The dynamic external rotatory impingement test (DEXRIT) includes a wide arc movement of passive abduction and external rotation. The patient holds the contralateral leg in flexion to establish the zero set point of the pelvis. The is dynamically taken from 90° flexion or beyond through an arc of abduction and external rotation to extension (Fig. 4c). The DEXRIT is an examination of supero-lateral and posterior femoroacetabular impingement. Patients with antero-inferior hip instability, antero-inferior acetabular hypoplasia, torn teres ligament, and capsular laxity may also exhibit a positive DEXRIT. A positive result is noted with re-creation of pain or feeling of instability. Both the DEXRIT and DIRI can be performed intraoperatively for direct visualization of femoroacetabular congruence.

The posterior rim impingement test is performed to assess the congruence between the posterior wall and femoral neck (Fig. 4d). The patient is positioned at the edge or end of the examination table so that the leg can hang freely to full extension. The patient established the pelvic zero set-point with both legs held in flexion. The examined leg is allowed to reach full extension off the table, and then taken into abduction and external rotation. Recreation of the symptoms is a positive test and can also present as an apprehension sign in cases of anterior instability.

Lateral examination

Palpation in the lateral position includes suprasacroiliac area, sacroiliac (SI) joint, gluteus maximus origin, piriformis muscle, and sciatic nerve. The facets of the greater trochanter (anterior, lateral, supero-posterior and posterior) are palpated. The insertion of the gluteus minimus located at the anterior facet, the gluteus medius at the supero-posterior and lateral facets, and the trochanteric bursa at the posterior facet.
Strength is assessed with any type of lateral-based hip complaint. The tests are performed in lateral decubitus with the patient actively abducting the hip against resistance. The gluteus medius strength test is performed with the knee in flexion to release the gluteus maximus contribution for the iliotibial band. The overall abductor strength is evaluated with the knee in extension and the gluteus maximus is tested asking the patient to abduct and extend the hip.

A set of passive adduction tests (similar to Ober’s test) is performed with the leg in 3 positions - extension (tensor fascia lata contracture test) (Fig. 5a), neutral (gluteus medius contracture test) (Fig. 5b), and flexion (gluteus maximus contracture test) (Fig. 5c).

The lateral decubitus is also utilized for femoroacetabular congruence evaluation. The passive flexion adduction internal rotation (FADDIR) test is performed in a dynamic manner (Fig. 6a) Any reproduction of the patient’s complaint and the degree of femoroacetabular impingement are noted. FADDIR is traditionally performed as part of the supine assessment.

The lateral rim impingement test is performed with the hip passively abducted and externally rotated (Fig. 6b). Reproduction of the patient’s pain is scored positive and can be caused by anterior instability or posterior impingement. If the feeling of guarding or anterior pain is present, the test is positive for instability. An apprehension test with a provocative maneuver is also executed in the lateral position (Fig. 6c), including a forward force to test antero-inferior instability [22]. Beyond the capsular and teres ligament, this test is also useful to detect acetabular antero-inferior hypoplasia.

Prone examination

In the prone position is also performed the rectus contracture test (also known as Ely test) (Fig. 7b). Passively bring the lower leg into flexion noting the end range of motion. The femoral anteversion test, traditionally known as Craig’s test, will give the examiner an idea of femoral anteversion and retroversion (Fig. 7a). Palpate the greater trochanter and internally/externally rotate the hip until the greater trochanter is in the most lateral position. Note the angle of the lower leg compared with vertical. Normally, femoral anteversion is between 10° and 20°.

Specific tests

Complex coexisting conditions may present, such as snapping hip, extra-articular peritrochanteric pain, and extra-articular posterior pain, which will require further examination. In these cases, specific tests have been described for the differential diagnosis [3, 21, 23, 24, 25•, 26]. The clinical exams described in this paper form the basis of a thorough physical examination that will guide the examiner toward the incorporation of specific tests when necessary.

Conclusion

As our understanding of anatomy and biomechanics evolve, the structured 21-step physical examination of the hip allows for a 4 layer assessment in the patients who present with hip pain [27•].

Compliance with Ethics Guidelines

Conflict of Interest

Hal D. Martin declares that he has no conflict of interest.

Ian J. Palmer declares that he has no conflict of interest.

Human and Animal Rights and Informed Consent

This article does not contain any studies with human or animal subjects performed by any of the authors.

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Papers of particular interest, published recently, have been highlighted as:
• Of importance

11. Mohtadi NG, Griffin DR, Pedersen ME, et al. The development and validation of a self-administered quality-of-life outcome measure for young, active patients with symptomatic hip disease: the


Imaging findings of femoroacetabular impingement syndrome

Abstract Femoroacetabular impingement syndrome (FAI) is a pathologic entity which can lead to chronic symptoms of pain, reduced range of motion in flexion and internal rotation, and has been shown to correlate with degenerative arthritis of the hip. History, physical examination, and supportive radiographic findings such as evidence of articular cartilage damage, acetabular labral tearing, and early-onset degenerative changes can help physicians diagnose this entity. Several pathologic changes of the femur and acetabulum are known to predispose patients to develop FAI and recognition of these findings can ultimately lead to therapeutic interventions. The two basic mechanisms of impingement—cam impingement and pincer impingement—are based on the type of anatomic anomaly contributing to the impingement process. These changes can be found on conventional radiography, MR imaging, and CT examinations. However, the radiographic findings of this entity are not widely discussed and recognized by physicians. In this paper, we will introduce these risk factors, the proposed supportive imaging criteria, and the ultimate interventions that can help alleviate patients’ symptoms.

Keywords Musculoskeletal radiology · Hip · Conventional radiography · Magnetic resonance · Anatomy

Introduction

Hip pain, resulting from disorders of the acetabular rim in nondysplastic hips, has been increasingly recognized. Degeneration and tearing of the labrum can be detected on Magnetic resonance (MR) imaging and can be associated with progressive damage to the adjacent cartilage. This phenomenon may be the result of impingement of the anterior and anterosuperior femoral head-neck junction against that portion of the acetabular labrum adjacent to it. This type of impingement mechanism is also thought to be one of the precursors of degenerative arthritis [1]. It has been suggested that the etiology of the degenerative arthritis is related to repetitive microtrauma due to the impingement of the femoral neck against the acetabular rim [1]. This type of impingement can be in patients with prominent femoral head-neck junctions or in patients with normal anatomy who place unusual stress on the hip. Alternatively, a cam effect, in which a portion of the anterolateral femoral head that is abnormally prominent is squeezed under the acetabular rim, has also been proposed as an etiology for this predisposition to degenerative arthritis [2].

The diagnosis of femoroacetabular impingement (FAI) is based on the patient’s clinical history and physical examination and is further supported by findings at radiography, computed tomography (CT), and MR imaging. Radiographic findings suggestive of FAI include premature onset of degenerative arthritis, acetabular retroversion, a decreased femoral head-neck junction, and evidence of impaction in regions of the anterosuperior acetabulum and anterior femoral neck. CT optimally demonstrates the bony anatomy that may be seen in patients with FAI, including acetabular retroversion and prominence of the anterior femoral head-neck junction. MR imaging is also effective at demonstrating the findings that may be seen with CT but is also capable of demonstrating articular cartilage damage and acetabular labral tears.

A number of conditions exist that may predispose the patient to FAI. These conditions include: Legg-Calve-Perthes disease, congenital hip dysplasia, slipped capital...
femoral epiphysis, avascular necrosis of the femoral head, malunited femoral neck fractures, acetabular protrusion, an elliptical femoral head, prominence of the femoral head-neck junction, and a retroverted acetabulum [2-4].

To date, imaging features of this condition have not been widely discussed in the radiologic literature. We present a review of the topic of FAI which includes discussion of the two basic mechanisms of impingement: cam impingement and pincer impingement. These two types of conditions are based on the type of anatomic anomaly contributing to the impingement process. We will also provide the imaging appearance and the imaging criteria that have been proposed as diagnostic signs of this condition.

**Clinical symptoms in patients with FAI**

Patients with FAI usually have clinical symptoms of groin pain, pain overlying the trochanters, pain with flexion and internal rotation, and may even have clinical symptoms after surgery [2]. The symptoms of impingement are usually unilateral but bilateral FAI can occur in individuals who have hip joint laxity such as that seen in patients with connective tissue disorders. On physical examination, pain may be elicited by a combined maneuver of 90° of flexion, adduction, and internal rotation of the hip. This provocation test causes pain by shear or compression of the acetabular labrum. The acetabular labrum, similar to the meniscus of the knee, is known to carry proprioceptive and nociceptive nerve fibers and compression or disruption of the labrum is a well-documented source of pain [5].

In addition to the combined maneuver described above, physical examination in patients with FAI involves evaluation for loss of internal rotation out of proportion to the loss of range of movement at other positional extremes. Loss of internal rotation out of proportion with other motions favors FAI over osteoarthritis, which can produce a universal limited range of motion. In patients with FAI, a grinding and popping sensation can be felt when the femur is externally rotated when the hip is maximally abducted.

The importance of the clinical history should not be underestimated as it is very helpful in initially separating the possible diagnoses based on pain location and the presence or absence of mechanical symptoms. The clinical history should be combined with patient self-assessment tools such as the Harris Hip Score and the Short Form 36 score [6]. Given the potential for significant symptomatic overlap, the diagnosis is not made by one test alone but by a combination of an accurate and thorough history and physical examination, merging the pertinent findings of both.

The pain associated with FAI often begins after some form of mild trauma and presents in patients that are younger (i.e., fourth and fifth decades of life) than the typical patient population that presents with hip pain due to degenerative arthritis (i.e., in the seventh to ninth decades). Pain due to FAI has been described as being worse after prolonged periods of sitting or when significant stress is placed on the hip. The pain may often be located in the groin region rather than confined to the hip itself. Pain is typically worse when the hip is in internal rotation or at least 70° of flexion [7].

Clinical symptoms of hip pain may often persist even after surgery. This is likely due to the irreversible cartilage damage of the hip joint that is often established at the time the patient seeks medical attention for their hip pain.

**Anatomy and mechanism of impingement in FAI**

In a 2001 article by Ito et al., the authors found that patients who had clinical symptoms of FAI had certain anatomic characteristics (Table 1) [2]. The authors thought it possible that patients with the above characteristics may experience impingement of the femoral head-neck junction against the anterior acetabular rim even with normal movement.

Patients may be predisposed to developing FAI due to their intrinsic anatomy. The impingement in FAI is caused by abnormal anatomic features of the proximal femur, the ipsilateral acetabulum, or both. The predisposing factors to FAI are thought to be due primarily to a congenital dysplasia or prominence of the femoral head-neck junction in the anterior/anterosuperior portion of the proximal femur (Fig. 1). This anomaly can be seen as a reduction in the femoral head-neck offset in the anterior aspect of the femoral neck or to an overall decreased offset at the femoral head-neck junction. The offset refers to the difference between the maximal anterior radius of the femoral head and the anterior radius of the adjacent femoral neck. This is also called the head to neck ratio. The decreased offset produces a tubular appearance to the femoral head and neck. This appearance has been termed the “pistol grip deformity” due to its similarities with the smooth hand-grip of many pistols (Fig. 2). These anatomic abnormalities are

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Anatomic characteristics of patients with FAI</th>
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<tr>
<td></td>
<td>Reduction in femoral anteversion or acetabular retroversion</td>
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<tr>
<td></td>
<td>Decreased tapering at the femoral head-neck junction anteriorly (decreased femoral head-neck offset)</td>
</tr>
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<td></td>
<td>Nonspherical head with abnormal prominence of the femoral head-neck junction</td>
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<td></td>
<td>Retrotorsion of the femoral head</td>
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<td></td>
<td>Prominent postsurgical anterosuperior acetabulum</td>
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<tr>
<td></td>
<td>Coxa vara</td>
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<td></td>
<td>Acetabular protrusion</td>
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</table>
even more apparent when the anomalous femoral head-neck configuration is compared with normal anatomy (Fig. 3).

Impingement may also be seen in patients who have normal anatomy that puts unusual stress on the hip joints or who may have an occupation (e.g., carpet layers) that predisposes them to this type of impingement. Any type of repetitive or occupational activity that occurs in flexion, adduction, and internal rotation could potentially lead to impingement provided the joint capsule is sufficiently lax or if the patient’s anatomy intrinsically contributes to this process. It is thought that less stress and abnormal movement is necessary to cause FAI in a person with anatomic features that would predispose them to FAI.

There are generally two basic types of FAI: cam impingement and pincer impingement [8]. Cam impingement is seen when the nonspherical femoral head, characterized by the abnormal prominence of the head-neck junction, produces a cam effect when the prominent portion of the femoral head rotates into the hip joint (Fig. 4). This prominence produces intermittent and consistent stress (the cam effect) on the associated articular cartilage and the shear forces cause damage to both the acetabular labrum and the articular cartilage of the femoral head and acetabulum. The pincer type of impingement involves abnormal contact between the femoral neck and the acetabular rim with no abnormal sphericity of the femoral head. This type of impingement may be seen in patients who have any anatomic characteristics that cause a closer approximation of the acetabular rim with the femoral head. This can be seen with acetabular abnormalities (i.e., acetabular retroversion) or proximal femoral abnormalities (i.e., coxa magna). Impingement of this type can result in damage to the acetabular labrum and bony reaction of the acetabulum that can lead to bony proliferation and an increased prominence of the acetabulum which further exacerbates the problem.

The cartilage lesions seen in pincer impingement tend to be more focal and confined to a smaller area of the acetabular rim. This is in contradistinction to the cartilage abnormalities seen in cam impingement, which tend to be more extensive due to the greater degree of articular compression that results from the femoral head-neck junction prominence that rotates into the joint with flexion and internal rotation. Pincer impingement tends to present in an
older age group and is more common in women, while cam impingement that most commonly presents in young males [8]. Both cam impingement and pincer impingement result in abnormalities of the femoral head-neck junction, the articular cartilage, and acetabular rim that can be seen on various imaging examinations (Table 2).

Although the congenital or developmental characteristics are thought to be the most common predisposing factors to the development of FAI, other specific clinico-pathologic entities have also been associated with FAI (Table 3).

### Anatomic structural indicators of FAI

Lack of normal acetabular anteversion

Retroversion of the acetabulum has been described as a posterior orientation of the acetabular opening in relation to the sagittal plane [9]. Retroversion may be seen as a result of trauma, as part of a complex acetabular dysplasia, or in isolation and is thought to play a role in early-onset degenerative arthritis [1]. When the acetabulum is retroverted, the anterior and anterolateral portion of the acetabulum and acetabular labrum is located more laterally than is typical and may be an obstacle to normal internal rotation and flexion (Fig. 5). This obstruction gives rise to an impingement phenomenon and, over time, will produce unusual wear and tear of the acetabular labrum anteriorly and can result in articular cartilaginous lesions adjacent to the site of impingement [1, 10].

### Table 2 Imaging abnormalities seen in cam impingement and pincer impingement

<table>
<thead>
<tr>
<th><strong>Cam impingement</strong></th>
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<tbody>
<tr>
<td><strong>Conventional radiography</strong></td>
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<tr>
<td>Anterior prominence on lateral radiograph of the hip</td>
</tr>
<tr>
<td>“Pistol grip deformity”</td>
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<tr>
<td>Early-onset degenerative arthritis</td>
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<tr>
<td><strong>MR imaging</strong></td>
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<tr>
<td>Increased alpha angle</td>
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<tr>
<td>Anterosuperior acetabular labral tear</td>
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<tr>
<td>Articular cartilage defects</td>
</tr>
<tr>
<td>Flattening of the superior femoral head-neck junction</td>
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<tr>
<td>Nonsphericity of the femoral head</td>
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<table>
<thead>
<tr>
<th><strong>Pincer impingement</strong></th>
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</thead>
<tbody>
<tr>
<td><strong>Conventional radiography</strong></td>
</tr>
<tr>
<td>Evidence of impaction of the anterosuperior femoral head-neck junction and corresponding acetabular rim location</td>
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<tr>
<td>Early-onset degenerative arthritis</td>
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<tr>
<td>Seen in entities that result in a closer approximation of the femoral head-neck junction and the lateral acetabular rim (i.e., coxa vara, acetabular protrusion, retrotorsion of femoral head, coxa magna, ossification of acetabular rim, acetabular retroversion)</td>
</tr>
</tbody>
</table>

| **MR imaging** |
| Normal alpha angle |
| Anterosuperior acetabular labral tearing |
| Articular surface defects (typically smaller and more focal than those seen in cam impingement) |
| Evidence of osseous impaction along the anterosuperior or superior femoral neck |
| Spherical femoral head |

### Slipped capital femoral epiphysis and femoral neck fractures

Slipped capital femoral epiphysis (SCFE) may result in FAI due to the alteration of the anatomy of the femoral head and femoral head-neck junction. The process of SCFE may even be subclinical prior to the patient’s later presentation due to hip pain caused by FAI [11]. Impingement caused by SCFE has been shown to cause early damage to the acetabular labrum and adjacent articular cartilage due to the prominent femoral metaphysis in this region [12]. This type of mechanical impingement process is also seen after femoral neck fractures. Eijer et al. described anterior FAI

### Table 3 Entities associated with the development of FAI

| **Congenital acetabular retroversion** |
| **Slipped capital femoral epiphysis** |
| **Developmental dysplasia of the hip** |
| **Malunited femoral neck fractures** |
| **Elliptical femoral head** |
| **Avascular necrosis of the femoral head** |
in 9 patients due to retrotorsion of the femoral head (average retrotorsion was 20°) and varus position of the proximal femur (coxa vara) [13].

FAI after repair of developmental dysplasia of the hip

Acetabular deformity that may give rise to FAI may also occur in adults who were born with developmental dysplasia of the hip (DDH) and have undergone reconstruction of the acetabulum [1]. This reconstruction often produces a prominence of the anterosuperior acetabulum and may result in impingement of the acetabulum by the adjacent femoral neck. In addition to a repair of the acetabulum in children with DDH, consideration must also be given to the resultant appearance of the osseous structures after surgery. If there is a risk for developing FAI, consideration should be given to performing an osteoplasty of the femoral head-neck junction. This has been described previously as an effective treatment for FAI in patients who were born with DDH and have undergone acetabular reconstruction [1].

Coxa vara

A varus position of the femur was seen in 2 of the 9 patients studied by Eijer et al and was found to produce a mechanical predisposition to anterolateral FAI [13]. The patients in this description had a mean caput collum diaphysis angle of 115° and the process of FAI was surgically confirmed. The varus position gives rise to an abnormally located femoral neck that is situated more superiorly than normal given the decreased caput collum diaphysis angle (Fig. 6). This will predispose the patient to impingement from the compression of the anterosuperior femoral neck against the anterosuperior portion of the acetabulum.

Acetabular protrusion (arthrokatadysis)

Abnormal protrusion of the femoral head centrally into the pelvis is termed acetabular protrusion or arthrokatadysis (Fig. 7). This can be seen in a number of conditions including decreased bone density (osteoporosis or osteo-

---

**Fig. 5** Anteroposterior view of the pelvis shows evidence of acetabular retroversion. The anterior acetabulum (continuous black line) is normally located medial to the posterior acetabulum (dotted line). In this case, the anterior acetabulum is more laterally located than is typical. This is indicative of acetabular retroversion and has been called the “figure of 8” sign.

**Fig. 6** Anteroposterior radiograph of the pelvis shows coxa vara deformity on the right (white arrow) and a normal caput collum diaphysis angle on the left. The result of the coxa vara deformity is that the femoral neck is situated more superiority than normal given the decreased caput collum diaphysis angle (angle as measured is 117°; normal angles range from 120° to 135°). Additionally, this image shows coxa magna, acetabular dysplasia, and a prominent superolateral femoral head that likely impinges upon the lateral acetabulum when the child’s hip is abducted. The left hip proximal femur and acetabulum are normal.

**Fig. 7** Anteroposterior radiograph shows acetabular protrusion, primarily on the right side (arrows), along with loss of the hip joint space bilaterally, consistent with the patient’s clinical diagnosis of rheumatoid arthritis.
malacia, osteogenesis imperfecta, rickets), rheumatoid arthritis, Paget’s disease, hypophosphatemia, or it can be idiopathic. The idiopathic form is called Otto’s disease or arthrokatadysis. The protrusion anatomically brings the lateral portion of the acetabular rim closer to the superior portion of the femoral neck. Patients with Otto’s disease are also known to have premature onset of degenerative arthritis. It is conceivable that the FAI seen in these patients may play a contributing role to the premature development of the degenerative joint disease.

Table 4 Imaging findings in femoroacetabular impingement

<table>
<thead>
<tr>
<th>Conventional radiography</th>
<th>MR imaging</th>
<th>CT imaging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flattening of the femoral head-neck junction (“pistol grip deformity”)</td>
<td>Anterior/anterosuperior/anteroinferior/posterosuperior acetabular labral damage and associated MR evidence of corresponding impaction damage at the superior/superolateral femoral head-neck junction</td>
<td>Ossification or calcification along the acetabular margin in the region of impingement</td>
</tr>
<tr>
<td>Prior trauma or deformity of the femoral head/acetabulum</td>
<td>Articular surface cartilage degeneration</td>
<td>Increased alpha angle (&gt;50°)</td>
</tr>
<tr>
<td>Synovial herniation pits</td>
<td>Increased width of the femoral neck relative to the diameter of the femoral head</td>
<td>Increased width of the femoral neck relative to the diameter of the femoral head</td>
</tr>
</tbody>
</table>

Radiographic or MR imaging changes of the lateral margin of the acetabulum such as an os acetabuli (Fig. 8) may indicate patients at risk for developing symptoms of FAI. The result of the pathologic mechanism of pincer impingement with the repetitive impaction of the acetabular labrum by the corresponding femoral head-neck junction may also result in acetabular labral ossification. This ossification further compromises the shock-absorbing characteristics of the acetabular labrum and may exacerbate the impingement process.

**Imaging findings in FAI**

Several imaging modalities can be used to identify the specific imaging findings of FAI (Table 4). The imaging investigation of patients with hip pain most often begins with or without ossification.
with conventional radiography. Radiographic examination of the hip includes an anteroposterior view (usually of the hip and entire pelvis) and a lateral view. Anteroposterior radiographs in patients with FAI will sometimes show flattening of the femoral head-neck junction (Fig. 2), commonly known as the “pistol grip deformity.” The lateral view may also be helpful to show the decreased femoral head-neck offset.

Conventional radiography is also helpful for evaluating patients who have had prior trauma and fractures of the acetabulum or proximal femur. Residual bony deformities contributing to FAI can be globally surveyed using conventional radiographs. Eijer et al. found that residual post-traumatic retroversion of the femoral head (with a mean of 20°) caused anterior impingement in all the patients they examined [13]. In order to characterize the various osseous components of the hip joint, the authors used anteroposterior views, axial views and Lequesne’s false profile view (Lequesne’s view is an ipsilateral posterior oblique obtained with the patient standing in a position 25° removed from the true lateral projection).

In addition to the above described anatomic alterations around the hip joint, some authors have described a relationship between synovial herniation pits and FAI [8]. These synovial herniation pits are often located in the anterolateral portion of the femoral head, may be symptomatic, and may show an area of increased uptake on bone scintigraphy. The herniation pits are well seen on conventional radiographs as regions of decreased bone density with well-defined borders. Synovial herniation pits are usually located in the subcapital region of the femoral neck. They are often seen in athletes and an abnormal interaction between the iliopsoas tendon and the joint capsule producing increased pressure on the anterior portion of the proximal femur has been proposed as one potential mechanism [14]. Some authors believe that synovial herniation pits may also be indicative of FAI, especially when they occur in their typical anterolateral position [8]. The increased pressure of the soft tissue just anterior to the femoral head-neck junction that is thought produce synovial herniation pits may be a similar mechanism to the process of soft tissue impingement that has been previously described in patients with FAI [1]. The relationship of the presence synovial herniation pits to symptomatic FAI remains unclear.

The process of FAI is well demonstrated with MR imaging. These examinations may show anterior and anterosuperior or anteroinferior acetabular labral damage. The acetabular labrum, when damaged, shows increased signal on T2-weighted images that extends to the articular surface. This increased signal can either be well defined or ill defined as is seen in linear and degenerative tears, re-

Fig. 9 A Coronal STIR MR image of the hips and pelvis shows a region of increased signal within the right acetabular labrum (white arrow) indicative of an acetabular labral tear. This may be contrasted with the normal left acetabular labrum (white arrowhead). Some evidence of impaction injury is visible in the superolateral femoral head (black arrow). Scanning parameters include: TR 2500, TE 35, inversion time 150, FOV 36, and matrix 256×256. B Coronal STIR MR image demonstrates a small cartilage defect in the lateral portion of the acetabulum (white arrow). Scanning parameters include: TR 2500, TE 35, inversion time 150, FOV 36, and matrix 256×256. C Anteroposterior radiograph of the right hip shows evidence of impaction injury to the superolateral portion of the femoral head-neck junction (black arrow)
spectively. On MR arthrography, gadolinium will extend into the tear on the T1-weighted fat-saturated images. There is often MR imaging evidence of corresponding impaction damage at the superior portion of the superolateral femoral head-neck junction (Fig. 9). The imaging appearance of the acetabular labral damage and associated change of the femoral neck are sequelae from the impingement phenomenon that occurs between the acetabulum and the adjacent femoral head/neck junction. Notzli et al. described posterior acetabular labral damage in patients with FAI and Leunig et al. reported that the posterior acetabular labral damage was most likely to be located posterosuperiorly [4, 15]. Overall, the MR imaging frequency of the location of the acetabular lesions from most frequent to less frequent is as follows: anterosuperior, posterosuperior, anteroinferior, and posteroinferior [16].

MR imaging is also useful for demonstrating the hip joint cartilage damage that is often seen in patients with FAI (Fig. 10). The cartilage injury is primarily in the superolateral hip joint, either anterior or posterior, and usually adjacent to the acetabular labral damage. The damage to the articular cartilage is typically seen as focal or diffuse defects of the articular cartilage of the femoral head or adjacent acetabulum. This can be seen as smooth wear (chondromalacia) or as partial/full-thickness cartilaginous defects. The cartilage damage is often associated with subchondral cyst formation, bony sclerosis, and osteophyte formation.

MR arthrography will provide an optimal evaluation of the acetabular labrum and the articular cartilage [15]. The MR arthrography technique should be combined with a small field of view, a dedicated phased-array or quadrature coil capable of producing optimal signal-to-noise ratio, and MR imaging sequences that are effective at demonstrating articular cartilage defects (i.e., fat-saturated T1-weighted images, 3D gradient echo images, fast spin echo images, etc.).

Wagner et al. took samples of 22 nonspherical femoral heads removed from patients with young adults with FAI, compared them with samples from age-matched controls, histologically examined and graded the cartilage damage, and examined the cartilage by immunohistologic methods [17]. They found that the nonspherical portion of the femoral head showed signs of degenerative change typical for the type of degeneration that is seen in patients with osteoarthritis and that the histologic appearance of the cartilage was distinctly different from the appearance of the cartilage in the control group.

Cross-sectional evaluation of the hip affected by FAI may show an increased alpha angle on the oblique axial images. This imaging plane is obtained by prescribing the cross-sectioning parallel to the femoral neck (Fig. 11) and was originally developed as a cross-sectional equivalent to the lateral radiograph of the femoral neck with the cassette parallel to the femoral neck. The alpha angle is used as an objective representation of the prominence of the anterior femoral head-neck junction (Fig. 12). This prominence of

Fig. 10  Coronal T2-weighted MR image of the hip joint shows cartilage damage (chondral defects) in the superolateral portion of the hip joint (small white arrows). There is also an associated acetabular labral tear (black arrow). These findings are typical of those seen in patients with FAI. Scanning parameters include: TR 2500, TE 35, inversion time 150, FOV 36, and matrix 256×256

Fig. 11  Coronal T1-weighted MR image shows the orientation of the slices that are obtained along the plane of the femoral neck (black lines). Oblique axial plane images are the result of scanning parallel to the femoral neck. Scanning parameters include: TR 2500, TE 35, inversion time 150, FOV 36, and matrix 256×256
the head-neck junction may produce either a cam effect or a pincer type of impingement. The more prominent the alpha angle, the more the predisposition for impingement of the anterior/anterosuperior femoral head/neck against the adjacent acetabulum. In a 2002 article Notzli et al. examined the contour of the femoral head-neck junction as a predictor for the risk of anterior impingement [4]. They used the alpha angle as a measurement of the femoral head-neck contour. In the 39 patients with clinical symptoms of FAI, a mean alpha angle of 74° was found, compared with a mean alpha angle of 42° for the control group. They proposed that an alpha angle of >50° may be an appropriate cross-sectional criterion in assessing for FAI and they concluded that patients with clinical symptoms of FAI have hips with significantly less concavity at the femoral head-neck junction that do the patients in the control group.

In certain circumstances, the actual process of impingement as it occurs in FAI can be demonstrated with cross-sectional imaging. In open MR units or in MR or CT units with a large bore, the patient may flex and internally rotate their hip thereby producing a physiologic demonstration of FAI [18]. The patient can subsequently be imaged with their hip in maximum flexion and internal rotation. The resulting impingement of the femoral head-neck junction on the acetabular labrum and acetabulum may be directly visualized. Although this type of view gives a representative view of what is happening biomechanically, the direct apposition of the impinged elements makes the anatomy in the region of the impingement difficult to analyze.

**Sequelae of FAI**

As mentioned above, the primary effect on the acetabular labrum as a result of FAI is tearing of the labrum due to the repetitive microtrauma and shear forces placed on the labrum at the sites of the impingement. The pincer type of impingement has more of a direct effect on the acetabular labrum than does the cam type of FAI and continued impaction of the femoral head-neck against the acetabular labrum can result in labral degeneration and paralabral cyst formation. Chronic impaction injury to the acetabular labrum may also produce calcification or ossification along the margin of the labrum which increases its prominence in the region of the impaction and thereby exacerbates the process.

Arguably the most damaging sequela of FAI is premature degenerative arthritis resulting from the damage to the
articular cartilage and subchondral bone due to shearing of the adjacent acetabular cartilage from the underlying subchondral bone [1, 10, 19]. The cam effect of a nonspherical femoral head or prominent head-neck junction places intermittent but regular stress on the articular cartilage. The prominence of the femoral head is the abnormality that produces the cam effect as this prominence is rotated into the ball and socket joint. This prominence results in intermittent increased pressure within the hip joint. The hip joint is a stable joint with a prominent acetabular covering and strong ligamentous support that does not allow for laxity sufficient to compensate for the intermittent increase in pressure. As a result, the brunt of the intermittently increased pressure within the joint is directed toward the articular cartilage. This increased stress is thought to lead to early-onset degenerative arthritis. This theory is supported by the observation that a flattened femoral head-neck junction on standard anteroposterior radiographs (“pistol grip deformity”) may be seen in up to 40% of patients who develop osteoarthritis of the hip [20].

The distinct distribution of acetabular rim lesions found by various authors suggests that FAI is a mechanical etiology of osteoarthritis [8]. This type of mechanical predisposition to early-onset degenerative arthritis may also be more common than other causes of premature-onset degenerative arthritis such as metabolic or genetic abnormalities of cartilage or subchondral bone. The degenerative process may also occur earlier and progress more quickly if FAI is present [12].

Treatment of FAI

The treatment of prominent femoral head-neck junctions has traditionally been seen with proximal femoral or acetabular deformities due to prior trauma. Eijer et al. described the treatment of post-traumatic patients with a resection osteoplasty at the impinging site on the femoral head-neck junction [13]. This was done to improve the femoroacetabular offset and to decrease or eliminate the prominence of the junction [13]. This was done to improve the femoroacetabular impingement at the impinging site on the femoral head-neck treatment of post-traumatic patients with a resection osteoplasty in patients with FAI [1].

The surgical procedure most often used involves entering the hip joint anteriorly via a capsulotomy. The hip joint is then dislocated and the femoral head and the acetabulum are inspected. The treatment involves removing any portion of the femoral head that is non-spherical and femoral neck osteoplasty to remove any prominences that could lead to cam impingement. For the pincer type of FAI, the acetabular rim portion that is involved in the impaction process is reduced in size. The portion of the acetabular labrum that is torn is repaired or removed and any portion of the labrum that is detached is reattached to the acetabulum via suture anchors. After the femoral head, femoral neck, and/or acetabular osteoplasties are performed the range of motion of the hip joint is assessed to ensure adequacy of movement. When optimal range of motion and the absence of residual impingement are ensured, the procedure is complete. Other procedures such as osteotomies of the proximal femur or acetabulum may be required in addition to the osteoplasties described above. The osteotomies may be performed whenever additional clearance is needed to alleviate the impingement.

Although good short-term results have been reported for the surgical treatment of FAI, no long-term results are available to date [21]. Determination of the efficacy of the surgical treatment in the long term is important to establish the effect of the surgery on the natural history of the disease, specifically whether early surgical intervention can delay the typical early onset of degenerative arthritis.

Conclusion

Femoroacetabular impingement is increasingly recognized as a source of hip pain that results from the impingement of the femoral head-neck junction against an adjacent portion of the acetabulum. This phenomenon can result in tearing of the acetabular labrum and progressive damage to the adjacent articular cartilage. The impingement is generally due to repetitive microtrauma and is thought to be the precursor of early-onset degenerative arthritis. The two basic mechanisms of impingement—cam impingement and pincer impingement—are based on the type of anatomic anomaly contributing to the impingement process. A number of post-traumatic or dysplastic conditions may also predispose patients to the development of hip impingement symptoms and there are certain anatomic structural indicators that are indicative of the potential for FAI. As this process may be surgically corrected with an osteotomy, an osteoplasty, or a combination of both, the early recognition of the anomalous anatomy and impingement process is important so that the appropriate treatment is expedited.
The initial diagnosis is primarily based on a combination of clinical symptoms and physical examination results but the anatomic characteristics as determined by the imaging data are important to confirm the clinical suspicion of FAI and for the purposes of surgical planning. Although a number of imaging criteria have been proposed, these are sporadically discussed as they relate to other parts of the disease process of FAI and have not been introduced in terms of an inclusive set of radiologic criteria that support the diagnosis of femoroacetabular impingement. We present the clinical characteristics of FAI along with the imaging appearance and the imaging criteria that have been proposed as diagnostic indicators of this condition.

Appendix. Definitions

1 Femoral head-neck offset: The offset refers to the difference between the maximal anterior radius of the femoral head and the anterior radius of the adjacent femoral neck. This is also called the head to neck ratio.

2 Cam impingement: Impingement characterized by a nonspherical femoral head and an abnormal prominence of the head-neck junction. The prominence produces a cam effect as the prominence of the femoral head impinges against the associated region of the acetabulum when the femoral head rotates into the hip joint.

3 Pincer impingement: Abnormal contact between the femoral neck and the acetabular rim with no abnormal sphericity of the femoral head. This type of impingement is most often seen in patients that have abnormal anatomy (i.e., acetabular retroversion, coxa magna or coxa vara).

4 Alpha angle: Analogous to the lateral radiographic view of the femoral neck, this angle is obtained by measuring the angle from the center of the femoral head (at the level of the center of the femoral neck) to the point where the osseous femoral head-neck junction meets the extrapolated circular diameter of the femoral head. This angle is measured on an oblique axial plane that is parallel to the femoral neck.

References

Intra-Abdominal Fluid Extravasation During Hip Arthroscopy: A Survey of the MAHORN Group


Purpose: The purpose of this study was to survey experts in the field of hip arthroscopy from the Multicenter Arthroscopy of the Hip Outcomes Research Network (MAHORN) group to determine the frequency of symptomatic intra-abdominal fluid extravasation (IAFE) after arthroscopic hip procedures, identify potential risk factors, and develop preventative measures and treatment strategies in the event of symptomatic IAFE.

Methods: A survey was sent to all members of the MAHORN group. Surveys collected data on general hip arthroscopy settings, including pump pressure and frequency of different hip arthroscopies performed, as well as details on cases of symptomatic IAFE. Responses to the survey were documented and analyzed.

Results: Fifteen hip arthroscopists from the MAHORN group were surveyed. A total of 25,648 hip arthroscopies between 1984 and 2010 were reviewed. Arthroscopic procedures included capsulotomies, labral reattachment after acetabuloplasty, peripheral compartment arthroscopy, and osteoplasty of the femoral head-neck junction. Of the arthroscopists, 7 (47%) had 1 or more cases of IAFE (40 cases reported). The prevalence of IAFE in this study was 0.16% (40 of 25,650). Significant risk factors associated with IAFE were higher arthroscopic fluid pump pressure (P = 0.004) and concomitant iliopsoas tenotomy (P < .001). In all 40 cases, the condition was successfully treated without long-term sequelae. Treatment options included observation, intravenous furosemide, and Foley catheter placement, as well as 1 case of laparotomy.

Conclusions: Symptomatic IAFE after hip arthroscopy is a rare occurrence, with an approximate prevalence of 0.16%. Prevention of IAFE should include close intraoperative and postoperative monitoring of abdominal distention, core body temperature, and hemodynamic stability. Concomitant iliopsoas tenotomy and high pump pressures may be risk factors leading to symptomatic IAFE.

Level of Evidence: Level IV, therapeutic case series.

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The authors report that they have no conflicts of interest in the authorship and publication of this article.

Received September 14, 2011; accepted April 24, 2012.

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0749-8063/11580/$36.00

http://dx.doi.org/10.1016/j.arthro.2012.04.151

Note: To access the MAHORN survey (Fig 1) accompanying this report, visit the November issue of Arthroscopy at www.arthroscopyjournal.org.
Hip arthroscopy has become an established procedure for the treatment of a variety of pathologic hip conditions, including labral tears, loose bodies, and femoroacetabular impingement. The number of hip arthroscopies has increased over the past 2 decades with advancements in specialized instruments and education within the orthopaedic community. The reported prevalence of complications during hip arthroscopy has been estimated between 1% and 13%. The most common complications include traction-related injuries, peripheral nerve injuries, trochanteric bursitis, portal hematoma, and instrument breakage. Several recent case reports have detailed both intraoperative and postoperative complications as a result of intra-abdominal fluid extravasation (IAFE) during arthroscopy of the hip.

The purpose of this study was to survey experts in the field of hip arthroscopy from the Multicenter Arthroscopy of the Hip Outcomes Research Network (MAHORN) group to determine the frequency of symptomatic IAFE during arthroscopic hip procedures. Secondary goals included the identification of risk factors leading to such a complication and the development of preventative measures and treatment strategies in the event of such a complication. The hypothesis of this study is that IAFE is a rare but potentially serious complication of hip arthroscopy.

METHODS

A standardized survey (Fig 1, available at www.arthroscopyjournal.org) was sent to each member of the MAHORN group to retrospectively recollect general data on their performed hip arthroscopies. In addition, surgeons reviewed the medical records for any symptomatic IAFE cases that they might have encountered to complete the second part of the questionnaire for each case.

The MAHORN group is a study group composed of clinicians from around the world with a large experience in hip arthroscopy. Although there is 1 member who is a physical therapist, the rest of the members perform a high volume of hip arthroscopies. Members were asked to complete the survey and anonymously document each individual case of IAFE that they encountered.

Out of a total of 17 MAHORN members, 15 arthroscopists (88%) responded to the survey. Responses were collected by the senior author, and all data were aggregated and analyzed.

RESULTS

Survey Results

Fifteen arthroscopists returned our questionnaire, with an overall number of 25,648 arthroscopies performed. The mean number of arthroscopies performed per surgeon in our group was 1,768.4 (range, 300 to 5,200). All participants except 1 (93%) used a fluid pump in more than 75% of their arthroscopies, and 1 (7%) used it in less than 25% of cases. Of the surgeons, 12 (80%) reported their typical fluid pump pressure setting.

Among the different types of arthroscopic procedures currently performed, capsulotomy, labral reattachment after acetabuloplasty, peripheral compartment arthroscopy, and osteoplasty of the femoral head-neck junction were commonly reported by most participants. Iliopsoas tenotomy constituted less than 25% of all arthroscopies as reported by 14 (93%) of the participants (Table 1).

Osteoplasty of the femoral head-neck junction was the most frequently performed procedure in our group, followed by acetabuloplasty and labral repairs.

Of the 15 arthroscopists who responded to our survey, 7 (47%) had at least 1 case of IAFE. The 3 surgeons with the highest numbers of IAFE cases were also those with the largest number of procedures overall. There was no significant correlation between the number of procedures and the incidence of IAFE per surgeon. Overall, 40 cases of IAFE were reported, with a range per arthroscopist of 1 to 13, as shown in Fig 2.

Pump pressure in cases of fluid extravasation was reported in 26 of 40 cases (65%), with a mean of 69.42 mm Hg (range, 45 to 90 mm Hg) as compared with a reported mean of 55.62 mm Hg in all arthroscopies. The mean operative time in the fluid-extravasate patients was 120.2 minutes (range, 45 to 319 minutes). The volume of extravasated fluid was reported in 14 of the 40 cases (35%), with a mean of 1.4 L (range, 0.70 to 4.00 L). The volume of fluid extravasated was measured only in 35% of fluid extravasation cases, mainly those patients who had a Foley catheter or ultrasound, in addition to 1 patient treated with a laparotomy.

Within the 40 cases of abdominal fluid extravasation, 25 (63%) had an iliopsoas tenotomy, 11 (44%) of which occurred at the beginning of the arthroscopy compared with 1 (4%) performed in the middle portion of the case. There were 13 iliopsoas tenotomies (52%) performed at unreported times during the case. A capsulotomy was performed in 31 patients (78%), and 38 patients (95%) had a peripheral compartment arthroscopy.
Of the patients, 3 (8%) presented with postoperative dyspnea, 2 (5%) had a drop in core body temperature postoperatively, and 1 (3%) presented with hemodynamic instability. Abdominal fluid extravasation was detected in the recovery room postoperatively in 20 cases (50%) versus intraoperatively in the other 20 cases (50%). For 16 of the 20 cases (40%) with fluid extravasation intraoperatively, it was noted at the end of the procedure, whereas 4 cases (10%) were identified midway through the procedure. Intraoperative and/or postoperative symptoms were reported in 39 patients (98%). The location of the extravasated fluid was reported for 39 patients (97.5%). Of the patients, 22 (57%) had intra-abdominal extravasation in which the exact location was uncertain, 14 (35%) had retroperitoneal extravasation, and 3 (8%) had intraperitoneal fluid accumulation. The location of the extravasated fluid was detected through a computed tomography (CT) scan and/or ultrasound in 24 patients (60%) and through abdominal palpitation in 16 (40%).

Treatment for IAFE varied among participants. Among the 39 patients (98%) who received treatment, 14 (36%) received intravenous furosemide and Foley catheter placement, 12 (30%) were treated with furosemide alone, and 12 (30%) were admitted and observed overnight. An emergent laparotomy was performed in 1 patient (3%). This patient had respiratory distress, a tense abdomen, and decreased venous return circulation from the lower extremities. Four liters of intraperitoneal fluid was released, and he had no sequelae. One patient (3%) did not receive any treatment other than observation. All 40 patients (100%) had complete resolution of symptoms and were discharged on postoperative day 1. There were no reported long-term sequelae from this complication.

In 13 cases (33%) the surveyed specialists could not identify risk factors associated with the extravasation. The remaining 27 cases (68%) were attributed to elevated pump pressure, early iliopsoas tenotomy, or a combination thereof.

### Table 1. Percentage of Different Arthroscopic Procedures Performed by Participants

<table>
<thead>
<tr>
<th>Procedure</th>
<th>No. of Providers</th>
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<tbody>
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<td>Capsulotomy</td>
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</tr>
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<td>0</td>
</tr>
<tr>
<td>&lt;25%</td>
<td>1</td>
<td>6.7</td>
</tr>
<tr>
<td>25%-50%</td>
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<td>6.7</td>
</tr>
<tr>
<td>&gt;75%</td>
<td>12</td>
<td>80</td>
</tr>
<tr>
<td>Iliopsoas release</td>
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<td>&gt;75%</td>
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<tr>
<td>&lt;25%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>25%-50%</td>
<td>1</td>
<td>6.7</td>
</tr>
<tr>
<td>51%-75%</td>
<td>3</td>
<td>20.0</td>
</tr>
<tr>
<td>&gt;75%</td>
<td>11</td>
<td>73.3</td>
</tr>
<tr>
<td>Labral repair</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>&lt;25%</td>
<td>6</td>
<td>40.0</td>
</tr>
<tr>
<td>25%-50%</td>
<td>1</td>
<td>6.7</td>
</tr>
<tr>
<td>51%-75%</td>
<td>5</td>
<td>33.3</td>
</tr>
<tr>
<td>&gt;75%</td>
<td>3</td>
<td>20.0</td>
</tr>
<tr>
<td>Osteoplasty of femoral head-neck junction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>&lt;25%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>25%-50%</td>
<td>3</td>
<td>20.0</td>
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<tr>
<td>51%-75%</td>
<td>4</td>
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<tr>
<td>&gt;75%</td>
<td>8</td>
<td>53.3</td>
</tr>
<tr>
<td>Acetabuloplasty</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>&lt;25%</td>
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<tr>
<td>51%-75%</td>
<td>2</td>
<td>13.3</td>
</tr>
<tr>
<td>&gt;75%</td>
<td>4</td>
<td>26.7</td>
</tr>
<tr>
<td>Arthroscopy on acute hip dislocation without fracture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never</td>
<td>6</td>
<td>40</td>
</tr>
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<td>60</td>
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<td>0</td>
<td>0</td>
</tr>
<tr>
<td>&gt;75%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Arthroscopy on acute acetabular fracture with or without dislocation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never</td>
<td>8</td>
<td>53.3</td>
</tr>
<tr>
<td>&lt;25%</td>
<td>7</td>
<td>46.7</td>
</tr>
<tr>
<td>25%-50%</td>
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<td>0</td>
</tr>
<tr>
<td>51%-75%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>&gt;75%</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Table 1.** Percentage of Different Arthroscopic Procedures Performed by Participants

**Figure 2.** Number of cases per surveyed arthroscopist.
<table>
<thead>
<tr>
<th>Study Title</th>
<th>Year</th>
<th>IAFE Presentation</th>
<th>Treatment</th>
<th>Study Recommendations/Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complications in hip arthroscopy⁸</td>
<td>1996</td>
<td>Abdominal pain</td>
<td>Close observation</td>
<td>Careful fluid management, tight control of pump pressure, and application of general anesthesia</td>
</tr>
<tr>
<td>Cardiac arrest as a result of intra-abdominal extravasation of fluid during arthroscopic removal of a loose body from the hip joint of a patient with an acetabular fracture¹⁰</td>
<td>1998</td>
<td>Intra-abdominal compartment syndrome and cardiopulmonary arrest</td>
<td>Exploratory laparotomy</td>
<td>Do not advocate hip arthroscopic procedures for acute or healing acetabular fractures</td>
</tr>
<tr>
<td>Complications of hip arthroscopy³</td>
<td>2001</td>
<td>Not reported</td>
<td>Laparoscopy and CT-guided paracentesis</td>
<td>Careful attention to pump mechanics and pump pressure and strict attention to outflow</td>
</tr>
<tr>
<td>Intra- and retroperitoneal irrigation liquid after arthroscopy of the hip joint¹¹</td>
<td>2008</td>
<td>Core body temperature drop with abdominal pain</td>
<td>Close observation</td>
<td>Close monitoring of body temperature</td>
</tr>
<tr>
<td>Abdominal compartment syndrome during hip arthroscopy⁹</td>
<td>2009</td>
<td>Hypotension, patient becoming unresponsive, and intubation</td>
<td>Emergent mini-laparotomy</td>
<td>Close monitoring of fluid pump settings, frequent evaluation of abdomen, and tight hemodynamic control by anesthesia</td>
</tr>
<tr>
<td>Abdominal fluid extravasation during hip arthroscopy¹</td>
<td>2010</td>
<td>Abdominal distension</td>
<td>Furosemide and bedside paracentesis</td>
<td>Maintenance of core body temperature, frequent abdominal examinations, pH and cardiac monitoring, use of diuretics, paracentesis, and a low threshold for a general surgical consultation, as well as exploratory laparotomy if abdominal compartment syndrome is suspected</td>
</tr>
<tr>
<td>Intrathoracic fluid extravasation after hip arthroscopy¹²</td>
<td>2010</td>
<td>Shortness of breath</td>
<td>Close observation</td>
<td>Five warning signs of arthroscopic fluid extravasation: (1) inability to distend joint, (2) increased fluid requirement to maintain distension, (3) frequent cutoff of pump irrigation systems, (4) abdominal and thigh distension, and (5) acute hypothermia</td>
</tr>
<tr>
<td>Abdominal compartment syndrome after hip arthroscopy⁷</td>
<td>2010</td>
<td>Abdominal distension and elevated bladder and peak inspiratory pressures</td>
<td>Emergent exploratory laparotomy</td>
<td>Emergent laparotomy and abdominal decompression with delayed closure in suspected cases</td>
</tr>
</tbody>
</table>
Different preventative measures were suggested by the MAHORN members. In 13 cases (33%) lowering the pump settings to prevent fluid extravasation was recommended. In 10 cases (25%) a combination of lowered pump settings and delaying iliopsoas tenotomy to the end of the case was suggested. The remaining complications were attributed to extended capsulotomies, prolonged operative times, and other unknown factors. The surveyed arthroscopists suggested different monitoring measures intraoperatively and postoperatively to account for possible IAFE. In 25 cases (63%) periodic monitoring of abdominal distension intraoperatively was suggested. Other recommendations included strict control of pump settings, careful hemodynamic monitoring and body temperature monitoring by anesthesia, and finally recording of bladder pressures to identify early fluid extravasation.

**Risk Analysis**

The mean pump pressure in reported cases of symptomatic IAFE (69.42 mm Hg; range, 45 to 90 mm Hg) was significantly higher than the general pump pressure setting reported by all 15 surveyed participants.
Although most surveyed participants (14 surgeons [93.3%]) performed an iliopsoas tenotomy on less than 25% of their patients, 25 of the 40 extravasation cases (63%) had an iliopsoas tenotomy performed. On the basis of the contingency table for the association of this variable (dichotomized as yes or no) with the incidence of symptomatic IAFE, there was a strong association between concomitant iliopsoas tenotomy and fluid extravasation ($\chi^2 = 6.54, P < .001$, Fisher exact test). Using contingency tables, we did not find any strong associations between symptomatic IAFE incidence and performing a capsulotomy ($P = .715$) or peripheral compartment arthroscopy ($P = .153$).

**DISCUSSION**

Hip arthroscopy is being performed more frequently for the treatment of a variety of pathologic hip conditions. Complications of hip arthroscopy are infrequent.²⁻⁹ IAFE is a serious and potentially life-threatening complication of hip arthroscopy. In the last 2 decades, several cases of IAFE have been reported, and these are summarized in Table 2.¹⁻³⁻⁷⁻¹²

In this survey of 15 expert hip arthroscopists, 40 cases of intra-abdominal and/or retroperitoneal fluid extravasation occurred among approximately 25,650 hip arthroscopies. The prevalence of symptomatic IAFE was 0.16%. Risk factors associated with fluid extravasation included elevated pump pressures and concomitant iliopsoas tenotomy.

In this study the most common symptoms of IAFE were abdominal pain and distension. Others included hypothermia, hemodynamic instability, and shortness of breath. All patients were diagnosed either intraoperatively or in the recovery room. The diagnosis was made based on physical examination of the abdomen with supporting imaging studies, including ultrasound or CT scan. Treatment varied, including observation and intravenous furosemide, as well as an emergent laparotomy for a patient with hemodynamic instability.

Prevention of IAFE includes periodic intraoperative abdominal examination underneath the surgical drapes and careful monitoring of hemodynamic status and body temperature. Excessively high pump pressures should be avoided. Iliopsoas tenotomy should be performed toward the end of the procedure.

Treatment for IAFE (Fig 3) includes frequent abdominal examinations and hemodynamic monitoring. There should be a low threshold to obtain an ultrasound and/or CT scan to establish the volume of fluid within the abdominal and retroperitoneal cavities. Small volumes of fluid (<500 mL) can be managed with intravenous diuretics (e.g., furosemide) and careful observation. Larger volumes may require a general surgery consultation with consideration for either paracentesis in the patient in stable condition or lap-
arotomy and fluid evacuation in the patient with abdominal compartment syndrome. Having the patient lie on his or her left side may help reduce pressure on the inferior vena cava during evaluation and initial treatment.

The pathoanatomy behind this complication is a result of fluid tracking either along the iliopsoas sheath from an iliopsoas tenotomy (Figs 4 and 5) or directly intra-abdominally from an extended hip capsulotomy in the face of prolonged operative times and higher pump settings. A small- to moderate-sized accumulation will typically present with abdominal pain and distension, as well as hypothermia from the cool irrigation fluid. However, a larger collection can develop into abdominal compartment syndrome and hemodynamic instability. Excess pressure in the abdomen from the fluid collection can compress the inferior vena cava, causing decreased venous return to the heart and resultant paradoxical bradycardia and, ultimately, cardiopulmonary arrest. Renal and splanchnic circulation can also be compromised both from developing abdominal compartment syndrome and epinephrine within the irrigation fluid potentially resulting in end-organ failure.

Strengths of this study include a large volume of hip arthroscopies reviewed, all of which were performed by experienced hip arthroscopists who routinely track patient and surgical outcomes. Limitations of this study include its retrospective nature and lack of uniform technique for evaluating and defining this particular complication. Although the medical records of patients with IAFE were reviewed for data collection pertaining to this study, the reported data for the first part of the questionnaire were based on surgeons’ experiences overall, with potential recall bias. This study reported cases of symptomatic IAFE. Asymptomatic cases were potentially not detected, and hence the overall rate of this complication could be higher than reported. Finally, this study evaluated the prevalence of IAFE among a collection of very experienced hip arthroscopists. Therefore the data may not accurately apply to surgeons with less experience and lower volumes of hip arthroscopies. Future studies should include prospective collection of data or registries to better understand the incidence of this complication and associated risk factors.

CONCLUSIONS

Symptomatic IAFE after hip arthroscopy is a rare occurrence, with an approximate prevalence of 0.16%. Prevention of IAFE should include close intraoperative and postoperative monitoring of abdominal distention, core body temperature, and hemodynamic stability. Concomitant iliopsoas tenotomy and high pump pressures may be risk factors leading to symptomatic IAFE.

Acknowledgment: The authors thank all members of the MAHORN group for their time, efforts, and participation in this study.

REFERENCES

Complications of Intra-Abdominal Fluid Extravasation During Hip Arthroscopy: A Survey of the MAHORN Group

Participant ID: ________
Date questionnaire mailed: _____/_____/_______

INSTRUCTIONS: The following questions deal with complications of intra-abdominal fluid extravasation during hip arthroscopy. The goal of this questionnaire is to determine the frequency of intra-abdominal fluid extravasation and to identify risk factors leading to such a complication. For each question, please check only one box. If the directions ask you to skip a question please do so.

1. How many hip arthroscopies have you performed (total) to date?
   1a. Please specify during what time period you performed these arthroscopies (ex. 1996-present):

2. What percentage of your hip arthroscopies do you?
   2a. USE A FLUID PUMP
      □ 1 NEVER □ 2 <25% □ 3 [26-50%] □ 4 [51-75%] □ 5 >75%
      2a1. Please list your typical fluid pump setting (in mm Hg):
   2b. PERFORM A CAPSULOTOMY
      □ 1 NEVER □ 2 <25% □ 3 [26-50%] □ 4 [51-75%] □ 5 >75%
   2c. PERFORM AN IlioPSOAS RELEASE
      □ 1 NEVER □ 2 <25% □ 3 [26-50%] □ 4 [51-75%] □ 5 >75%
   2d. PERFORM A PERIPHERAL COMPARTMENT ARTHROSCOPY
      □ 1 NEVER □ 2 <25% □ 3 [26-50%] □ 4 [51-75%] □ 5 >75%
   2e. PERFORM A LABRAL REPAIR
      □ 1 NEVER □ 2 <25% □ 3 [26-50%] □ 4 [51-75%] □ 5 >75%
      2e.1 When did you start performing Labral Repairs (MM/ YYYY)?
      2e.2 How many Labral Repairs do you perform (On average) per year?
   2f. PERFORM AN OSTEOPLASTY OF THE FEMORAL HEAD NECK JUNCTION (OFHNJ)
      □ 1 NEVER □ 2 <25% □ 3 [26-50%] □ 4 [51-75%] □ 5 >75%
      2f.1 When did you start performing OFHNJ surgery (MM/ YYYY)?
      2f.2 How many OFHNJ surgeries do you perform (On average) annually?
   2g. PERFORM AN ACETABULOPLASTY
      □ 1 NEVER □ 2 <25% □ 3 [26-50%] □ 4 [51-75%] □ 5 >75%
      2g.1 When did you start performing Acetabuloplasties (MM/ YYYY)?
      2g.2 How many Acetabuloplasties do you perform (On average) per year?
   2h. PERFORM AN ARTHROSCOPY ON AN ACUTE (<3 WEEK) HIP DISLOCATION (WITHOUT FRACTURE)
      □ 1 NEVER □ 2 <25% □ 3 [26-50%] □ 4 [51-75%] □ 5 >75%
      2h.1 When did you start performing this surgery (MM/ YYYY)?
      2h.2 How many Arthroscopies on an acute hip dislocation do you perform (On average) per year?
   2i. PERFORM AN ARTHROSCOPY ON AN ACUTE (<3 WEEK) HIP FRACTURE (W/ OR W/O DISLOCATION)
      □ 1 NEVER □ 2 <25% □ 3 [26-50%] □ 4 [51-75%] □ 5 >75%
      2i.1 When did you start performing this surgery (MM/ YYYY)?
      2i.2 How many Arthroscopies on an acute hip fracture do you perform (On average) per year?

3. Have you had any cases of intra-abdominal fluid extravasation during or after hip arthroscopy?
   □ 1 YES (Please Proceed to Annex I on the next page)
   □ 2 NO

Children's Hospital Boston – Department of Orthopaedic Surgery – Division of Sports Medicine

**Figure 1.** Survey sent to arthroscopists. (A) Set of questions regarding arthroscopists’ general experience. (B) Survey pertaining exclusively to cases of IAFE.
Complications of Intra-Abdominal Fluid Extravasation During Hip Arthroscopy:
A Survey of the MAHORN Group

ANNEX I

For each of your hip arthroscopy cases complicated by intra-abdominal fluid extravasation please complete ONE set of
the following details specific to that particular case. (Please duplicate per need)

<table>
<thead>
<tr>
<th>Participant ID: ___</th>
<th>Patient Number: 01</th>
</tr>
</thead>
</table>

1. WAS A FLUID PUMP USED
   - YES, PLEASE SPECIFY THE HIGHEST PRESSURE SETTING USED DURING THE SURGERY: NO

2. WAS AN Iliopsoas Tenotomy Performed
   - YES, PLEASE SPECIFY AT WHAT POINT IN THE CASE IT WAS CARRIED OUT: NO

3. WAS A CAPSULOTOMY PERFORMED?
   - YES NO

4. WAS A PERIPHERAL COMPARTMENT ARTHROSCOPY PERFORMED?
   - YES NO

5. WAS THERE A DROP IN THE PATIENT'S BODY TEMPERATURE?
   - NO

6. WAS THERE ANY EVIDENCE OF HEMODYNAMIC INSTABILITY?
   - NO

7. DID THE PATIENT EXPERIENCE ANY SHORTNESS OF BREATH POST-OPERATIVELY?
   - NO

8. PLEASE DESCRIBE ANY OTHER PRESENTING SYMPTOMS EITHER INTRA- OR POST-OPERATIVELY

9. PLEASE SPECIFY THE LENGTH OF THE CASE (in minutes):

10. PLEASE SPECIFY WHEN (in minutes after start of case) AND HOW WAS THE IAPE DETECTED:

11. WAS A TREATMENT UNDERTAKEN ONCE THE EXTRAVASATION WAS DETECTED?
    - YES NO
    IF YES, PLEASE SPECIFY THE TYPE OF TREATMENT USED:

12. DO YOU HAVE ANY IMAGING OF THE EXTRAVASATION?
    - YES (If yes, please provide a copy) NO
    12a. PLEASE SPECIFY THE LOCATION OF THE EXTRAVASATION:
    12b. PLEASE SPECIFY THE VOLUME (in liters) OF EXTRAVASATED FLUID:
    12c. PLEASE LIST ANY OTHER FINDINGS YOU HAD:

13. PLEASE DESCRIBE THE FINAL OUTCOME OF THE COMPLICATION:

14. WHAT FACTORS DO YOU ASSOCIATE WITH THE EXTRAVASATION?

15. WHAT FACTORS DO YOU THINK MAY HAVE PREVENTED THIS COMPLICATION?

16. WHAT ADDITIONAL MEASURES CAN BE TAKEN TO MONITOR FOR THIS COMPLICATION EITHER INTRA-OPERATIVELY OR POST-OPERATIVELY?

17. WAS A HIP FRACTURE PRESENT?
    - YES NO
Is there a relationship between psoas impingement and increased trochanteric retroversion?

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Submitted 2 January 2015; Revised 5 February 2015; revised version accepted 25 February 2015

ABSTRACT

The concept of psoas impingement secondary to a tight or inflamed iliopsoas tendon causing impingement of the anterior labrum during hip extension has been suggested. The purpose of this study was to assess the relationship between the lesser trochanteric version (LTV) in symptomatic patients with psoas impingement as compared with asymptomatic hips. The femoral neck version (FNV) and LTV were evaluated on axial magnetic resonance imaging, as well as the angle between LTV and FNV. Data from 12 symptomatic patients and 250 asymptomatic patients were analysed. The mean, range and standard deviations were calculated. Independent t-tests were used to determine differences between groups. The lesser trochanteric retroversion was significantly increased in patients with psoas impingement as compared with asymptomatic hips (31.1° ± 6.5 versus 24.2° ± 11.5, P < 0.05). The FNV (9° ± 8.8 versus 14.1° ± 10.7, P > 0.05) and the angle between FNV and LTV (40.2° ± 9.7 versus 38.3° ± 9.6, P > 0.05) were not significantly different between groups. In conclusion, the lesser trochanteric retroversion is significantly increased in patients with psoas impingement as compared with asymptomatic hips.

INTRODUCTION

The iliopsoas muscle-tendon unit is formed from a confluence of the psoas and iliacus muscles, which originate from the lumbar vertebrae and pelvis, respectively. The iliopsoas tendon runs beneath the inguinal ligament to insert on to the anteromedial surface of the lesser trochanter [1]. Recently, anatomic variance has been reported that describes a double, and triple-banded iliopsoas tendon in 64.2 and 7.5% of the patients, respectively [2].

Iliopsoas impingement refers to an anterior labral injury due to the direct contact by the iliopsoas tendon. The location of these anterior labral injuries is the 3 o’clock position at the iliopsoas notch without any extension of the injury into the anterosuperior labrum [3–5]. The location of these tears is directly adjacent to the psoas tendon where it lies within the hip joint capsule [6]. These specific acetabular labral injuries have not been attributed to any of the known etiologies of labral injuries (femoroacetabular impingement, trauma, dysplasia, capsular laxity or osteoarthritis) [7].

Psoas impingement may be related to a: (i) tight or inflamed iliopsoas tendon causing impingement of the anterior labrum during hip extension, (ii) psoas scarred or adherent to the anterior capsulo-labral complex, (iii) a hyperactive iliocapsulares muscle causing a traction phenomenon [3].

A tight psoas tendon (a tense psoas tendon lying on the anterior labrum and producing labral contusion) is a common finding during hip arthroscopy in patients with symptomatic psoas impingement, the cause of the tightening has not been yet explored. In a previous study, a higher risk for inferior clinical outcomes was showed in patients
with increased FNV, however in those patients, lesser trochanteric version (LTV) was not assessed [8].

The purpose of this study was to assess the amount of LTV in patients with symptomatic psoas impingement and compare that to patients with asymptomatic hips. The hypothesis was that increased retroversion of the lesser trochanter would be found in patients with psoas impingement.

METHODS

Thirty-four patients with psoas impingement as a main diagnosis during a 7-year period from January 2007 to January 2014 from a single surgeon database were retrospectively reviewed. These cases were compared with 320 magnetic resonance imaging (MRI) of the asymptomatic side in patients who underwent examination for hip pain between January 2006 and January 2010.

The inclusion criteria were, for the symptomatic group: (i) patients with diagnosis of psoas impingement not responsive to conservative treatment, (ii) surgical confirmation of the psoas impingement by injury of the extrarticular margin of the labrum at 3 o’clock and a tight psoas in ~5°–10° of hip extension with no traction (Supplementary video), (iii) records available for review and confirmation on physical examination and (iv) MRI available for review including McKibbin protocol available for review of the asymptomatic contralateral side.

The exclusion criteria were: (1) a doubtful diagnosis of psoas impingement not positive clinical findings of psoas impingement with no evidence of a typical tightness and labral injury at the classic location, (2) prior hip fracture or surgery, (3) lesser trochanteric deformity (previous fracture, bone tumors, etc), (4) low quality or incomplete MRI and (5) incomplete records for review.

The diagnosis of psoas impingement was based on comprehensive history, physical examination and imaging assessment [7]. A surgical finding of a 3 o’clock labral injury beneath to a tight iliopsoas tendon in extension of the hip was considered necessary for detection of psoas impingement.

The medical records of all patients meeting the inclusion and exclusion criteria were reviewed under institutional approval.

Relevant demographic and clinical data, including age, gender, symptomatic side, pain characteristics, clinical tests, duration of symptoms until diagnosis and other associated hip conditions were noted for the symptomatic group. The age, gender and asymptomatic side were noted for the asymptomatic group.

The MRI measurements were obtained through the software Virtual Radiology Enterprise Connect PACS (Philips Healthcare Informatics, Inc.—The Netherlands). The axial cuts of the pelvis and knee obtained from the McKibbin protocol were utilized in this study for the evaluation of the angles. Three parameters were assessed: FNV, LTV and the angle between the femoral neck version and lesser trochanter version (FNVLTVa). The measurements were expressed in degrees.

The angles were measured using a new method based on studies performed by Unlu et al. [9] and Shon et al. [10] This new method was developed for a previous study about lesser trochanteric anatomy (in press). A previous analysis of the first 30 measurements in asymptomatic hips was made by interclass correlation coefficient (ICCs), with a 95% confidence interval for inter and intra-examiner. The ICCs for all measurements by examiner number one ranged from 0.896 to 0.923. The ICCs for all measurements by examiner number two ranged from 0.788 to 0.952. The ICCs for both examiners together ranged from 0.826 to 0.906.

The measurement process of the method was as follows: (i) two centroids were positioned in the body of lesser Trochanter or femoral neck, one in the midline of the basis and a second one at the border of the tip as seen in Figs. 1A and B, (ii) the angle of the line passing between the middle of both centroids and horizontal line was called lesser trochanter or femoral neck axis, (iii) the angle between the lesser trochanter axis or femoral neck axis and the posterior condylar axis (Fig. 1C) represented the LTV and the FNV, respectively.

Additionally, the angle between FNV and LTV was calculated through the formula: FNVLTVa = FNV – LTV.

The mean, range and standard deviations were calculated. Independent t-tests were used to determine differences between groups.

RESULTS

Twelve patients with psoas impingement and 250 asymptomatic hips met the inclusion criteria (Fig. 2).

The mean age of the included symptomatic patients was 40 years (range, 20 to 57 years) at time of diagnosis. Eight patients were female (75%) and the left side was the most commonly affected (eight cases, 75%). All 12 patients complained of groin pain, difficulty rising from a seated position and limited physical activities. All patients had positive straight leg raise test against resistance and were tender on palpation of the groin. Furthermore, the
diagnosis of psoas impingement was confirmed in all cases at arthroscopy by the finding of a 3 o’clock labral injury adjacent to a tight iliopsoas tendon as defined in the introduction section. Other clinical characteristics and associated problems are shown in Table I.

The asymptomatic group included patients with a mean age of 39.48 years (range, 14 to 73 years) at time of diagnosis. One hundred and sixty four patients were female (65.6%) and the right side was the most commonly assessed (140 cases, 56%).

**DISCUSSION**

The result of this study suggest that lesser trochanter retroversion is significantly increased in patients with psoas impingement. However, this study found that FNV and the angle between FNVLTV are similar to that of the asymptomatic hips.

This study contributes to the understanding of psoas impingement pathomechanics and lends value to the diagnostic approach of patients presenting with groin pain, difficulty rising from seated position and positive straight leg raise test against resistance. Furthermore, the evaluation of the LTV could provide an additional factor to decide the treatment in patients with suspected psoas impingement.

Alpert et al. dissected eight hip joints and described the anatomic relationship of the iliopsoas tendon with the acetabular labrum. In all cases, they found the iliopsoas tendon located directly anterior to the anterosuperior capsulolabral complex at the 2 to 3 o’clock position. This study suggests that the close anatomic relationship of the
psoas tendon to the anterior capsulolabral complex may lead to labral injury and higher possible incidence when the iliopsoas tendon is tight [11].

From an anatomic point of view, the psoas tendon could be tight due to a large femoral head, an anatomical abnormality around the pectineal eminence (bony prominence beneath the psoas tendon when it passes anterior to the hip), or a more anteverted native or artificial femoral head [12]. Phillipon described the consistent anatomical relationship of the lesser trochanter with the psoas insertion [2]. Considering that the psoas tendon makes an obtuse angle over the pectineal eminence and femoral head, which increases with hip extension, a more retroverted lesser trochanter may elevate contact pressures beneath the tendon thus contributing to the anterior impingement phenomenon.

Although Unlu et al. [9] observed a constant relationship between the lesser trochanter and posterior femoral condyles in 59 hips (34.1° SD ± 3.0°), this study could not confirm similar results. Of the 250 asymptomatic hips assessed in this study with the described method the mean LTV was −24.2° (SD ± 11.5°).

To further show the anatomic variation in LTV, a statistical significant difference was found between asymptomatic hips and psoas impingement hips, with a more negative and smaller range of variability as seen in Fig. 3. Additionally, this finding may indicate that lesser trochanteric retroversion may predispose one to psoas impingement.

Table I. Demographic data and other associated conditions in symptomatic patients

<table>
<thead>
<tr>
<th>Case</th>
<th>Age (y)</th>
<th>Gender</th>
<th>Side</th>
<th>Other associated conditions</th>
</tr>
</thead>
<tbody>
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Table II. Comparison between the patients with symptomatic psoas impingement and asymptomatic hips

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To date, most of the studies reporting psoas impingement are related to hip replacements [1, 13–16]. In this case, impingements can be related to malposition or large size of the acetabular component, producing a pulley beneath the tendon [17]. However, in cases of psoas impingement with a good position and a normal size of the acetabular component, a relative retroversion of the lesser trochanter due to an increased anteversion of the femoral component could explain part of the problem.

Iliopsoas impingement may be present in both artificial and natural hips, and as Yoshio et al. [12] reported, the most important pulley of the psoas tendon is the prosthetic or native femoral head. Interestingly, the result of the current study found the mean femoral version was similar to the normal value reported in the literature [18].

Furthermore, the angle between FNV and LTV was similar between psoas impingement and asymptomatic hips in this study, suggesting that only the increased retroversion of the lesser trochanter could be an important contributing factor for psoas impingement.

The anatomically retroverted lesser trochanter may help explain why patients with normal anteversion could present with psoas tendon pathology. However, psoas impingement should also be understood as a multifaceted problem that can include scarred or adherent psoas tendon, repetitive traction injury, prosthesis malposition, increased femoral anteversion and hyper-active iliocapsularis muscle [3].

Limitations of this study include: (i) the sample size limits the generalizability of the results, however, psoas impingement is a rare diagnosis even in hip centers and the sample of this report is comparable with previous reports [3], and the Post-Hoc analysis revealed a power of 92.2%, (ii) 22 out of 34 cases had unavailable MRI or non-complete MRI for measuring the angles with the knee as a reference. Exhaustive attempts were made to acquire adequate MRI without success. (iii) Some patients had other associated conditions that could be the cause of the groin pain.

**CONCLUSION**

The lesser trochanteric retroversion is significantly increased in patients with symptomatic psoas impingement as compared with asymptomatic hips.

**SUPPLEMENTARY DATA**

Supplementary data are available at Journal of Hip Preservation Surgery online.
CONFLICT OF INTEREST STATEMENT
None declared.

REFERENCES
Is there a relationship between psoas impingement and increased trochanteric retroversion?

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². Department of Orthopaedic Surgery, University of Antioquia, Medellin, Colombia, USA
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Submitted 2 January 2015; Revised 5 February 2015; revised version accepted 25 February 2015

ABSTRACT
The concept of psoas impingement secondary to a tight or inflamed iliopsoas tendon causing impingement of the anterior labrum during hip extension has been suggested. The purpose of this study was to assess the relationship between the lesser trochanteric version (LTV) in symptomatic patients with psoas impingement as compared with asymptomatic hips. The femoral neck version (FNV) and LTV were evaluated on axial magnetic resonance imaging, as well as the angle between LTV and FNV. Data from 12 symptomatic patients and 250 asymptomatic patients were analysed. The mean, range and standard deviations were calculated. Independent t-tests were used to determine differences between groups. The lesser trochanteric retroversion was significantly increased in patients with psoas impingement as compared with asymptomatic hips (31.1° ± 6.5 versus 24.2° ± 11.5, P < 0.05). The FNV (9° ± 8.8 versus 14.1° ± 10.7, P > 0.05) and the angle between FNV and LTV (40.2° ± 9.7 versus 38.3° ± 9.6, P > 0.05) were not significantly different between groups. In conclusion, the lesser trochanteric retroversion is significantly increased in patients with psoas impingement as compared with asymptomatic hips.

INTRODUCTION
The iliopsoas muscle-tendon unit is formed from a confluence of the psoas and iliacus muscles, which originate from the lumbar vertebrae and pelvis, respectively. The iliopsoas tendon runs beneath the inguinal ligament to insert on to the anteromedial surface of the lesser trochanter [1]. Recently, anatomic variance has been reported that describes a double, and triple-banded iliopsoas tendon in 64.2 and 7.5% of the patients, respectively [2].

Iliopsoas impingement refers to an anterior labral injury due to the direct contact by the iliopsoas tendon. The location of these anterior labral injuries is the 3 o’clock position at the iliopsoas notch without any extension of the injury into the anterosuperior labrum [3–5]. The location of these tears is directly adjacent to the psoas tendon where it lies within the hip joint capsule [6]. These specific acetabular labral injuries have not been attributed to any of the known etiologies of labral injuries (femoroacetabular impingement, trauma, dysplasia, capsular laxity or osteoarthritis) [7].

Psoas impingement may be related to a: (i) tight or inflamed iliopsoas tendon causing impingement of the anterior labrum during hip extension, (ii) psoas scarred or adherent to the anterior capsulo-labral complex, (iii) a hyperactive iliocapsulares muscle causing a traction phenomenon [3].

A tight psoas tendon (a tense psoas tendon lying on the anterior labrum and producing labral contusion) is a common finding during hip arthroscopy in patients with symptomatic psoas impingement, the cause of the tightening has not been yet explored. In a previous study, a higher risk for inferior clinical outcomes was showed in patients
with increased FNV, however in those patients, lesser trochanteric version (LTV) was not assessed [8].

The purpose of this study was to assess the amount of LTV in patients with symptomatic psoas impingement and compare that to patients with asymptomatic hips. The hypothesis was that increased retroversion of the lesser trochanter would be found in patients with psoas impingement.

METHODS

Thirty-four patients with psoas impingement as a main diagnosis during a 7-year period from January 2007 to January 2014 from a single surgeon database were retrospectively reviewed. These cases were compared with 320 magnetic resonance imaging (MRI) of the asymptomatic side in patients who underwent examination for hip pain between January 2006 and January 2010.

The inclusion criteria were, for the symptomatic group: (i) patients with diagnosis of psoas impingement not responsive to conservative treatment, (ii) surgical confirmation of the psoas impingement by injury of the extrarticular margin of the labrum at 3 o’clock and a tight psoas in ~S°–10° of hip extension with no traction (Supplementary video), (iii) records available for review and confirmation on physical examination and (iv) MRI available for review including McKibbin protocol controlling rotation from the knee to the femoral neck by securing the feet in functional walking position. And the inclusion criteria for the asymptomatic group were: (a) patients who underwent physical examination for unilateral hip pain and (b) MRI with McKibbin protocol available for review of the asymptomatic contralateral side.

The exclusion criteria were: (1) a doubtful diagnosis of psoas impingement on the symptomatic group defined as positive clinical findings of psoas impingement with no evidence of a typical tightness and labral injury at the classic location, (2) prior hip fracture or surgery, (3) lesser trochanteric deformity (previous fracture, bone tumors, etc), (4) low quality or incomplete MRI and (5) incomplete records for review.

The diagnosis of psoas impingement was based on comprehensive history, physical examination and imaging assessment [7]. A surgical finding of a 3 o’clock labral injury beneath to a tight iliopsoas tendon in extension of the hip was considered necessary for detection of psoas impingement.

The medical records of all patients meeting the inclusion and exclusion criteria were reviewed under institutional approval.

Relevant demographic and clinical data, including age, gender, symptomatic side, pain characteristics, clinical tests, duration of symptoms until diagnosis and other associated hip conditions were noted for the symptomatic group. The age, gender and asymptomatic side were noted for the asymptomatic group.

The MRI measurements were obtained through the software Virtual Radiology Enterprise Connect PACS (Philips Healthcare Informatics, Inc.—The Netherlands). The axial cuts of the pelvis and knee obtained from the McKibbin protocol were utilized in this study for the evaluation of the angles. Three parameters were assessed: FNV, LTV and the angle between the femoral neck version and lesser trochanter version (FNLTVa). The measurements were expressed in degrees.

The angles were measured using a new method based on studies performed by Unlu et al. [9] and Shon et al. [10] This new method was developed for a previous study about lesser trochanteric anatomy (in press). A previous analysis of the first 30 measurements in asymptomatic hips was made by interclass correlation coefficient (ICCs), with a 95% confidence interval for inter and intra-examiner. The ICCs for all measurements by examiner number one ranged from 0.896 to 0.923. The ICCs for all measurements by examiner number two ranged from 0.788 to 0.952. The ICCs for both examiners together ranged from 0.826 to 0.906.

The measurement process of the method was as follows: (i) two centroids were positioned in the body of lesser Trochanter or femoral neck, one in the midline of the basis and a second one at the border of the tip as seen in Figs. 1A and B, (ii) the angle of the line passing between the middle of both centroids and horizontal line was called lesser trochanter or femoral neck axis, (iii) the angle between the lesser trochanter axis or femoral neck axis and the posterior condylar axis (Fig. 1C) represented the LTV and the FNV, respectively.

Additionally, the angle between FNV and LTV was calculated through the formula: FNLTVa = FNV – LTV.

The mean, range and standard deviations were calculated. Independent t-tests were used to determine differences between groups.

RESULTS

Twelve patients with psoas impingement and 250 asymptomatic hips met the inclusion criteria (Fig. 2).

The mean age of the included symptomatic patients was 40 years (range, 20 to 57 years) at time of diagnosis. Eight patients were female (75%) and the left side was the most commonly affected (eight cases, 75%). All 12 patients complained of groin pain, difficulty rising from a seated position and limited physical activities. All patients had positive straight leg raise test against resistance and were tender on palpation of the groin. Furthermore, the
diagnosis of psoas impingement was confirmed in all cases at arthroscopy by the finding of a 3 o’clock labral injury adjacent to a tight iliopsoas tendon as defined in the introduction section. Other clinical characteristics and associated problems are shown in Table I.

The asymptomatic group included patients with a mean age of 39.48 years (range, 14 to 73 years) at time of diagnosis. One hundred and sixty four patients were female (65.6%) and the right side was the most commonly assessed (140 cases, 56%).

The lesser trochanter was significantly ($P < 0.05$) more retroverted in patients with psoas impingement as compared with the asymptomatic group ($-31.1^\circ$ SD ± 6.5 versus $-24.2^\circ$ SD ± 11.5). The FNV between groups and the angle between FNVLTV resulted in no significant differences between the two groups (Table II and Fig. 3). Post-hoc power analysis indicated that the power to detect the described findings was 92.2%.

DISCUSSION

The result of this study suggest that lesser trochanter retroversion is significantly increased in patients with psoas impingement. However, this study found that FNV and the angle between FNVLTV are similar to that of the asymptomatic hips.

This study contributes to the understanding of psoas impingement pathomechanics and lends value to the diagnostic approach of patients presenting with groin pain, difficulty rising from seated position and positive straight leg raise test against resistance. Furthermore, the evaluation of the LTV could provide an additional factor to decide the treatment in patients with suspected psoas impingement.

Alpert et al. dissected eight hip joints and described the anatomic relationship of the iliopsoas tendon with the acetabular labrum. In all cases, they found the iliopsoas tendon located directly anterior to the anterosuperior capsulolabral complex at the 2 to 3 o’clock position. This study suggests that the close anatomic relationship of the
Psoas tendon to the anterior capsulolabral complex may lead to labral injury and higher possible incidence when the iliopsoas tendon is tight [11].

From an anatomic point of view, the psoas tendon could be tight due to a large femoral head, an anatomical abnormality around the pectineal eminence (bony prominence beneath the psoas tendon when it passes anterior to the hip), or a more anteverted native or artificial femoral head [12]. Phillipon described the consistent anatomical relationship of the lesser trochanter with the psoas insertion [2]. Considering that the psoas tendon makes an obtuse angle over the pectineal eminence and femoral head, which increases with hip extension, a more retroverted lesser trochanter may elevate contact pressures beneath the tendon thus contributing to the anterior impingement phenomenon.

Although Unlu et al. [9] observed a constant relationship between the lesser trochanter and posterior femoral chondyles in 59 hips (34.1° SD ± 3.0°), this study could not confirm similar results. Of the 250 asymptomatic hips assessed in this study with the described method the mean LTV was 24.2° (SD ± 11.5°). To further show the anatomic variation in LTV, a statistical significant difference was found between asymptomatic hips and psoas impingement hips, with a more negative and smaller range of variability as seen in Fig. 3. Additionally, this finding may indicate that lesser trochanteric retroversion may predispose one to psoas impingement.

Blakenbanker et al. recently reported that the MRI is a good tool for detecting psoas impingement when an acetabular labral injury is present at the 3 o’clock position.

Table I. Demographic data and other associated conditions in symptomatic patients

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**CONCLUSION**

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**SUPPLEMENTARY DATA**

Supplementary data are available at Journal of Hip Preservation Surgery online.
CONFLICT OF INTEREST STATEMENT
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REFERENCES
Ligamentum teres: a functional description and potential clinical relevance

RobRoy L. Martin · Ian Palmer · Hal D. Martin

Abstract

Purpose The primary purpose of this study was to investigate the role the ligamentum teres has in providing hip stability using a biomechanical model. The second purpose was to review arthroscopic findings in those with a complete ligamentum teres rupture and question them regarding instability to determine how clinical findings related to the biomechanical model.

Methods A string model was created to examine ligamentum teres excursion during various hip positions. A retrospective review of 350 consecutive surgical patients identified 20 subjects with a complete ligamentum teres rupture that was not repaired at the time of surgery.

Results The model found the ligamentum teres to have the greatest excursion when the hip was externally rotated in flexion (ER/FLEX) and internally rotated in extension (IR/EXT). During operative assessment, it was noted that all 20 subjects had laxity during dynamic impingement testing when their hip was in a position of ER/FLEX. Nine (45%) of the 20 subjects with ligamentum teres rupture were available for follow-up (mean 31 months post-op). Five out of these 9 subjects noted instability: 5 of 9 with squatting (ER/FLEX) and 4 of 9 with crossing one leg behind of the other (IR/EXT). These 5 subjects had osseous risk factors that compromised hip stability including inferior acetabular insufficiency.

Conclusions The ligamentum teres may contribute to hip stability when the hip is in ER/FLEX and IR/EXT. Individuals with osseous risk factors for instability, including inferior acetabular insufficiency, may have instability with squatting (ER/FLEX) and crossing one leg behind of the other (IR/EXT).

Level of evidence IV.

Keywords Ligamentum teres rupture · Instability · Inferior acetabular insufficiency

Introduction

The function and clinical relevance of the ligamentum teres has not been well investigated [9], despite the increased awareness of pathology. A ligamentum teres lesion was the third most common arthroscopic finding [7], noted in 4–15% of individuals [1, 8, 12, 20]. Traditionally, it has been believed that the ligamentum teres does not play a significant role in joint stabilization. However, recently, this came under debate, particularly in those with capsular laxity [11, 17].

The ligamentum teres is thought to tighten with adduction, external rotation, and flexion based on its anatomical attachment [15, 20]. Limited research is available to support this theory. In 7 cadavers, adduction increased only 1.3° when the ligamentum teres was completely sectioned [10]. Reports of how the ligamentum teres is injured and its effect on hip movement are largely derived from observational information [2]. Pain, catching, popping, locking, and giving way have been noted by those with
ligamentum teres ruptures [8, 20]. This pattern of symptom presentation is not unique from other intraarticular pathologies and gives little insight to functional limitations. Byrd and Jones [8] noted 12 subjects with complete unrepaired ligamentum teres ruptures had good outcomes with an average modified Harris hip score of 90 (range 66–100) at a 25 months (range 12–60 months) average follow-up period. However, no specific functional limitations were reported for these individuals [8]. Similar, findings were reported by Haviv and O’Donnell [12] as they noted the average modified Harris hip scores improved from 70 to 86 at a 12-month follow-up period in their case series of 29 subjects. Again specific functional limitations were not reported for these individuals [12]. While short-term benefit from debridement seems positive for most subjects, the role of ligamentum teres reconstruction is being investigated [21].

The primary purpose of this study was to investigate the role the ligamentum teres has in providing hip stability using a biomechanical string model. The second purpose of this study was to review arthroscopic findings and assess for complaints of instability in those with a complete ligamentum teres rupture. The hypothesis was that hip positions that produced the greatest ligamentum teres excursion according to the biomechanical model would relate to clinical findings of instability in those with complete ruptures.

Materials and methods

A string model was developed based upon previous work by Beck et al. [3]. Plastic bones molded from a human left hemipelvis and left femur (Sawbones, Pacific Research laboratories, Inc., Vashon, WA) were utilized to recreate the dynamic relationship of the femoral head and acetabulum (Fig. 1). The ligamentum teres was simulated using a surgical grade suture (1 mm thick) secured at the insertion point on the femoral head with a suture anchor. The suture was threaded through a hole at the acetabular origin and continued along a ruler to measure ligamentum teres excursion. Two insertion points were analyzed separately: the two o’clock and three o’clock positions.

Starting from a neutral position (0° flexion, abduction, and rotation), the hip was taken into 15 specific sagittal and frontal plane positions. Angles included the following: Flexion 0°, 30°, 90°, 120°, and extension 20° combined with abduction 0°, 45°, and adduction 10°. From each of these 15 positions, the hip was then moved in the transverse plane to obtain internal rotation 0°, 15°, 30°, 45°, 60°, and external rotation 0°, 15°, 30°, 45°, 60°. Ligamentum teres excursion was defined by the length of suture that moved through the acetabular origin as the hip was moved from a neutral hip and corresponding zero ruler position, to each combination of test angles. Positive excursion represented ligamentous tension, while negative excursion represented ligamentous relaxation. Three trials were obtained in each position, and the mean ± SD was calculated. Between each of the three trials, the model was disassembled, reassembled, and reset to zero.

Statistical analysis

Test re-test reliability of the measurements was assessed using intraclass correlation coefficients (ICC) of the 3 repeated measurements. Precision of the string model was performed by calculating coefficients of variation [(mean/SD) × 100] in each position. The standard error of measure (SEM) was also calculated to further assess accuracy of the measurement. The SEM for each measurement was calculated using the formula as SEM = SD(1−r)1/2, where SD is the standard deviation and r the reliability coefficient of each measurement.

Clinical data collection

Subjects

Retrospectively, the records from 350 consecutive patients who underwent hip arthroscopy between 2003 and 2007 were reviewed. A standard physical, radiographic, and arthroscopic examination was completed on all subjects.
Hip arthroscopy was performed supine as described by Byrd [6]. Each hip was examined in a consistent fashion, beginning with probing the anterior and posterior aspect of the ligamentum teres. Complete ligamentum teres tears were entirely debrided. For avulsed tears, chondroplasty was performed at the site of avulsion. Examination continued in the internal and peripheral compartments noting and addressing significant findings as appropriate. As part of the arthroscopic examination, all patients underwent dynamic impingement testing in the same fashion as described for the clinical examination [5]. During this assessment for FAI, the hip is moved into combinations of flexion with abduction/adduction and external/internal rotation.

Twenty (5.7%) patients with arthroscopically confirmed complete ligamentum teres tears were identified. All subjects were also noted to have FAI (19 cam and 1 Pincer) and labral tears that were surgically addressed, as previously described [15, 19]. Subjects included 13 females and 7 males with an average age of 41.3 years (range 22–61 SD 12.6). The average duration of symptoms was 3.3 years (range 2 months to 14 years SD 50 months). Thirteen (65%) of 20 reported an atraumatic mechanism of injury. All 20 subjects reported to be very athletic with activities including running, soccer, weight lifting, golf, and cycling, prior to injury. Nine subjects reported high occupational demands, which included military, police, personal training, karate, yoga, collegiate soccer, and professional dance. Nine (45%) of the 20 subjects were able to be contacted by phone for follow-up and were questioned whether they had complaints of instability. Institutional Review Board approval was obtained for this study.

Results

The mean ICC for test re-test reliability of the measures was >0.99 (range 0.96–1.0). Coefficients of variation ranged from 0.0 to 0.9%. The average SEM was <0.001 (range 0–0.01). These results indicated the methods for measuring ligamentum teres excursion were reliable and accurate.

When interpreting the ligamentum teres string model, positive excursion represented ligamentous tension, while negative excursion represented ligamentous relaxation. Figures 2, 3, 4, respectively, represent ligamentum teres excursion in 120° and 90° of flexion and 20° extension. Total change in ligamentum teres length at 30° and 0° of flexion was minimal (<1 cm) and, therefore, not represented graphically. Maximum ligamentum teres tension was noted when the hip was in: (1) 90° flexion, 0° adduction and 60° external rotation (2.0 cm of positive excursion) and (2) 20° extension, 0° adduction, and 60° internal rotation (1.7 cm of positive excursion). It was noted that these two positions of maximal tension were similar, with respect to hip orientation, to that obtained when an individual: (1) squats and (2) attempts to cross one leg behind the other when standing.

All 20 subjects were noted to have laxity when the hip was positioned in flexion and external rotation during arthroscopic dynamic impingement testing. Nine (45%) subjects were able to be contacted for follow-up at an average of 29 months post-op (range 7–52 months). Five of these 9 noted instability, with all 5 having instability
squatting and 4 of 5 having instability when attempting to cross their involved leg behind their uninvolved when standing. Table 1 presents pattern of instability, results of radiographic examination, age, and gender for these 9 subjects. Two subjects did not have radiographs available to determine inferior acetabular insufficiency. Two subjects had symptoms so severe that they decided to have a total hip replacement at another facility and, therefore, current post-op modified Harris hip scores were not obtained. The average modified Harris hip score for the remaining 4 individuals with instability was 72 compared to 87 in those without instability.

**Discussion**

The most important finding of the present study was that the ligamentum teres may serve as an important stabilizer in a squatting position (hip flexion and externally rotation) in those with osseous instability. This study is significant in that it helps to define the function of the ligamentum teres and relates these findings to possible functional limitations in subjects with complete ruptures. Our model found the combination of external rotation in 90° flexion (ER/FLEX) and internal rotation in 20° extension (IR/EXT) placed the ligamentum teres under the greatest tension. All subjects with complete ligamentum teres ruptures were noted to have laxity during arthroscopic impingement assessment when the hip was in a position of flexion and external rotation. Fifty-five percent of subjects with follow-up information noted instability, particularly with squatting. The subjects with complaints of instability had osseous findings that compromised hip stability.

The laboratory model results suggesting the ligamentum teres contributes in stability when the hip is in flexion with external rotation was confirmed during arthroscopic assessment. Arthroscopic dynamic impingement testing for FAI incorporates flexion with external rotation. Therefore, the increase in hip laxity in those with complete ligamentum teres ruptures could be detected when in this position. It was noted while under anesthesia, gravity would cause inferior subluxation in individuals with a complete ligamentum teres rupture and compromised osseous when positioned in flexion and external rotation. The position of flexion with external rotation during arthroscopic assessment was similar, with respect to hip orientation, to that obtained when an individual squats.

Similar to the arthroscopic examination findings, the laboratory model results were also confirmed with the instability pattern in subjects with compromised osseous stability. As our laboratory model suggested, squatting (ER/FLEX) and attempting to cross the involved leg behind the other (IR/EXT) would be positions likely associated with complaints of instability in those with complete ligamentum teres ruptures. This pattern of instability was, respectively, noted in 5 of 9 and 4 of 9 individuals with follow-up information. The fact that these complaints were not present in all subjects emphasizes the importance of osseous structures in maintaining hip stability.

Osseous risk factors for hip instability have been described. These factors include a neck shaft angle greater than 140°, a center edge (CE) angle less than 23°, and acetabular index (AI) less than 13°. The results of this research also suggest inferior acetabulum insufficiency as a potential risk factor for instability. Inferior acetabular insufficiency is defined as an abnormal acetabular shape, resembling a teardrop where the lateral limb lies in close proximity to the medial limb and appears vertical. This can be identified on the standing anterior–posterior pelvic radiograph (Fig. 5). The radiographic teardrop is made up of a convergence of radiographic lines. The lateral limb of the teardrop corresponds to the floor of the cotyloid fossa while the medial limb corresponds to the lateral wall of the obturator canal. The instability in cases with inferior acetabular insufficiency becomes apparent when the hip is abducted, flexed and externally rotated. In this position, the floor of the acetabulum becomes the roof in relationship to the femur. The finding of inferior acetabular insufficiency may be an important factor for instability as all five subjects with instability were positive for inferior acetabular

<table>
<thead>
<tr>
<th>Case</th>
<th>Instability squatting</th>
<th>Instability crossing</th>
<th>NS (°)</th>
<th>CE (°)</th>
<th>AI (°)</th>
<th>IAI</th>
<th>Age</th>
<th>Gender</th>
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<td>40</td>
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<tr>
<td>4</td>
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<td>No</td>
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<tr>
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<td>49</td>
<td>F</td>
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</tbody>
</table>

NS neck shaft angle, CE center edge angle, AI acetabular index, IAI anterior acetabular insufficiency, N/A not available.
insufficiency. As noted in Table 1, the other factors of increased neck shaft angle, narrow center edge angle and small acetabular index were inconsistently present. There was one subject that had inferior acetabular insufficiency that did not have instability. However, other risk factors for instability were not present, particularly the CE angle of 40. A study to determine how these osseous factors interrelated and contribute to instability is required.

After reviewing our 20 cases of complete ligamentum teres rupture, the possibility an interrelationship between the abnormal osseous structure associated with FAI, labral tears and ligamentum teres pathology may also require investigation. All of our subjects with complete ligamentum teres ruptures had labral pathology and evidence of FAI, with 19 cam and 1 pincer. Additionally, 12 subjects reported an atraumatic onset of symptoms, which suggests an overuse or degenerative mechanism of injury. In contrast to our 100% of subjects having coexisting labral pathology, Byrd and Jones [8] noted 9 of 23 had concurrent labral and ligamentum teres pathologies. However, the population included patients with complete and partial tears of the ligamentum teres. Philippon et al. [18] retrospectively looked at 45 professional athletes with FAI and found 65% (29 of 45) had ligamentum teres pathology, with partial and complete ligamentum teres tears noted 58 and 7%, respectively. These findings raise a concern for the potential of ligamentum teres damage in a highly active population with abnormal femoral head/neck junction and/or acetabular geometry.

An obvious limitation of this study is the poor control and lack of follow-up data. We were only able to contact 9 of 20 the subjects with complete ligamentum teres ruptures, despite numerous contact attempts. However, we feel our outcome data provide some useful information, particularly to introduce theories for further investigation. Generally, the good outcome in the 4 subjects without instability was similar to that obtained from other studies investigating labral tears and FAI [4, 13, 14, 16, 18]. When specifically looking at modified Harris hip scores, our average follow-up score was 87 in these 4 subjects. This score was comparable to the follow-up score of 83 reported by Larson and Giveans in a similar population with FAI [16].

In addition to the limitations related to clinical follow-up, the potential limitation of the ligamentum teres string tension modeling must also be recognized. While the string model was able to provide some clinically relevant information, the absence of the surrounding capsule musculature as well as an intact labrum may have altered some of the tension measurements. Martin et al. [17] found the capsular ligaments to offer resistance to movement when the hip was in extension. Therefore, the increase ligamentum teres tension noted in extension with our model may be argued to be offset by the capsule. Martin et al. [17] also noted the capsular ligaments to be lax in flexion while this study found the ligamentum teres to be under increase tension. Therefore, it is plausible that the ligamentum teres may serve as more of a co-stabilizer in extension but may be the primary stabilizer in flexion, particularly when the hip is in external rotation.

Despite its limitations, the model results were validated by the dynamic impingement testing movement during surgery and clinical follow-up data with patterns of instability.

Our clinical findings suggest that patients should possibly be questioned, for diagnostic purposes, if they have instability with squatting or attempting to cross the involved leg behind the other. In subjects that have this pattern of instability, a complete ligamentum teres tear with osseous risk factors for instability may be suspected. Similarly, if a ligamentum teres rupture is known to exist, the patient may need to be carefully screened for osseous risk factors of instability for prognostic and treatment planning purposes. These are areas of further research interest.

**Conclusion**

The ligamentum teres may contribute to hip stability when the hip is in external rotation in 90° flexion and internal...
rotation in 20° extension. Individuals with osseous risk factors for instability, including inferior acetabular insufficiency, may have instability with squatting and crossing one leg behind of the other.

References
Neuromuscular Hip Biomechanics and Pathology in the Athlete

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Dynamic movement occurs at the hip joint and is characterized and constrained by the anatomy of the region, including osseous, ligamentous, and musculotendinous structures. The majority of patients who require hip arthroscopy are young, active individuals with a history of hip or groin pain. In some athletes, the onset of hip pain may be due to a traumatic event such as a fall, tackle, or collision. However, in many sports, athletes suffer a minor hip injury or perform repetitive motions that exacerbate a chronic pathologic or congenital hip condition that leads to increased capsular laxity and labral tears over time. One of the obvious benefits of arthroscopic hip surgery in this population is that it allows the surgeon to perform procedures within the hip joint with a minimal amount of postoperative morbidity, allowing for a return to sporting activities in a shorter time period. This type of surgery is relatively new, with only a few experts advancing in the field worldwide. However, this surgery is gaining popularity among sports medicine/orthopedic surgeons, and is being performed more and more on all levels of athletes and in the nonarthritic, hip-injured population alike.

Although joint mechanics for total hip joint replacements (THR) are well described, little is known with regard to hip joint mechanics in injuries such as hip labral tears that are observed in younger athletes; and although hip arthroscopic techniques have been developed and evolved over the last 5 years, the mechanisms of these injuries across various sports are not well understood. Moreover, rehabilitation protocols associated with hip arthroscopy remain rooted in THR theories and paradigms. It is evident from the literature that rehabilitation after hip arthroscopic surgery requires a mechanical foundation for its implementation during initial, intermediate, and return to sport/agility protocols. Without such a scientific foundation, the risk of an unsuccessful surgery or reinjury is greatly enhanced.
The purpose of this article is to review the literature related to the osseous, ligamentous support as well as the neuromuscular control strategies associated with hip joint mechanics. The neuromuscular contributions to hip stability and mobility with respect to gait will be provided because the data related to gait represents the largest body of knowledge regarding hip function. Further, this article will describe the probable mechanisms of injury in sporting activities most often associated with hip injury in the young athlete.

**OSSEOUS STRUCTURES CONTRIBUTING TO HIP STABILIZATION**

The adult hip is a multiaxial ball-and-socket synovial joint composed of two bony structures: the femur and the acetabulum. This bony architecture provides the hip with inherent stability. Three biomechanical and anatomic geometries of the femur and acetabulum are significant to joint stability and preservation of the labrum and articular cartilage: appropriate femoral head–neck offset, acetabular anteversion, and acetabular coverage of the femoral head. Proper function of the hip joint necessitates that the amount of offset from the femoral head to the femoral neck be enough to allow a full range of motion without impinging upon the acetabular labrum. A lack of offset from the femoral head to the femoral neck has been described as a cause for femoroacetabular impingement [1]. Flexion at the hip may cause the osseous femoral head–neck junction to come into contact with the acetabular labrum, resulting in impingement [1–3]. A large femoral head can compensate for a flat head–neck junction by simulating offset and adding stability to the joint [4].

Large variations exist in the rotational axis that characterizes the relationship between the acetabular and femoral osseous structures. The range of acetabular anteversion to femoral anteversion affects the rotation of the extremity and changes from the time of birth and through mature skeletal development. The transfer of dynamic and static load to the ligamentous and osseous structures is dependent on this relationship. Abnormal distribution of force or pressure in an incongruent joint precipitates chronic or acute injury. Normal adult acetabular positioning intersects the sagittal plane at 40° and the transverse plane at 60°, opening anteriorly and laterally [5]. The acetabulum is positioned approximately 45° caudally and 15° anteriorly [6,7]. Normal anteversion of the acetabulum is essential to maintaining a normal relationship with the femoral head and is critical in avoidance of impingement [8]. Normal range of acetabular anteversion as defined by Tonnis and Heinecke [9] is 15° to 20°, decreased anteversion is 10° to 14°, and increased anteversion is 21° to 25°. An increase in external rotation is commonly found with decreased acetabular anteversion.

In addition to recognizing acetabular anteversion, it is also important to appreciate the degree of femoral head coverage provided by the acetabulum. This can be measured radiographically as the central edge angle of Wiberg, which is defined as the angle between the horizontal line through the center of the femoral head and a line tangent to the superior and inferior acetabular rims. The normal center edge angle is 30° and a decrease in this angle (dysplasia) has been associated with rapid onset of osteoarthritis [10–13]. Center edge angles of less...
than 20° correlate with an abnormal orientation of the acetabulum, providing less than satisfactory head coverage and load transfer.

Anteversion of the femur is also important in maintaining proper static and dynamic mechanics in the hip. Anteversion of the femur diminishes with age. A healthy 1 year old has an average anteversion of 31°. This anteversion decreases to 24° at 8 years and to 15° by 15 years [14]. The McKibbin instability index is based on the sum of the angles of the femoral and acetabular anteversion. This ratio will affect range of motion. The sum of the angles of femoral and acetabular anteversion predicts instability for summed angles of 60° or more and predicts low instability for angles of less than 20°. The authors found that, of 290 hips tested, 38% had a low and 6% had a high index.

Ligamentous Structures Contributing to Hip Stabilization

The hip capsule is comprised of a series of ligaments, which can be subdivided into functional and anatomic components. The five primary ligaments discussed in the hip are the iliofemoral (lateral and medial arms), pubofemoral, ischiofemoral, the ligamentum teres femoris, and the ligamentum obicularis. The collagen structure of the hip as demonstrated by electron microscopy is similar to that of the shoulder and the elbow [15].

The iliofemoral ligament (also referred to as the Y-ligament of Bigelow) is the largest of the ligaments and reinforces the capsule anteriorly. Originating at the anterior superior iliac spine (ASIS) and the acetabular rim, it inserts at the intertrochanteric line and the front of the greater trochanter. The ischiofemoral ligament supports the capsule posteriorly, fastening the ischial portion of the acetabular rim to the neck of the femur, medial to the base of the greater trochanter. The pubofemoral ligament reinforces the capsule inferiorly, extending from the superior pubic ramus and acetabular rim to the lower femoral neck. These ligaments are connected to each other by the circular ligamentum obicularis, which circumvents the femoral neck. The ligamentum teres femoris originates at the acetabular notch from the transverse acetabular ligament, and inserts in the fovea of the femoral head.

The function of these ligaments has been well described in terms of limiting ranges of motion. There is debate in the literature over which ligament might limit what motion. Most authors agree that the iliofemoral ligament limits extension [16], the pubofemoral ligament limits abduction, and the ischiofemoral ligament limits internal rotation. It is thought that with an elongated or surgically resected iliofemoral ligament, the ligamentum teres has a limiting effect on external rotation. There is debate regarding the ligament limitation in other motions and debate as to what role is played by the functional subdivisions of each ligament (such as the lateral and medial iliofemoral ligament) [17]. The ligamentum obicularis appears to be overlooked as a major key in stability of the hip joint. Traditionally, the ligamentum obicularis was thought to be relevant only to extension by tightening the posterior capsule [18]. It now appears to play a vital role in stability, particularly in the area where the lateral arm of the
iliofemoral ligament and the orbicularis merge together and continue over the anteroinferior portion of the capsule.

Although studies have described independent motions limited by the ligaments, it is believed that they do not function independently. The ligament complex surrounding the hip acts to stabilize the hip in all ranges of motion. Fuss and Bacher [17] discussed three varieties of interconnections between the ligaments as they form the capsule: parallel fibers either join and become one ligament, join and intermingle though separate ligaments, or join by fusing at the borders (pilema, confluens and conjunction fibrarum, respectively). Fuss and Bacher performed a kinematic study on 10 intact pelves secured to a table mount. The ligaments of the hip were removed except for the iliofemoral ligament (medial and lateral arm). The hip was taken through extension, abduction, adduction and internal/external rotation movements (as guided by a grid) and the motion of the ligament was recorded. In many hips, the iliofemoral ligament appeared to lock when the hip was in pure terminal extension without rotation. The ligament moved to the lateral aspect of the femoral head in abduction or external rotation unlocking the major anterior structure. The pubofemoral ligament contribution to the capsular structures is thought to play a role in controlling this motion.

Certain in vivo studies have illustrated the importance of the ligamentous structures in providing stability to the hip joint [19–22]. While standing, the body’s center of gravity lies just posterior to the axis of the hip in the sagittal plane, which causes the pelvis to tilt posteriorly on the femoral head [19]. This tilt is opposed by the tensile forces from the stretching of the anterior capsule, implying that the energy required to stand stationary should be compensated by the ligaments without muscular contribution [19]. Gait involves ranges of motion in all three planes. The force for motion is derived from the musculature of the lower limbs, although stability could not be maintained without the ligamentous capsule. Abnormal functioning of the iliofemoral ligament has been identified as a cause for coxa sultans [20]. Owing to the relatively large tensile forces of the ligaments of the capsule, dislocation of the hip requires high impact forces, except in children, due to their relatively shallow acetabulum [21,22].

**NEUROMUSCULAR FACTORS CONTRIBUTING TO HIP STABILIZATION**

Maintaining an appropriate femoral head position within the joint capsule and labral complex is paramount to normal hip function and failure in this mechanism can lead to debilitating labral and cartilage compression in active individuals. Thus, hip congruency, although affected by, is not solely dependent upon the femoral head–acetabular bony and labral constituents for complete hip stabilization. The ligaments described above and the muscles that cross the hip joint contribute and provide for articular congruency (ie, proper joint rotation of the femoral head within the acetabular–labral complex) and maintain articular stabilization (ie, limit translations of the femoral head within the acetabular–labral complex). To accomplish this, muscles that cross the hip must act as force
regulators across a very wide range of motions by regulating their stiffness. Muscular stiffness is determined by a complex neural feedback control system. A highly regulated hierarchy of neuromuscular control strategies begins with the activation of the single fiber and progresses to the mechanical properties of the whole muscle. Discussing the exact mechanisms that are involved in this neuro-mechanical hierarchy is beyond the scope of this article, but a few of the more pertinent aspects are listed briefly below:

1. Muscle stiffness is regulated by muscle activation frequency (ie, temporal summation) [23].
2. Muscle stiffness is regulated by muscle fiber recruitment (ie, spatial summation) [24].
3. Muscle stiffness is regulated by the sarcomere length–tension relationship [25].
4. Muscle stiffness is regulated by sarcomere force-velocity relationship [26].
5. Muscle stiffness is regulated by passive sarcomere length tension relationships [27].
6. Intrafusal and extrafusal (muscle spindle) fibers feedback mechanisms [28].
7. Muscle force and moment regulation by skeletal muscle architecture [29,30].

The first six points relate a specific muscle’s function primarily to its intrinsic properties and are standard across all skeletal muscles. However, point 7, muscle stiffness regulation by skeletal muscle architecture (ie, the physical arrangement of the muscle fibers within a specific muscle) is of substantial importance at the hip given the large, “irregular” shaped muscles that cross this joint, and much work has been recently constructed in this area [31,32]. Functionally, the force generated by a muscle is proportional to its physiologic cross-sectional area (PCSA). The total excursion of a muscle is determined by its fiber length. Traditionally, fiber length were determined by dissection methods and histologic analysis; but recently, newer MRI-based technologies have been used with great success and detail [31,33,34]. Thus, from a muscle design perspective, muscle architecture results in muscle function based on unique fiber arrangements. Mechanical properties of many of the larger muscles surrounding the hip have been characterized and are presented in Table 1. Although detailed studies of muscles architecture have been conducted for the lower extremity [34], these studies often omit many of the smaller muscles (eg, piriformis, superior and inferior gemellus and obturator internus and externus) that cross the hip.

Because many of the hip muscles involve very complex geometric architectures, determining their exact mechanical influence on hip function is difficult. Computer modeling techniques enhanced by computer tomography (CT) and MRI are some of the newer techniques of estimating the complex hip muscular actions. These methods have allowed researchers to reconstruct the hip muscle geometry with “lumped parameter muscle models,” where each muscles is represented by a single line of action estimated from a centroid of the muscles taken from the a 3D reconstruction via an MRI image [31,33,34]. These “lumped parameter muscle models,” however, only allow for a one length of muscle fiber and moment arm to be estimated for each muscle path [31,33,34].
## Table 1
Muscle–tendon parameters for the hip muscles

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Physiological cross-sectional Area (cm²)</th>
<th>Peak muscle force (N)</th>
<th>Optimal fiber length (cm)</th>
<th>Pennation angle (degrees)</th>
<th>Tendon slack length (cm)</th>
<th>Tendon length/fiber length</th>
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<tr>
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<td>22.0</td>
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<td>9.5</td>
<td>3</td>
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Optimal muscle fiber length is defined as the number of sarcomeres in series, and has been shown to be a major component of maximal velocity of shortening during a contraction [26]. Muscle belly fiber lengths can be determined by methods described by Veeger et al [82], where the distance between the most proximal and most distal musculotendinous conjunctions are measured in situ then removed, macerated, and measured again via calibrated microscopic examination.

Tendon slack length is typically measured in situ prior to dissection and after muscular tissue separation. Tendon slack length represents the noncontractile element of the musculotendinous unit and each bundle’s tendon slack length is usually quantified (cm) via calibrated microscopic examination.

Pennation angle of muscle fibers represents the angle or direction of pull between the insertion and origin of the muscles. These angles are noted in situ and prior to dissection and the angle of pull can be measured with a goniometer. Of note, how researchers determine individual muscle bundles within each broad fan shaped muscle is subject to much debate. For instance, most hip anatomic studies have divided the glutus medius into at least three separate bundles based on the broad anatomic insertion sites across the pelvic–iliac crest. Similarly, some authors have combined the iliacus and psoas; while others separate their functions.

Physiologic cross-sectional area of muscle is defined as the number of sarcomeres in parallel and is reported to be directly related to the amount of tension a muscle can produce [26] (muscle mass + fiber length) / pennation angle).

Because muscle moment arms and fiber length may be different within the resting geometry of a muscle, or may change over a given range of motion for a specific muscle, using single lines of action to represent these actions may over- or underestimate each muscle’s force generating capacity given a dynamic movement [31,33,34]. Moreover, Herzog and Keurs [36] have shown that lumped parameter models do not accurately predict in vivo force–velocity behaviors for muscles with complex geometries. To illustrate this point further, Blemker and Delp [32] developed a mathematical model of the hip joint in which the complex geometries of the major muscles of the hip over a specified range of hip flexion and extension were estimated from an MRI of a single subject. This technique allowed the researchers to reconstruct and characterize the complex 3D geometries of the hip musculature and to represent each muscle with multiple muscle fibers with varying fiber lengths and with each fiber possessing its own moment arm. This 3D model highlighted the diverse behaviors (please see Figs. 6A–L and 7A–L in Blemker and Delp, *Annals Biomedical Engineering*, 2005, pp. 668–9) among individual muscle fibers within a specific hip muscle as well as illustrated the changing roles specific fibers of a particular hip muscle may have while undergoing flexion and extension [31,33,34]. The considerable change in fiber moment arms within each muscle indicates that the force generating capacity of a muscle may in fact change with different femoral, pelvic, or lumbar motions. This is also evident from the work of Arnold et al [37], who suggested that during upright standing with normal femoral anteversion, the medial hamstrings, adductor brevis, adductor longus, pectineus, and ischiocondylar portion of the adductor magnus produce internal rotation via hip internal rotation moments; the gracilis and proximal portion of the adductor magnus produce external hip rotation moments; and, the middle and distal portions of the adductor magnus have negligible rotation moments. When the hip is rotated more than 20°, or when the knee is flexed more than 30°, the rotational moment arms of the semimembranosus and semitendinosus switch from internal to external [37]. The gracilis also becomes more external with hip internal rotation and knee flexion and the moment arm of the ischiocondylar portion of the adductor magnus becomes less internal with internal hip rotation.

**FUNCTIONAL ANALYSIS OF HIP BIOMECHANICS**

In vivo estimates of hip mechanics for dynamic activities have been attempted using optical capture, accelerometer, or goniometric methods. Optical methods employ high speed cameras to capture the 3D motion of reflective markers that are placed on pertinent and relative boney landmarks of the subjects. These systems produce 3D trajectories of the markers, which used to estimate internal joint centers and determine segment motions, velocities, and accelerations. These kinematic parameters are then combined with subject’s anthropometric inertial data and external forces to yield external reaction forces and moments. These external forces and moments are then used to estimate internal joint reaction forces and internal “muscle” moments. The internal muscles moments must generate equal and opposite forces to the externally measured moments,
and are composed of the muscle contraction, passive soft tissues, and joint reaction forces. However, using the inverse dynamics solution only yields net muscle moments, and these cannot be decomposed into individual muscle contributions to the motion without appropriate assumptions to obtain an equal number of unknowns and equations; or by employing an optimization scheme. Optimization methods assume that the force distribution among the muscles is made by applying an objective function (usually based on a physical property of a muscle). Early hip models [35] were limited in that they assumed muscles
were single bundles represented by straight muscle paths that possess similar fibers lengths with the same moment arms over the cross-section of a large muscle. Today, more sophisticated models [38] have employed more precise muscle paths with better defined “wrapping functions” to deflect muscles path around pertinent anatomic structures and more specific fiber length parameters for individual muscle bundles within the complex geometry of a whole muscle. These advancements have contributed to the understanding of the functional roles for the individual muscles surrounding the hip, as they more closely represent the true functional geometry of those muscles in vivo.

Anderson and Pandy [38] developed a muscle model that included select hip musculature to analyze a complete gait cycle. This model contained 54 independent muscles, and the results estimated each muscle’s contribution to the support phase of gait. A muscle’s potential for generating support was described by its contribution to the vertical ground reaction force per unit of muscle force. Of the hip muscles, the gluteus medius, maximus, and minimus provided the majority of the support in first 0% to 30% of stance (Fig. 1A) . From foot flat to just after contralateral toe-off (eg, 10–50% of stance), the gluteus maximus and posterior medius/minimus contributed significantly to the vertical ground reaction force. With assistance from joints and bones to gravity, the anterior and posterior gluteus medius/minimus generated nearly all the support evident in midstance. Posterior gluteus medius/minimus provided support throughout midstance, while the anterior gluteus medius/minimus contributed only toward the end of midstance (Fig. 1B). Interestingly, the iliopsoas developed substantial forces during late stance, but this muscle did not make substantial contributions to support [38].

The study of Anderson and Pandy [38] has shown that the muscular actions of the gluteus medius and minimus depend strongly on body positions. Anterior gluteus medius/minimus developed forces as large as the posterior gluteus

![Fig. 1.](A–C) Individual muscles contributions to support during gait from heel strike (HS) to toe-off (TO). Here, support is represented by the shaded gray area, which is the vertical ground reaction force. Symbols used to represent muscles in the figure are: DF, ankle dorsiflexors; GAS, gastrocnemius; GMEDP, posterior gluteus medius/minimus; GMAX, medial and lateral portions of the gluteus maximus; GMEDA, anterior gluteus medius/minimus; SOL, soleus; VAS, vasti. In this figure the gluteus maximus contributes the most muscle force to supprt in early stance; The posterior gluteus medius/minimus contributes notable force throughout the stance phase. In later stance, the anterior gluteus medius/minimus is most effective at maintaining support during gait. The passive resistance of the skeleton to the force of gravity was less then 50% of body weight through out stance, suggesting that muscles are the most important parameter to support the body during gait. Of these muscles, the hip gluteus maximus contributed the most force to support, followed by the vasti, gluteus medius/minimus, and soleus/gastrocnemius of the body compared with all other muscles during gait. Unfortunately, the mechanical roles of the smaller hip muscles such as the pectineus, piriformis, superior and inferior gemellus, and obturator internus and externus were not included in this model. (From Anderson FC, Pandy MG. Individual muscle contributions to support in normal walking. Gait Posture 2003;17(2):159–69; with permission.)
medius, yet the anterior gluteus medius contributed very little to support during early stance. The reason for this is that the anterior gluteus medius possesses a moment arm at the hip that acts to flex the hip as well as abduct it. These two actions oppose one another and prevent the anterior gluteus medius from generating support in early stance no matter how large its force. As the hip extends during mid and late stance phase, the anterior gluteus medius moment arm falls close to zero. The muscle becomes more of a pure abductor and its action more closely resembles the actions of the posterior gluteus medius. The value of the study by Anderson and Pandy [38] is that this study estimated true muscle forces (N) for each muscle (Fig. 2), offering considerably more information than one can derive from electromyography (EMG) alone or from inverse dynamic analysis techniques.

HIP JOINT REACTION FORCES

Studies have been published that examine the specific forces encountered in walking, climbing stairs, skiing, and in routine daily activities [39–42]. Variance of forces rises from incongruence of the femoral head to the acetabulum and the hip muscles that control these motions. It is estimated that the hip endures forces ranging from one-third of the body weight with double leg support to five times the body weight during running [43,44]. The asymmetry between the femoral head and the acetabulum allocates weight to multiple areas. This incongruence is inherent to the hip and necessary for sustaining normal function [45].
During gait, a stride will take the hip through an average of 40° to 50° of motion (30°–40° of flexion and 5°–10° of extension) [19,46]. The force from weight bearing in the acetabulum during gait is biphasic with peaks in force occurring at heel strike and toe off. Areas of contact form two columns of force on the anterior and posterior rims, joining together in the superior aspect of the fossa [47]. As more force is applied to the hip, the areas enlarge as the femoral head settles deeper in the acetabulum. The areas of most frequent weight bearing are also associated with the stiffest and thickest articular cartilage [47].

The result of the forces transferred across the hip can be visualized radiographically in the femoral neck as Ward’s triangle [48]. This triangle is outlined by cortical and tensile trabecular osseous formations in the femoral neck. Tensile forces are generated in the medial subtrochanteric cortex and applied into the weightbearing portion of the femoral head [48]. Cortical forces span from the foveal area of the femoral head through the superior femoral neck to the subtrochanteric cortex [48]. In hips with a neck shaft angle of greater than 125° (coxa valga), compressive trabeculae are more prominent due to the increased compressive forces accounted for by the deformity of the femur. In hips with a neck shaft angle of less than 125° (coxa varus), tensile trabeculae are more prominent due to the increased tensile stresses [49].

**ELECTROMYOGRAPHY OF HIP MUSCULATURE**

EMG is a technique used to measure the electrical input (excitation) of a specific muscle. Considerable literature regarding EMG of the hip musculature for walking, climbing stairs, and various sporting motions has been reported. Due to space limitations and the completeness of data content, only the EMG of hip muscles during gait are presented below. Although EMG studies are valuable in determining which and when individual muscles are active, it is important to note that EMG cannot provide information regarding the amount of force a specific muscle is producing. This limitation of EMG underscores the importance of computer modeling techniques in understanding hip mechanics during functional activities and in understanding the basic mechanics associated with hip stabilization and the interaction of bony geometries and the actual muscle forces that stabilize the hip joint.

**Pectineus, Piriformis, Superior and Inferior Gemullus, and Obturator Internus and Externus Muscles**

Studies on the muscles of the hip joint have typically neglected the roles of the deep musculature (Pectineus, Piriformis, Superior and Inferior Gemullus and Obturator Internus and Externus) because of their inaccessibility and their proximity to femoral vessels. Thus, the functional roles of these muscles have been debated [50–52] with little direct evidence to support opposing views. These muscles are often thought to be the “rotator cuff” muscles for the hip, and many studies in the canine models have supported their roles in “fine tuning” hip motions [53]. However, unlike the glenohumeral joint, the human hip is considered a more stable joint via its bony articulations requiring less muscular...
stabilization. To this end, many authors have suggested that the small PCSA of these deep muscles combined with their small moment arms (eg, pectineus moment arms during gait has been estimated at less then 9 mm for stance phase of gait) are negligible in providing any “meaningful” forces for maintaining hip stability. Nevertheless, clinical views of the function of the pectineus make this muscle’s role in hip function more important than one would ascertain from its small size and moment arm. Lamb and Pollock [54] suggested that pectineus overactivity is the major cause of flexion deformity of the hip in children with cerebral palsy. Arnold and Delp [37] have shown that the pectineus possesses a small external hip rotation moment when walking with an exaggerated internal thigh rotation (as noted in Fig. 7 of Arnold and Delp) [37]. These computational results correspond well with EMG profiles during gait in healthy persons. The pectineus is moderately active at mid-heel strike to mid-heel-off, functioning to limit femoral abduction and contributing to femoral medial rotation. Some minor activity is also present during the swing phase [55].

Assessing the functional EMG of the piriformis, superior and inferior gemellus, and obturator internus and externus) has proven difficult given their anatomic locations and relative inaccessibility and their proximity to femoral vessels. However, new technologies such as dynamic MRI combined with computer modeling and simulation may offer some exciting advancements in understanding the functional roles of these muscles in the years to come.

Iliopsoas

Based on the anatomic insertion and origins of the iliopsoas, it is the only muscle that has the anatomic prerequisites to simultaneously and directly contribute to stability and movement of the trunk, pelvis, and leg. This muscle has two major portions (the iliacus and the psoas). These two portions have separate innervations, which makes selective activation of each portion feasible for any given movement. However, only a few studies have attempted to define and differentiate the function roles of the iliacus and psoas independently and simultaneously [56,57].

When one begins to search the literature for precise information about the actions and functions of the iliopsoas (or psoas and the iliacus independently), the only point that is agreed upon is that this muscle is a flexor of the hip and probably has some influence on the lumbar vertebrae and pelvis in maintaining appropriate postures. Thus, there is some disagreement in the EMG information of this muscle, partly resulting from different techniques and the difficulty in measuring EMG in this muscle due to its location and pennation. Andersson et al [57] found both muscles are inactive during ipsilateral leg extension; whereas, contralateral leg extension resulted in selective recruitment of the iliacus alone. Andersson et al also noted that both muscles are active during maximal thigh abduction, but no postural activity is noted for either psoas or iliacus during standing at ease or with the whole trunk flexed 30° forward at the hip [57]. These postural positions also did not recruit the psoas or iliacus after
loads up to 34 kg were added. In summary, Andersson et al concluded that the iliacus primarily stabilizes the motions between the hip and pelvis, whereas the psoas assists in stabilizing the lumbar spine in the frontal when a heavy load is applied to the contralateral side.

**Iliacus**

Attempts to measure EMG of the iliacus alone have shown notable activity throughout flexion of the hip during the “sit-up in the supine position” [56]. LaBan et al [58], however, found that there was little or no activity in the iliacus during the first 30° of hip flexion, but these authors noted activity during a sit-up from the “hook-lying” position. Greenlaw and Basmajian [56] further reported both medial and lateral rotation of the hip joint may produce some slight iliacus activity, whether the hip joint is passively or actively held in any of the extended, semiflexed, or flexed positions.

**Psoas Major**

Direct recordings from the psoas muscle are generally similar to those measured from the iliacus with a few noted exceptions. There is slight activity during relaxed standing and strong activity during flexion in many postures [57]. Also, slight to moderate activity in abduction and lateral rotation (depending on the degree of accompanying hip flexion) [57] is present, with no activity during most medial rotations and little activity during most other conditions involving the thigh [56,57]. Nachemson [59] concluded that the psoas has a significant role in maintaining upright postures.

**Gluteus Maximus**

Karlsson and Jonsson [60] concluded that the gluteus maximus was active during extension of the thigh at the hip joint, lateral rotation, abduction against heavy resistance when the thigh is flexed to 90°, and adduction against resistance that holds the thigh abducted. The studies of Joseph and Williams [61] show that the gluteus maximus is not an important postural muscle but it exhibited moderate activity when bending forward and when straightening up from the toe-touching position [61]. In positions in which one leg sustains most of the weight, the ipsilateral gluteus maximus is active. Joseph and Williams [61] also found that, during standing, rotation of the trunk activates the muscle that is contralateral to the direction of rotation (ie, corresponding to lateral rotation of the thigh).

**Gluteus Medius and Minimus**

The finding of Joseph and Williams [61] that the gluteus medius and minimus are quiescent during relaxed standing serve to confirmed that these abductors prevent the Trendelenburg sign, during abduction of the thigh and in medial rotation. The Gluteus medius’ and minimus’ role(s) in medial rotation was confirmed by Greenlaw [62], who reported triphasic activity for gluteus medius and biphasic activity for gluteus minimus during each cycle of walking. Houtz and Fischer [63] concluded that the activity in all the glutei was minimal in bicycle pedaling (Fig. 14.5). During elevation (flexion) of the thigh in erect
posture, Goto et al [64] found that the anterior part of the gluteus medius was also active in the initial stage only.

**Tensor Fasciae Latae**

Wheatley and Jahnke [65], Carlsoo and Fohlin [66], Goto et al [64], and Carvalho et al [67] found moderate activity in this muscle during flexion, medial rotation, and abduction of the hip joint. Duchenne [68] reported that the power of tensor fasciae latae as a rotator in response to faradic stimulation is weak. Carlsoo and Fohlin [66] argued the rotary influence of tensor fasciae latae affect at the knee, finding no activity. Greenlaw [62] found the muscle was active biphasically during each stride of the gait cycle. Unlike the glutei, tensor fasciae latae was active during bicycling, showing their greatest activity during the hip flexion phases [63].

**Adductors of the Hip Joint**

Janda and Vele [69], and Janda and Stara [70] investigated the role(s) of the hip adductors in children and adults during flexion and extension of both the hip and the knee, with and without resistance. They showed that the adductors were activated during flexion or extension of the knee, and became more active with resistance in children. Similarly, adults exhibited activity during flexion of the knee, but only a minority was active during extension compared with children. Janda and Stara [70] stated that this response of the adductors is related to postural control, and suggested that these muscles are facilitated through reflexes of the gait pattern rather than being called upon as prime movers.

De Sousa and Vitti [71] investigated the adductor longus and magnus during movements of the hip joint. During adduction, the longus was always active while the magnus is was almost always silent unless acting against resistance. Both muscles were shown to be active during medial thigh rotation but not during lateral rotation of the hip with the upper fibers of the adductor magnus showing the greatest activity.

Greenlaw [62] examined subjects during both fast test movements and various postures and locomotions. When standing on one foot, the adductors on that side remained silent. Medial thigh rotation recruited all the adductors. During walking, these adductors showed different types of phasic activity. There is marked difference between the two parts of the adductors magnus: the upper, possessing a pure adductor role and was active throughout the whole gait cycle, while adductor brevis and longus showed triphasic periods with the main peaks occurring at toe-off [62].

**SPORT-SPECIFIC MECHANISMS OF HIP INJURIES IN THE ATHLETE**

As arthroscopic treatments of the hip continue to evolve, there is an increasing need to understand the basic performance biomechanics of the hip joint. This information is important, as it can provide the foundation by which joint function, pathology, and therapeutic modalities can be evaluated. There are a number of recent studies that have applied different approaches to study the hip biomechanics, particularly in THR. However, there is clearly a void in the
amount of literature related to the function, and pathology of the normal or in-
jured, nonarthritic hip. Thus, the remainder of this article will offer our under-
standing as to how these injuries result in athletes. It is important to keep in mind
that a majority of athletes undergoing hip arthroscopy have a complex injury
pattern, with damage to the acetabular labrum, capsular structure, and cartilage
surfaces. To ascertain the specific injury sequence and pattern(s) of cause and
effect, significant research still needs to be performed.

**Golf**
During the downswing of a right-handed golfer, the right hip is forced into
external rotation during axial loading. This movement tends to push the femoral
head anteriorly, and over time may lead to focal anterior capsular laxity and
stretching of the iliofemoral ligament [72,73]. Subsequent joint instability may
result leading to increased translation of the ball in the socket. Labral tears,
particularly in the anterosuperior weight-bearing region of the acetabulum, may
follow. The labrum has been shown to function as a physiologic seal, stabilizing
the femoral head in the acetabulum [74,75]. In a further propagation of the
injury, labral tear leads to reduction in seal function; increased translation of the
femoral head may result. In addition, an unpublished report by Bharam et al
(70th Annual Meeting of the American Academy of Orthopaedic Surgeons)
showed that chondral delamination in the area adjacent to the labral tear is a
frequent finding in golfers.

**Taekwondo**
In martial arts, particularly taekwondo, a good kick can be performed well above
an athlete’s head. The proper positioning for a taekwondo side kick places the
stance leg in 90° of external rotation. The stance leg must then sustain significant
loads while the opposite leg performs the kick. Similar to the mechanism in
golfers, the forced external rotation and axial loading in the stance leg (not the
kicking leg) may cause anterior capsular laxity and elongation of the iliofemoral
ligament. As a result of the increased translation of the femoral head with respect
to the acetabulum, labral and chondral injuries may follow.

**Ballet/Figure Skating**
Elite ballet dancers and figure skaters perform the extremes of rotational move-
ment during their routines. Flexibility of the lower extremities is crucial for
success. Some athletes excel at these sports due to their generalized ligamentous
laxity; yet, despite this apparent advantage, they may also suffer from symptoms
of hip instability. Other ballet dancers and figure skaters may suffer from in-
stability secondary to repeated hip rotation and focal capsular laxity. Hip laxity
has been reported in a ballet dancer to be the cause of atraumatic dislocation of
the hip [76]. A very common finding in ballet dancers and figure skaters under-
going hip arthroscopic surgery is capsular laxity with associated labral tear
[72,73].

Injuries to the ligamentum teres are also common in ballet dancers and fig-
ture skaters. This ligament connects the margins of the acetabular notch and
transverse ligament to the fovea capitus on the femoral head. It is thought to function as a secondary stabilizer to external hip rotation [77]. In athletes with hip instability, the ligamentum teres is under increased stress to help stabilize the joint. Tears to the ligament often result.

Ice Hockey

Hockey players may suffer from traumatic hip injuries after direct blows to the greater trochanter. Isolated labral tears and chondral injuries from simple mechanical shearing are commonly found in these patients [78]. In addition to trauma, hockey players can suffer from overuse-type hip injuries. While skating, significant flexion, abduction, and slight external rotation forces are present at the hip. As a goalie, the hip sustains significant flexion and internal rotation forces. In flexion and abduction or flexion and internal rotation, any morphologic abnormality at the femoral head–neck junction would hit the anterosuperior labrum and the acetabular rim. This abnormality is found in patients with cam-type femoroacetabular impingement [1,2,79] and is a very common finding in elite hockey players undergoing hip arthroscopy. Whether this is a subtle developmental deformity exacerbated by sport or whether there is a unique mechanism for the development of cam-type impingement in athletes is still not known.

Running

Although most cases of hip instability are present in athletes whose sports demand excessive rotational movements, runners may also present with subtle anterior hip instability [80]. In the stride phase of high-level extensive running, repeated hip hyperextension may stretch the anterior capsule and iliofemoral ligament. The resulting microinstability may subtly increase femoral head translation, and with repeated insults, cause labral tear and chondral injury.

During running, when the foot contacts the ground the femur is in an abducted position in relation to the pelvis. Thus, the gluteus medius and tensor fascia latae are eccentrically loaded. As the running support phase progresses, these muscles must then contract as abduction occurs at the hip. Thus, it is believed that gluteus medius weakness may lead to decreased thigh control manifesting in increased thigh adduction and internal femoral rotation. These changes may predispose the runner to several pathologic conditions including iliotibial band syndrome at the knee [81].

References

[31] Arnold AS, Salinas S, Asakawa DJ, et al. Accuracy of muscle moment arms estimated...


Panel discusses new types and treatments for hip impingement
Orthopedics Today, May 2015

Femoroacetabular impingement has been a topic of substantial interest and investigation. Classically described as an anterolateral bump at the femoral head-neck region (cam femoroacetabular impingement) and focal or global acetabular over coverage (pincer femoroacetabular impingement), fresh concepts and controversies have emerged. I have sought the input of an esteemed panel to discuss some new and unusual types of femoroacetabular impingement and extra-articular hip impingement.

Dean K. Matsuda, MD
Moderator

Dean K. Matsuda, MD: Before we delve into newer types of hip impingement, what are your thoughts regarding the treatment of global pincer femoroacetabular impingement (FAI), i.e., coxa profunda and acetabuli protrusio?

Robert T. Trousdale, MD:
Global impingement occurs in two clinical scenarios, either coxa profunda or acetabuli protrusio which is defined by the magnitude of how profound the global over-coverage is. Coxa profunda is defined as the ilioischial line crossed by the floor of the acetabulum, and protrusio is defined by the fact that the medial part of the femoral head is medial to the ilioischial line. Both of those conditions, in my mind, should be treated nonsurgically initially.

There are a lot of etiological causes with these deformities. If the nonoperative things have failed and if the
pain is bad enough to warrant surgical intervention, then one should assess the status of the articular cartilage closely. If the cartilage is in poor shape, those patients are probably best treated with a total joint replacement (TJR). If the cartilage is in good shape and the pain appears to be mechanical in nature, in my mind, these are best treated with an open surgical dislocation.

Even well-versed arthroscopists have a difficult time treating the posterior compartment of the hip joint. We treat these patients with global rim resection and labral reconstruction and/or reattachment depending on the status of the labrum. In light of the fact that the coverage is global, typically pelvic osteotomies have a limited role for those patients.

Christopher M. Larson, MD: Global over-coverage is observed more frequently in women and is typically associated with a lateral center edge angle (LCEA) greater than 40° with “global” anterior, lateral and posterior acetabular over-coverage. Focal over-coverage, on the other hand, is most frequently anterior acetabular over-coverage, often in the setting of cranial acetabular retroversion, with normal lateral (LCEA 25° to 40°) and normal posterior coverage (negative posterior wall sign [PWS]).

Although focal anterior over-coverage can be predictably managed with an arthroscopic approach, the ideal surgical treatment and approach for global pincer-type FAI is controversial. For profunda hips, arthroscopic and open global rim resections can be performed but these are more challenging arthroscopically and require experience. The posterior rim resection is the most challenging portion arthroscopically and can be facilitated with a short period of increased traction and establishment of a posterolateral portal.

Protrusio is a much more complex pathomorphology and is often associated with proximal femoral-sided deformities (i.e., coxa vara). Although some cases of protrusio can be managed by an experienced arthroscopist, I believe it is most predictably managed with an open approach in most cases. If the lunate fossa and sourcil are relatively normal, then rim resection is an option which can be done via surgical hip dislocation or by an experienced hip arthroscopist. If the lunate fossa is large and associated with a shorter sourcil, rim resections should be avoided in order to prevent increased medial femoroacetabular contact pressures. Pelvic and or femoral-sided osteotomies might be most appropriate in this situation.

Matsuda: The classic cam deformity was described as an anterolateral bump. How has our understanding and treatment of cam FAI evolved?

Larson: Cam morphology is a 3-D deformity, and the extent is variable between patients. Anteromedial extension (Figures 1a and 1b) can occur to or beyond the medial synovial fold (MSF)/vessels and often extends distally along the MSF. The medial femoral neck can contact the anterior rim and/or anterior inferior iliac spine (AIIS) in flexion and flexion/internal rotation (IR) positions. Femoral resections along the MSF region may be critical to maximize straight hip flexion and IR clearance postoperatively.

Trousdale: The classic cam deformity has been well-described in the literature. The natural history of this deformity is not well elucidated. Recently, at this year’s American
Academy of Orthopaedic Surgeons Annual Meeting, the Salt Lake City group documented that this deformity is common in senior athletes and, interestingly, these active athletes do not all develop arthritis. This emphasizes the need to treat these patients nonsurgically initially. Joint salvage surgery should only be entertained in symptomatic patients and in patients with viable cartilage. The fact that a lot of the senior athletes do not develop end-stage hip arthritis re-emphasizes the role for nonsurgical management, at least initially, in these patients. That, of course, is different in patients who have major structural problems at a relatively young age. There might be some justification in being more aggressive in that patient population.

Images: Matsuda DK, reprinted with permission of the *Arthroscopy Association of North America*
Panel discusses new types and treatments for hip impingement
Orthopedics Today, May 2015

Femoroacetabular impingement has been a topic of substantial interest and investigation. Classically described as an anterolateral bump at the femoral head-neck region (cam femoroacetabular impingement) and focal or global acetabular over coverage (pincer femoroacetabular impingement), fresh concepts and controversies have emerged. I have sought the input of an esteemed panel to discuss some new and unusual types of femoroacetabular impingement and extra-articular hip impingement.

Dean K. Matsuda, MD
Moderator

Dean K. Matsuda, MD: Before we delve into newer types of hip impingement, what are your thoughts regarding the treatment of global pincer femoroacetabular impingement (FAI), i.e., coxa profunda and acetabuli protrusio?

Robert T. Trousdale, MD: Global impingement occurs in two clinical scenarios, either coxa profunda or acetabuli protrusio which is defined by the magnitude of how profound the global over-coverage is. Coxa profunda is defined as the ilioischial line crossed by the floor of the acetabulum, and protrusio is defined by the fact that the medial part of the femoral head is medial to the ilioischial line. Both of those conditions, in my mind, should be treated nonsurgically initially.

There are a lot of etiological causes with these deformities. If the nonoperative things have failed and if the
pain is bad enough to warrant surgical intervention, then one should assess the status of the articular cartilage closely. If the cartilage is in poor shape, those patients are probably best treated with a total joint replacement (TJR). If the cartilage is in good shape and the pain appears to be mechanical in nature, in my mind, these are best treated with an open surgical dislocation.

Even well-versed arthroscopists have a difficult time treating the posterior compartment of the hip joint. We treat these patients with global rim resection and labral reconstruction and/or reattachment depending on the status of the labrum. In light of the fact that the coverage is global, typically pelvic osteotomies have a limited role for those patients.

Christopher M. Larson, MD: Global over-coverage is observed more frequently in women and is typically associated with a lateral center edge angle (LCEA) greater than 40° with “global” anterior, lateral and posterior acetabular over-coverage. Focal over-coverage, on the other hand, is most frequently anterior acetabular over-coverage, often in the setting of cranial acetabular retroversion, with normal lateral (LCEA 25° to 40°) and normal posterior coverage (negative posterior wall sign [PWS]).

Although focal anterior over-coverage can be predictably managed with an arthroscopic approach, the ideal surgical treatment and approach for global pincer-type FAI is controversial. For profunda hips, arthroscopic and open global rim resections can be performed but these are more challenging arthroscopically and require experience. The posterior rim resection is the most challenging portion arthroscopically and can be facilitated with a short period of increased traction and establishment of a posterolateral portal.

Protrusio is a much more complex pathomorphology and is often associated with proximal femoral-sided deformities (i.e., coxa vara). Although some cases of protrusio can be managed by an experienced arthroscopist, I believe it is most predictably managed with an open approach in most cases. If the lunate fossa and sourcil are relatively normal, then rim resection is an option which can be done via surgical hip dislocation or by an experienced hip arthroscopist. If the lunate fossa is large and associated with a shorter sourcil, rim resections should be avoided in order to prevent increased medial femoroacetabular contact pressures. Pelvic and or femoral-sided osteotomies might be most appropriate in this situation.

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Parameters for assessment of the inferior acetabulum morphology in 300 adult hips

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Submitted 16 May 2016; revised version accepted 15 October 2016

ABSTRACT

The inferior acetabulum (IA) has been studied as a stabilizer of the hip in flexed positions with potential implications in femoroacetabular impingement and hip instability. However, there is a paucity of studies considering the normal morphology and parameters for assessment of the IA. The purpose of this study was to define parameters to assess the IA morphology and their normal range. Specifically, the objectives were to assess: (i) the width of the anterior horn (AH) and posterior horn (PH) of the acetabulum; (ii) the inclination of the articular surface of the AH angle (AHA) and PH angle (PHA) in the axial plane; (iii) the anterior opening angle of the IA and differences between genders. One hundred and fifty adult skeletons were utilized in this study. Measurements were taken directly from acetabula in 300 innominate bones utilizing digital calipers. In sequence, the innominate bones were assembled to sacrum and 150 pelvises were digitally photographed in standardized positions. Angular parameters of the acetabulum were then measured utilizing the Adobe Photoshop software. The mean width of the AH was 14.80 ± 2.35 mm (range 9.44–20.88). The mean width of the PH was 19.72 ± 2.61 mm (range 13.16–25.86). The AHA was on average 43.58 ± 7.10° (range 24.70–64) and the PHA was on average 36.07 ± 7.54° (16.10–53.20). The mean anterior opening angle of the IA was 25.33 ± 5.40° (10.90–43.10). The IA morphology can be evaluated in all anatomical planes through quantitative parameters. The assessment of the osseous morphology of the IA is the first step to elucidate abnormalities of the IA as potential source of hip pain.

INTRODUCTION

The normal morphology of the acetabular roof and walls is well understood and their abnormalities are known to have deleterious consequences to the hip joint, potentially leading to hip pain and cartilage degeneration [1–4]. Conversely, the inferior portion of the acetabulum has a more complex and not well-understood morphology. The inferior acetabulum (IA) contributes to the stability of the femoral head [5–7] and recent publications have given attention to the potential role of the IA in femoroacetabular impingement [8] and hip instability [9]. The anatomy of the acetabular fossa and IA was studied by Govsa et al. in 226 adult acetabula [10]. Those authors described a clover-leaf shape in 60% of the acetabular fossae and observed a smooth unusual facet located anteroinferior to the lunate surface in 62 acetabula (27%) [10]. Steppacher and Lerch [11] studied the size of the semilunar surface in patients with normal and abnormal acetabular coverage, reporting that dysplastic acetabula covered a decreased area of the femoral head anteroinferiorly when compared with normal hips, while hips with acetabular protrusion had an increased coverage [11]. There is a paucity of investigations regarding the normal morphology and assessment of the IA. Most published reports are descriptive or do not provide objective quantitative parameters for the evaluation of the IA [10, 12]. Considering the role of the IA in stabilizing the femoral head and the potential damage associated with femoroacetabular impingement [5–9], there is a need for a better understanding of the IA morphology through parameters.
allowing a quantitative analysis in different anatomical planes. These parameters would serve as foundation for the assessment of the IA in diagnostic imaging studies of patients with hip pain.

The purpose of this study was to define parameters to assess the IA morphology and their normal range in 300 acetabula of adult cadavers. Specifically, the objectives were to assess: (i) the width of the anterior horn (AH) and posterior horn (PH) of the acetabulum, correlating them with the acetabular diameter; (ii) the inclination of the articular surface of the AH angle (AHA) and PH angle (PHA) in the axial plane, correlating them with the acetabular version; (iii) the angle of cephalization of the AH related to the PH in the sagittal plane, or anterior opening angle of the IA; (iv) differences between genders.

MATERIALS AND METHODS

The Hamann-Todd Osteological Collection at the Cleveland Museum of Natural History contains skeletons collected between 1912 and 1938 in Cleveland, OH, United States. Three hundred adult acetabula (150 pelvic specimens) were obtained from this collection. Eighty acetabula were from African-American females, 80 from Caucasian females, 78 from African-American males and 62 from Caucasian males. The inclusion criteria involved specimens aging from 18 to 50 years (average 34.6 years) at the time of death without signs of arthrosis, fracture or surgical intervention.

The assessment of the IA morphology was first performed through direct measurements in innominate bones individually. In sequence, the right and left innominate bones were rearticulated to sacrum and digital photographs taken in order to assess the angular parameters of the acetabulum in assembled pelvises (Table I). All assessments were performed in each of the 300 acetabula by one examiner.

Parameters assessed directly in the acetabula

A digital caliper (500-196-20 Mitutoyo Absolute Digital Caliper, Model CD-6 inches, error 0.01 mm, Mitutoyo Corp., Japan) was utilized for the measurements taken directly from the 300 acetabula.

Acetabular diameter

The acetabular diameter was measured positioning the caliper perpendicular to the plane between the anterior superior iliac spine (ASIS) and pubis (Fig. 1). The diameter was defined as the greatest distance between the anterior and posterior acetabular walls.

Widths of the AH and PH

The width of the AH was measured at 10 mm proximal to its distal limit (Fig. 2). The same method was utilized to measure the width of the PH. Additionally, the relation between the width of each acetabular horn and the acetabular diameter was calculated for all acetabula through the following equation:

\[
\text{AH or PH width} = \frac{\text{Acetabular diameter}}{}
\]

Angular parameters measured in photographs

Some anatomical and functional aspects of the acetabulum can only be assessed when considering its relation to the
whole pelvis. Therefore, the angular parameters of the IA were assessed in photographs of rearticulated pelvises. Left and right innominate bones were rearticulated to sacrum utilizing elastic tapes. A piece of foam was used in order to reproduce the pubic symphysis width of 5 mm [13, 14].

In sequence, the pelvis was secured to a customized wood device with additional elastic tapes (Fig. 3). This device was manufactured under control of a digital inclinometer in order to maintain the squareness of the borders. Each pelvis was secured to the device with the ASISs and pubis in the same plane, while the iliac crests were maintained in a neutral stabilized plane [15].

Following the stabilization of each of the 150 rearticulated pelvises, photographs of 300 acetabula were obtained with the acetabula in standard positions and placed at 60 cm from the camera lens and at the center of the image (Fig. 4). This set-up was utilized after preliminary testing in order to avoid inaccurate measurements in consequence of image distortion. A digital inclinometer with resolution of 0.1° was utilized to assure that the camera was positioned within 0.5° from the horizontal. The angular parameters of the IA were then measured in digital photographs utilizing the Adobe Photoshop software version 6.0 (Adobe Systems Corporation, San Jose, CA, United States).

**AHA and PHA**

The AHA was defined as the angle between the articular surface of the AH and the coronal plane. Likewise, the PHA was defined as the angle between the articular surface of the PH and the coronal plane (Fig. 5). For the assessment of these angles, the rearticulated pelvis was positioned with the distal acetabulum facing the camera at the center of the image. Photographs were taken with a ruler sequentially positioned on the articular surface of the AH and PH, at 10 mm proximal to the distal limit of the respective horn (Fig. 6). Finally, the AHA and PHA were measured on Photoshop.

**Acetabular version**

Evaluation of the acetabular version was also performed utilizing a ruler with level control positioned at the greatest distance between the anterior and posterior acetabular walls (Fig. 7).
Anterior opening angle of the IA

The anterior opening angle of the IA represents the degree of cephalization of the AH related to the PH in the sagittal plane. Lateral view photographs of the rearticulated pelvic specimens were used to determine the anterior opening angle of the IA (Fig. 8).

Reliability analysis

In order to evaluate the intra-rater reliability of the assessments involving direct measurement with calipers (acetabular diameter and width of the anterior and PHs), a second measurement was performed in 28 acetabula randomly chosen from the 300 acetabula initially measured. The second measurement was performed by the same observer and compared with the first measurement performed at least 3 days earlier. The intra-rater reliability of the measurements performed with calipers demonstrated sub-millimeter mean differences with intraclass correlation coefficients (ICC) of 0.99, 0.95 and 0.98 for the acetabular diameter, width of the AH and width of the PH, respectively.

The additional assessments of the IA involved measurements performed in photographs of rearticulated pelvises. For those assessments, the reliability analysis also included 28 acetabula randomly chosen from the 300 acetabula initially measured. The reliability of the measurements was evaluated in three ways: (i) intra-rater reliability comparing the original measurement to another measurement of the same photograph performed with time interval greater than 1 month; (ii) reliability comparing the original measurements to measurements performed in different photographs of 28 acetabula of reassembled and repositioned pelvises, more than 3 days after the initial photograph; (iii) inter-rater reliability of measurements performed by 2 observers in the same photograph of 28 specimens. The intra- and inter-rater reliability analyses for the assessments performed in photographs of rearticulated pelvises are presented in Table II.

Statistical analysis

Student’s t tests for independent samples were utilized to establish the significance of any noted differences and P values of <0.01 were considered significant. The mean of the measurements performed in the right and left acetabula of each pelvis was considered to assess gender-related differences. Pearson’s coefficients were calculated to examine correlations between variables.

RESULTS

The mean width of the AH was 14.80 ± 2.35 mm (range 9.44–20.88) (Table III). The mean width of the PH was 19.72 ± 2.61 mm (range 13.16–25.86), being significantly higher than the width of the AH (P < 0.001). The relation between the width of the AH and the acetabular diameter was 0.31 ± 0.05 (range 0.17–0.44). The relation between the width of the PH and the acetabular diameter was 0.41 ± 0.04 (range 0.29–0.56). The mean width of the AH was 14.11 ± 1.89 mm (range 9.87–19.80) in female and 15.58 ± 2.16 mm (range 9.44–20.88) in male acetabula (Table IV). The mean width of the PH was 18.15 ± 1.84 mm (range 13.16–24.19) in female and 21.50 ± 1.88 mm (range 15–25.86) in male acetabula. Male presented values significantly greater than female when considering the...
However, when corrected to the acetabular size, no gender-related difference was observed in the width of the AH ($P = 0.228$) (Table IV).

The AHA was on average $43.58 \pm 7.10^\circ$ (range 24.70–64) and the PHA was on average $36.07 \pm 7.54^\circ$ (16.10–53.20). There was a moderate to strong correlation between the acetabular version and the AHA ($r = 0.64$) or PHA ($r = -0.59$). The mean AHA in female acetabula ($44.37 \pm 6.93^\circ$) was not significantly different from male acetabula ($42.69 \pm 6.10^\circ$) ($P = 0.12$). However, the mean PHA in female acetabula ($31.59 \pm 5.95^\circ$) was significantly lower than in male acetabula ($41.19 \pm 4.84^\circ$) ($P < 0.001$).

The opening angle the IA was on average $25.33 \pm 5.40^\circ$ (range 10.90–43.10). The mean opening angle of the IA in female acetabula ($25.82 \pm 4.83^\circ$) was not significantly different from the male acetabula ($24.78 \pm 5.19^\circ$) ($P = 0.21$).

**DISCUSSION**

This study found the absolute width of the AH and PH to be significantly increased in male acetabula compared with female acetabula. However, when considering the diameter of the acetabulum relative to the width of the AH, there was no gender-dependent difference. Steppacher and Lerch [11] investigated the acetabular lunate surface based on 164 magnetic resonance (MRI) arthrographies of patients with normal and abnormal acetabula morphology. Those authors reported increased absolute size of the lunate surface in male and no gender-dependent differences in the relative size.

The concept utilized to define the AHA and PHA was based on the well-known acetabular inclination or Tönnis angle, which refers to the inclination of the acetabular roof in the coronal plane [16, 17]. As for the Tönnis angle, increases in the AHA and PHA represent a decline in hip stability. The anteversion of the acetabulum as a whole explained at least part of the variation in the AHA and PHA among the specimens, since that a moderate to strong correlation was found between the acetabular version and the AHA ($r = 0.64$) or PHA ($r = -0.59$). Female acetabula had a significantly lower PHA when compared with male acetabula. Additionally, the acetabular version in female acetabula was higher than male acetabula. Those findings indicate that, in the 150 pelvises included in this
study, the female acetabula demonstrated a more stable posterior inferior osseous morphology and less stable anterior osseous morphology when compared with male acetabula. Although the previous authors did not specifically

Fig. 6. Distal view of the right acetabulum for assessment of the anterior horn angle (AHA) and posterior horn angle (PHA). (A) A ruler is placed on the articular surface of the anterior acetabular horn, at 10 mm proximal to its distal limit. Two level instruments (10 mm of width) were attached to the ruler to control its positioning on the axial plane, and also to guide the placement at 10 mm from the distal limit of the horn. The angle between the ruler (red line) and the coronal plane (blue line) represents the AHA. (B) PHA angle.

Fig. 7. Assessment of the version in a right acetabulum. A ruler is positioned horizontally at the greatest diameter of the acetabulum. The angle between the ruler (red line) and the sagittal plane (blue line) represents the degree of acetabular anteverision.

Fig. 8. Measurement of the anterior opening angle of the inferior acetabulum. A line is drawn (red line) between the distal ends of the anterior and posterior acetabular horns. A second line (blue line) is drawn perpendicular to the plane of the anterior superior iliac spines and the pubis (green line). The angle between the red and blue lines corresponds to the anterior opening angle of the inferior acetabulum.
study the morphology of the IA, their findings also indicate a less stable anterior acetabulum in females in comparison to males [18–20]. McKibbin reported a mean anteversion of 19° in females and 14° in males when comparing 30 adult acetabula of each gender [21]. Maruyama et al. compared 50 female with 50 male acetabula and found a mean acetabular anteversion of 21.3° and 18.5° in females and males, respectively [19]. Köhnlein et al. reported a mean acetabular anteversion of 21.0 ± 6.7 in 16 female acetabula and 16.9 ± 4.8 in 42 male acetabula [18].

Regarding the possible applicability of the AHA and PHA in imaging studies of individuals with hip pain, axial MRI or computed tomography (CT) images at 1 cm proximal to the distal end of the respective horn would represent the measurements performed in this study (Fig. 5).

The anterior opening angle of the IA was measured in a standard positioning of the pelvis with the ASISs and pubis in the same plane (Fig. 8) [15, 20]. Therefore, the mean IA opening angle of 25.33° (range 10.90–43.10°) represents a static measurement in a standard positioning. When analyzing living individuals, the positioning of the acetabulum in the sagittal plane may also be changed according to the pelvic tilt of each individual [21, 22, 23, 15]. Additionally, different activities may influence the positioning of the pelvis in the sagittal plane, increasing or decreasing the slope [21, 23]. The positioning of the acetabulum in the sagittal plane, or acetabular tilt, has been reported as

<p>| Table II. Reliability of the inferior acetabulum assessments performed in photographs of rearticulated pelvises |</p>
<table>
<thead>
<tr>
<th>Assessment</th>
<th>ICC, intra-ratera</th>
<th>ICC, intra-raterb</th>
<th>ICC, inter-raterc</th>
</tr>
</thead>
<tbody>
<tr>
<td>AHA</td>
<td>0.99</td>
<td>0.95</td>
<td>0.99</td>
</tr>
<tr>
<td>PHA</td>
<td>0.99</td>
<td>0.98</td>
<td>0.99</td>
</tr>
<tr>
<td>Acetabular version</td>
<td>0.99</td>
<td>0.98</td>
<td>0.99</td>
</tr>
<tr>
<td>Anterior opening angle of the IA</td>
<td>0.98</td>
<td>0.95</td>
<td>0.97</td>
</tr>
</tbody>
</table>

AHA, anterior horn angle; PHA, posterior horn angle.
aICC, intra-rater, remeasure performed in the same photograph of 28 specimens.
bICC, intra-rater, remeasure performed in two different photographs of 28 specimens reassembled in different times.
cICC, inter-rater, remeasure performed by two observers in the same photograph of 28 specimens.

<p>| Table III. Parameters of the IA for the entire sample (300 acetabula) |</p>
<table>
<thead>
<tr>
<th>Assessment</th>
<th>Mean (±SD)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetabular diameter (mm)</td>
<td>48.36 (±3.89)</td>
<td>39.80–58.25</td>
</tr>
<tr>
<td>Width of the AH (mm)</td>
<td>14.80 (±2.35)</td>
<td>9.44–20.88</td>
</tr>
<tr>
<td>Width of the PH (mm)</td>
<td>19.72 (±2.61)</td>
<td>13.16–25.86</td>
</tr>
<tr>
<td>AHA</td>
<td>43.58° (±7.10)</td>
<td>24.70–64°</td>
</tr>
<tr>
<td>PHA</td>
<td>36.07° (±7.54)</td>
<td>16.10–53.20°</td>
</tr>
<tr>
<td>Version of the acetabulum</td>
<td>18.93° (±5.74)</td>
<td>5.80–38.30°</td>
</tr>
<tr>
<td>Opening angle of the IA</td>
<td>25.33° (±5.40)</td>
<td>10.90–43.10°</td>
</tr>
</tbody>
</table>

IA, inferior acetabulum; AH, anterior horn; PH, posterior horn; AHA, anterior horn angle; PHA, posterior horn angle.

<p>| Table IV. Parameters of the IA according to the gender in 300 acetabula |</p>
<table>
<thead>
<tr>
<th>Assessment</th>
<th>Gender</th>
<th>Mean (±SD)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetabular diameter (mm)</td>
<td>F</td>
<td>45.53 (±2.21)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>M</td>
<td>51.60 (±2.58)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Width of the AH (mm)</td>
<td>F</td>
<td>14.11 (±1.89)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>M</td>
<td>15.58 (±2.16)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Width of the PH (mm)</td>
<td>F</td>
<td>18.15 (±1.84)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>M</td>
<td>21.50 (±1.88)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Version of the acetabulum</td>
<td>F</td>
<td>44.37° (±6.93)</td>
<td>0.120</td>
</tr>
<tr>
<td>M</td>
<td>42.69° (±6.10)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Opening angle of the IA</td>
<td>F</td>
<td>25.82° (±4.83)</td>
<td>0.21</td>
</tr>
<tr>
<td>M</td>
<td>24.78° (±5.19)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

IA, inferior acetabulum; AH, anterior horn; PH, posterior horn; AHA, anterior horn angle; PHA, posterior horn angle.
The acetabular tilt is measured between the frontal plane and the acetabular meridian line from 12:00 to 6:00 (acetabular notch) [18]. However, in opposition to the opening of the IA described in our study, the distal end of the articular surface of the AH and PH of the acetabulum are not considered in the acetabular tilt measurement. We considered important to include the distal ends of the AH and PH in the evaluation of sagittal plane positioning of the IA, since the AH and PH can have variable distal extension related to the acetabular notch and this do not directly articulate with the femoral head. Analyzing the variability observed in the IA opening angle of the 300 hips studied (mean 25.33°, SD ± 5.40, range 10.90–43.10°), the opening angle of the IA may influence the antero and posteroinferior osseous stability of the hip even if the AH and PH inclination and width are within the normal range. In a clinical scenario, the assessment of the opening angle of the IA and the width of the AH and PH would demand the application of three-dimensional reconstruction in MRI or CT images.

This study presents certain limitations. First, the 300 studied acetabula were not radiographically screened for developmental dysplasia. Considering that the post-natal development of the roof and acetabular horns is based on the same semilunar cartilaginous component [25, 26], it is probable that dysplastic hips present decreased width of the AH and PH and increased AHA and PHA. However, this factor in unlikely to significantly influence the results considering the number of acetabula studied and the low prevalence of dysplasia in mixed gender and race populations as in this investigation. Second, AHA, PHA, version and opening angles were measured in assembled pelvises including only bony components. The absence of the sacroiliac joint cartilage and pubic symphysis could change the orientation of the acetabulum when compared with living individuals. To minimize its potential influence, the pubic symphysis was reproduced with a piece of foam of 5 mm [13, 14]. The sacroiliac joint cartilage was not reproduced considering that its combined thickness is on average only 2.6 mm [27, 28]. Additionally, reproducing the sacroiliac joint cartilage would hinder the assembly of the sacrum to the innominate, unless performed with glue, potentially damaging the specimens. Third, the absence of a second observer measurement for the acetabular diameter and width of the horns is another limitation of this study. Fourth, the skeletons utilized in this study were collected between the years of 1912 and 1938. Modifications on lifestyle along the years may have influenced the morphology of the pelvis and acetabulum when compared with today's population.

Finally, this study reports objective parameters to evaluate the morphology of the IA and its relation to the pelvis in all anatomical planes. The availability of axial and tridimensional imaging studies of the acetabulum could allow the utilization of the assessments described in this study to evaluate patients with hip pain. However, the applicability of the measurements and their normal range in imaging studies needs to be investigated. Considering the role of the IA in hip stabilization, the assessment of the osseous morphology of the IA is the first step to elucidate abnormalities of the IA as a potential source of hip pain.

ACKNOWLEDGEMENTS

The authors wish to thank Francine P. Hatem (Curitiba, PR, Brazil) for contributing with the organization and data collection of this research. The authors would also like to show their gratitude to Lyman M. Jellema (Cleveland, OH, United States) for his assistance with the methodology and specimen organization.

FUNDING

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sector.

CONFLICT OF INTEREST STATEMENT

None declared.

REFERENCES


Pathological findings in patients with low anterior inferior iliac spine impingement

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Pathological findings in patients with low anterior inferior iliac spine impingement

Eyal Amar1 · Yaniv Warschawski1 · Zachary T. Sharfman1 · Hal David Martin2 · Marc R. Safran3 · Ehud Rath1

Received: 2 July 2015 / Accepted: 20 November 2015 © Springer-Verlag France 2015

Abstract

Purpose Femoroacetabular impingement (FAI) has been well described in recent years as one of the major causes of hip pain potentially leading to acetabular labral tears and cartilage damage, which may in turn lead to the development of early degenerative changes. More recently, extra-articular patterns of impingement such as the anterior inferior iliac spine (AIIS)/subspine hip impingement have gained focus as a cause of hip pain and limitation in terminal hip flexion and internal rotation. The purpose of this study was to evaluate the prevalence of low AIIS in patients undergoing hip arthroscopy and to characterize the concomitant intra-articular lesions.

Methods Between November 2011 and April 2013, 100 consecutive patients underwent hip arthroscopy for various diagnoses by a single surgeon. After intra-operative diagnosis of low AIIS was made, a comprehensive review of the patients’ records, preoperative radiographs, and intra-operative findings was conducted to document the existence and location of labral and chondral lesions.

Results Twenty-one (21 %) patients had low AIIS. There were 13 males (mean age 38.4 years) and eight females (mean age 35.5 years). Eight patients had pre-operative radiographic evidence of low AIIS. All patients had a labral tear anteriorly, at the level of the AIIS; 17 had chondrolabral disruption and 17 had chondral lesions in zone two (antero-superior); and four patients had lesion in zones two and three.

Conclusions Low AIIS is a common intra-operative finding in hip arthroscopy patients. Characteristic labral and chondral lesions are routinely found in a predictable location that effaces the low AIIS.

Level of Evidence—Level IV, Case Series

Keywords AIIS · Hip arthroscopy · Prevalence

Introduction

Femoroacetabular impingement (FAI) has been well described in recent years as one of the major causes of hip pain potentially leading to acetabular labral tears and cartilage damage, which may in turn lead to the development of early degenerative changes [3, 5, 6, 16]. More recently, extra-articular patterns of impingement such as the anterior inferior iliac spine (AIIS)/subspine hip impingement have gained focus as a cause of hip pain and limitation in terminal hip flexion and internal rotation [8–10, 12, 14, 15].

The AIIS is a bony prominence that serves as the origin of the direct head of the rectus femoris with a broad footprint [7, 17] and has quite variable bony morphology [1, 17]. Despite the extra-articular location of the AIIS, structural deformities, which may result from avulsion injuries, may cause hip pain and limited range of motion due to impingement with the proximal femur [13–15, 20, 23]. Large forces not great enough to cause an avulsion fracture may also result in a hypertrophy of the AIIS [18, 19, 22, 23]. A decrease in hip flexion and internal rotation is associated with AIIS extension to the level of the
acetabular rim or more distal protrusion [10]. Unlike FAI, where the existence and location of concomitant labral and chondral injuries are well described [2], no such studies have been reported to evaluate the prevalence of AIIS impingement, the concomitant labral and chondral injuries and “geographic” location of these injuries in AIIS impingement.

This study was, therefore, undertaken to evaluate the prevalence of low AIIS in patients undergoing hip arthroscopy and to characterize the concomitant labral and chondral injuries. The study hypothesis was that low AIIS is a common intraoperative finding in hip arthroscopy patients and that labral and chondral lesions may be found in a predictable location in correspondence with the low AIIS.

Materials and methods

The local institutional review board approved the study. Between November 2011 and April 2013, a single surgeon operated on 100 consecutive patients for intra-articular hip joint-related pain. The leading preoperative indication for operation in our study was the diagnosis of FAI, found in 61 patients, followed by isolated labral tear, found in 25 patients. Other indications included peritrochanteric syndrome requiring tensor fascia lata release and piriformis syndrome requiring sciatic nerve release in three patients each. Less prevalent indications included Legg–Calvé–Perthes disease, pigmented villonodular synovitis, and synovial chondromatosis in two patients each. Heterotopic ossification, labral cyst, and adhesions were indications in single patient. Patients with peritrochanteric or deep gluteal space pathology were excluded.

Surgical technique

All the operations were performed with the patient in the supine position under general anesthesia. The surgical technique and portal establishment were performed in accordance with the surgical technique previously described [21].

Capsulotomy between the two portals was preformed using a hooked radiofrequency probe (VAPR; DePuy Mitek, Raynham, MA, USA) in all cases to facilitate instrument maneuverability [4]. A thorough diagnostic evaluation of the central compartment of the hip was performed using a 70° arthroscope. The diagnosis of prominent or low-riding AIIS was performed statically by direct probing of the bony protuberance under fluoroscopy, also by comparing AP view to 30°–45° tilt view (the latter is similar to Judet view and provide “true” AP of the AIIS, Fig. 1a, b), and dynamically by flexing the hip under arthroscopic visualization for proof of impingement. The location of the AIIS in relative to the joint as well as the location of labral and chondral pathology was described in accordance with Ilizaliturri’s arthroscopic anatomic zone classification [11].

Low AIIS diagnosis

Diagnosis of low AIIS and the consequent bony decompression performed in this study were based on anatomical and clinical evidence. Hetsroni et al. [10] defined three morphological AIIS variants: Type I AIIS is defined by a smooth ilium wall between the AIIS and the acetabular rim; in type II, the AIIS extends to the level of the acetabular rim; and in type III, the AIIS extends distal to the acetabular rim. The authors demonstrate a stepwise decrease in hip flexion and internal rotation in association with AIIS (type III associated with the most severe limitations). Based on these findings, any AIIS that was at the level of the acetabular rim or lower (type II or III) was classified as a low AIIS (Fig. 2).

AIIS anatomy and morphology were studied in three recent papers [1, 7, 17]. Amar et al. [1] studied the morphology of the normal AIIS. In this study, the authors measured the AIIS dimensions (i.e., the length, width, and height) and distances (i.e., vertical, horizontal, and linear) between the most antero-inferior prominent point of the AIIS and the acetabular rim. Additionally, the authors recorded AIIS version. They conclude the finding that the mean vertical distance from acetabular rim was 13.5 and 11.4 mm in males and females, respectively.

Hapa et al. [7] defined the anatomy of the AIIS, its relation to the footprint of the rectus femoris tendon, and evaluated the clinical outcomes after AIIS/subspine decompression. They concluded that the origin of the rectus femoris tendon has a broad attachment to the AIIS and is protective against direct head detachment with subspine decompression. Philippon et al. [17] performed an anatomical study of the acetabulum. The authors measured the direct distance between the AIIS and relevant periacetabular structures, defined the bi-facetal structure of the AIIS, and defined the footprint of the direct head of rectus femoris and iliocapsularis muscle. They found a mean distance from the inner acetabular rim to the inf erolateral corner of the direct head of the rectus femoris footprint to be 19.8 mm. Based on these anatomical studies, the AIIS decompression was carried out to create at least 11 mm of flat anterior supra-acetabular surface (2 burr widths) between the most antero-inferior prominent point of the AIIS and the acetabular rim. This procedure safely creates a morphology classified as type I AIIS according to Hetsroni et al. [10].
Data acquisition

A comprehensive review of patient records was conducted to identify patients with intra-operative diagnosis of low AIIS. Demographic data and pre-operative diagnosis were recorded. The patients’ routine preoperative radiographs, including AP and frog view, were reviewed once more in search of radiographic evidence of a low AIIS, as well as FAI-related bony morphology (i.e., cam and pincer). Intra-operative findings including the existence of a labral tear and/or chondro-labral disruption [manifested as a “wave” sign, (Fig. 3)] were recorded with regard to the anatomic location of these lesions, according to the system described by Ilizaliturri et al. [11].

Statistical analysis

Statistical analysis of the data was carried out with the $\chi^2$ or Fisher exact test at a significance level of .05. The IBM® SPSS® 21 program for Windows was used for all analyses.

Results

One hundred consecutive patients who underwent hip arthroscopy performed by a single surgeon were studied. The mean age of these patients was 38.6 years (range 16–75 years). Fifty-nine males, mean age 34.9 years (range 16–68 years), and 41 females, mean age 43.8 years (range 16–75 years), were included (Table 1). A low AIIS was identified intra-operatively in 21 patients, with mean age 37.3 years (range 16–61 years). The low AIIS group included 13 males, with mean age 38.4 years (range...
22–60 years) and eight females, with mean age 35.5 years (range 16–61 years) (Table 1). According to the records of physical examination, patients with low AIIS presented with pain located at the anterior groin/hip and was provoked by a straight leg raise (either with or without resistance), aggravated by FADDIR, and by femoral stretch test (i.e., extension of the hip which creates pressure over the AIIS due to rectus femoris stretch). An additional review of preoperative radiographs for patients with an intra-operative diagnosis of low AIIS found that two patients had combined FAI morphology (i.e., both cam and pincer), one patient had pincer anatomy, and seven patients had cam anatomy (Table 2). Eight were identified with pre-operative radiographic evidence of low AIIS, of whom, six had either cam or pincer anatomy (Table 2).

All patients with low AIIS had suffered a labral tear that was repaired during surgery. The injured labrum was congested and hyperemic anteriorly at the level of the AIIS. 17 patients had chondro-labral disruption manifested as a “wave” sign (Fig. 3). The acetabular chondral lesion was under the AIIS, located at zone two in 17 patients (correlating with the antero-superior location of the acetabulum) and in zones two and three in four patients. The low AIIS functionally creates pincer type impingement. Cam type impingement may also be responsible for the labral tears in zones 2 and 3. 8 patients in this study had marked cam lesions and 2 patients had minimal cam lesions. The source of labral pathology remains unclear in patients with both cam lesions and low AIIS. There was no significant difference in the relative rate of low AIIS between males and females (P = 0.540). None of the patients with low AIIS demonstrated femoral head chondral damage.

**Table 1** Baseline characteristics of study population

<table>
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<tr>
<th>Study population</th>
<th>Males</th>
<th>Females</th>
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<td>Age&lt;sup&gt;a&lt;/sup&gt; (year)</td>
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<td>43.8 ± 2.52</td>
<td>38.6 ± 1.53</td>
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<tr>
<td>Low AIIS</td>
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<td></td>
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<tr>
<td>Number</td>
<td>13</td>
<td>8</td>
<td>0.649</td>
<td>21</td>
</tr>
<tr>
<td>Age&lt;sup&gt;a&lt;/sup&gt; (year)</td>
<td>38.4 ± 3.17</td>
<td>35.5 ± 4.9</td>
<td>37.3 ± 3.6</td>
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</tr>
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</table>

<sup>a</sup> Values are given as mean and standard error

**Discussion**

The principle outcome of this study reports 21 patients diagnosed intra-operatively with low AIIS in a cohort of 94 consecutive hip arthroscopies, with six exclusions for aforementioned criteria. Of this group, only eight had radiographic evidence of low AIIS as defined by retrospective analysis.

Subspinous impingement (due to the AIIS) is a relatively novel clinical entity. The most common clinical manifestations of AIIS impingement are groin pain and limitation in flexion as well as internal rotation. This description is in agreement with case reports published by Larson et al. [12]. Larson described diagnostic pearls consistent with AIIS impingement. They consist of anterior groin pain, pain in straight hip flexion, and limitations in range of motion. Limitations in range of motion were also demonstrated by Hetsroni et al. [10] who showed a stepwise decrease in flexion and internal rotation by severity of AIIS type. The clinical manifestations of AIIS impingement are also often seen with FAI. Therefore, it can be difficult to differentiate these two conditions based on clinical findings alone. These clinical findings were present in the cohort of patients included in this study, but it is relevant to mention that many of these patients had associated FAI.

The normal anatomy of the AIIS was recently described [1, 17], as well as the characterization of the rectus femoris “foot print” [7, 17], morphologic classification of the pathologic AIIS [10], and reports on arthroscopic decompression of the AIIS [8, 12, 14, 15].

This study has demonstrated that labral tears are located just below the low or prominent AIIS with chondralabral disruptions and chondral damage occurring in locations that correspond to the low AIIS, identified as zones two and three in Ilizarov’s arthroscopic anatomic zone classification (antero-superior) [11]. It remains unclear whether these labral tears are due to subspinous impingement alone or multifactorial causes, such as associated FAI.

Our literature review did not identify any study that had previously characterized the prevalence of AIIS impingement in hip arthroscopy, or defined any associated labral and chondral injuries.

The intra-operative diagnosis of low AIIS in 21 patients, of whom only eight had radiographic evidence of low AIIS, may be explained by the anatomy of the AIIS. A radiographic survey conducted to evaluate dimension, distance, and version of the AIIS showed that the mean deviation from the ilium axis is 9.2° and 8.1° medially for males and female, respectively. The mean vertical distance from the acetabular rim is 13.5 mm and 11.4 mm for males and females, respectively [1]. These findings suggest that a low AIIS with low vertical distance from the acetabular rim may be superimposed on iliac bone in an AP pelvic view, given enough medial version (Fig. 4a, b). Decompression of the AIIS was executed according to these data to create an 11 mm gap (2 burr widths) at minimum between the most antero-inferior prominent point of the AIIS and the acetabular rim (Fig. 5).
These data raise the question, is our routine radiographic pre-operative evaluation is adequate for low AIIS assessment? CT scan of the AIIS provides a clear and comprehensive visualization of the bony pelvic anatomy (with or without 3-dimension reconstruction). It is not practical to administer both MRI and CT scans to every patient, not to mention the radiation exposure from an additional CT. Our results coincide with the aforementioned study, both demonstrating that AP and frog view radiographs are not fully sensitive for the diagnosis of all patients with low AIIS.

The mechanism causing chondral and labral damage due to impingement of the extra-articular pelvic bony protuberance with the proximal femur is not clear. It is difficult to isolate the contribution of AIIS decompression in the patients’ overall improvement from the contributions of the

<table>
<thead>
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<th>No.</th>
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<th>Pre-operative radiographic data</th>
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<tr>
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LCEA lateral central edge angle, AIIS anterior inferior iliac spine, BJL below joint line

Fig. 4 a An antero-posterior view of a 60-year-old male (patient 11, Table 2) who underwent right hip arthroscopy. Note that the AIIS does not extend to joint line.
b CT scan axial snapshot. Medial (right) deviation of AIIS beyond the vertical line may superimpose on iliac bone and may not be clearly demonstrated in the antero-posterior view.
AIIS and concomitant FAI decompression (i.e., cam decompression, rim trimming, and labral repair). A future randomized controlled trial is advised to further build upon these preliminary findings. Future studies should continue to evaluate the surgical technique and effect of AIIS decompression. These studies should also consider monitoring patient outcome.

Study limitations

This study is a level IV case series. As such, no comparison was made to a controlled matched group. The cohort size may also make our analysis vulnerable to statistical bias. Increased awareness to this form of impingement may explain an unexpected high rate of the intra-operative diagnosis of low AIIS.

Conclusions

In conclusion, low AIIS is a common intraoperative finding in hip arthroscopy patients. The main clinical characteristics associated with low AIIS are pain in pure hip flexion associated with limited range of flexion. Radiographic diagnosis for this type of impingement is possible in less than half of the patients on routine pelvic radiographs. Characteristic labral and chondral lesions are commonly found in a predictable location adjacent to the low AIIS.

Compliance with ethical standards

Conflict of interest  No conflicts of interest to report.

References

The Pattern and Technique in the Clinical Evaluation of the Adult Hip: The Common Physical Examination Tests of Hip Specialists


Purpose: The purpose of this study was to systematically evaluate the technique and tests used in the physical examination of the adult hip performed by multiple clinicians who regularly treat patients with hip problems and identify common physical examination patterns. **Methods:** The subjects included 5 men and 6 women with a mean age (±SD) of 29.8 ± 9.4 years. They underwent physical examination of the hip by 6 hip specialists with a strong interest in hip-related problems. All examiners were blind to patient radiographs and diagnoses. Patient examinations were video recorded and reviewed. **Results:** It was determined that 18 tests were most frequently performed (≥40%) by the examiners, 3 standing, 11 supine, 3 lateral, and 1 prone. Of the most frequently performed tests, 10 were performed more than 50% of the time. The tests performed in the supine position were as follows: flexion range of motion (ROM) (percentage of use, 98%), flexion internal rotation ROM (98%), flexion external rotation ROM (86%), passive supine rotation test (76%), flexion/adduction/internal rotation test (70%), straight leg raise against resistance test (61%), and flexion/abduction/external rotation test (52%). The tests performed in the standing position were the gait test (86%) and the single-leg stance phase test (77%). The 1 test in the prone position was the femoral anteversion test (58%). **Conclusions:** There are variations in the testing that hip specialists perform to examine and evaluate their patients, but there is enough commonality to form the basis to recommend a battery of physical examination maneuvers that should be considered for use in evaluating the hip. **Clinical Relevance:** Patients presenting with groin, abdominal, back, and/or hip pain need to have a basic examination to ensure that the hip is not overlooked. A comprehensive physical examination of the hip will benefit the patient and the physician and serve as the foundation for future multicenter clinical studies.
As advances in technology aid in our understanding of normal and pathologic hip conditions, the clinical examination of the adult and adolescent hip continues to evolve. Many generations of surgeons, therapists, and physicians have developed clinical tests designed to detect a variety of hip disorders. A number of diagnostic tests of the hip are used for clinical evaluation; however, there is little research suggesting which tests are of the greatest value to the examiner. There have been a few reports published that have recommended the most effective tests that could help organize the structure of the physical examination of the hip in a simple, reproducible manner. There is no recognized hip evaluation protocol with a systematic structure as used in evaluating other joints such as the shoulder. Patients presenting with groin, abdominal, back, and/or hip pain need to have a basic examination to ensure that the hip is not overlooked. A comprehensive physical examination will benefit the patient and the physician and serve as the foundation for future multicenter clinical studies because a uniform patient evaluation process will facilitate common diagnostic strategies.

Assessment of hip pain can be quite complex, and in many cases symptoms of back pain present along with hip pain, which may be associated with or independent of a hip problem. Low-back dysfunction could lead to knee pain, groin pain, and/or a limited range of motion (ROM) in the hip. Likewise, contracture of hip flexion or leg length discrepancies have been implicated as causes of both hip and low-back pain. Furthermore, pelvic and genitourinary problems and symptoms may also present as hip pain. Therefore a thorough understanding of the osseous, ligamentous, and musculotendinous contribution to the underlying pathology is essential.

To establish a standardized protocol, there must be agreement within the community of hip specialists about which tests are considered important in the assessment of the adult and adolescent hip. An organized structured physical examination, together with an understanding of the osseous, ligamentous, and musculotendinous contribution to the underlying pathology, will guide the examiner to accurate treatment recommendations or further diagnostic studies. Although an experienced hip specialist is guided by finding during the examination, the inexperienced examiner would greatly benefit from a systematic and reproducible physical examination. Therefore the purpose of this study was to systematically evaluate the technique and tests used in the physical examination of the adult hip performed by 6 orthopaedic surgeons who regularly treat patients with hip problems and identify common physical examination patterns.

**METHODS**

**Study Design**

Institutional review board approval was obtained for this study. Eleven adult subjects with hip pain, five men and six women (mean age, 29.8 ± 9.4 years), volunteered for this study. All subjects read and signed a written informed consent form before the start of the study. In a randomized order, subjects underwent physical examination of the hip by 6 orthopaedic surgeons. All examiners have a strong interest in hip-related problems, have clinical expertise and experience in treating patients with hip-related problems, have been in practice for 4 to 9 years, and examine 10 to 70 patients with hip pain per week in their daily practice. A written summary of each subject’s history was provided to each examiner; however, all examiners were blind to patient radiographs and diagnoses. Subjects were asked to only answer specific questions asked by the examiner and not to discuss any procedures or information offered by previous examiners. Before the start of the study, there was no discussion of clinical tests between examiners and examiners were blind to the examinations performed by other examiners. Examiners were instructed to perform their examination in the same manner that they would in their own practice. Patient examinations were video recorded and reviewed by a single researcher for analyses. Outcome variables included the number of clinical tests, type of clinical test, and number of positive tests (reproduction of patient’s pain).

**Tests of Interest**

The descriptions of the following tests are based on the technique used by the clinicians in this study. For international clarification among clinicians, each test was given a descriptive functional title.

**Standing Assessment**

**Gait:** Gait testing is performed in a hallway so that at least 3 to 4 stride lengths can be viewed from both in front of and behind the patient. The clinician observes gait with awareness of abnormal gait patterns such as the abductor-deficiency gait (also known as the Trendelenburg gait), antalgic gait, pelvic wink, exces-
sive internal or external rotation, short leg limp, and abnormal foot progression.

**Single-Leg Stance Phase Test:** The single-leg stance phase test is similar to the traditional Trendelenburg test. The single-leg stance phase test is an assessment of the neural loop of proprioception of the extremity and function of the abductors to hold the pelvis in a balanced position by simulating the single-leg stance phase with load on the hip. The patient stands with the feet shoulder width apart and then lifts the unaffected leg forward to 45° of hip flexion and 45° of knee flexion and holds this position for 6 seconds. The single-leg stance phase test is performed on both sides for comparison. A positive test is a pelvic shift or a decrease of more than 2 cm.17

**Laxity:** Observation of increased ROM in other joints such as the thumb to forearm and hyperextension at the elbow and knee is performed to assess laxity.

**Supine Assessment**

**ROM Testing:** ROM testing is a critical test to determine both osseous and ligamentous functions. Internal and external rotation ROM is performed passively in a supine or seated position (Fig 1), with the hip flexed at 90°. The seated position ensures that the ischium is square to the table, thus providing sufficient stability at 90° of hip flexion and a reproducible platform for accurate rotational measurement. It is also helpful to determine the internal/external rotation with the hip extended, performed in a prone position. The extent of osseous versus ligamentous contribution can be determined by differentiation in both the flexed and extended positions. The flexed position releases the medial and lateral arms of the iliofemoral ligament; however, the dominate control for internal rotation, both in extension and in flexion is the ischiofemoral ligament.15 ROM is dictated by a fir endpoint or by patient pain. Preoperative ROM can be compared with intraoperative ROM.

**Dynamic External Rotatory Impingement Test:** The dynamic external rotatory impingement test (DEXRIT) is similar to the traditional McCarthy’s test, in which a positive test is associated with the detection of a pop during the maneuver.18,19 In the supine position the patient is instructed to hold the contralateral leg in flexion beyond 90°, thus establishing a zero set point of the pelvis by eliminating lumbar lordosis. The examined hip is then brought into 90° of flexion or beyond and is passively taken through a wide arc of abduction and external rotation (Figs 2A-C). A positive test is noted with re-creation of the patient’s pain. The DEXRIT can be performed in the operating theater for direct visualization of femoral neck and acetabular congruence.

**Dynamic Internal Rotatory Impingement Test:** The dynamic internal rotatory impingement test is similar to the traditional McCarthy’s test, in which a positive test is associated with the detection of a pop during the maneuver.18,19 As with the DEXRIT, elimination of lumbar lordosis and a zero pelvic set point is achieved by the patient holding the contralateral leg in flexion beyond 90° while in the supine position. The examined hip is then brought into 90° of flexion or beyond and is passively taken through a wide arc of abduction and internal rotation (Figs 2D-F). A positive test is noted with re-creation of the patient’s pain. The dynamic internal rotatory impingement test can also be performed in the operating theater for direct visualization of femoral neck and acetabular congruence.

**Palpation:** Palpation is always performed during every hip examination. The patient is asked to locate or point to the site of pain, and the examiner palpates the area to assess the osseous and musculotendinous locations. Additional areas of interest for palpation include the abdomen, supra-sacroiliac joint, sciatic notch, anterior-superior iliac spine, greater trochanter, ischial tuberosity, glutaeus maximus insertion, and piriformis tendon.4

**Flexion/Abduction/External Rotation:** The flexion/abduction/external rotation (FABER) test is historically known as the Patrick test, designed to differentiate between lumbar sacroiliac and posterior hip

*Figure 1.* Internal rotation ROM testing in seated position. With the patient in the seated position, the examiner passively brings the hip into internal rotation until a fir endpoint is achieved or the patient’s pain is reproduced.
pain by specifically locating the area of reproduced pain.\textsuperscript{4,20} The examiner brings the leg into 45° of flexion and externally rotates and abducts the leg so that the ipsilateral ankle rests proximal to the knee of the contralateral leg.\textsuperscript{4} Passive abduction ROM of the flexed leg is noted and compared side to side. Posterior pain is localized to indicate lumbar, sacroiliac joint, or posterior hip pathology. Of distinction from other tests of FABER is the pelvic set point and flexion angle. With the contralateral leg in extension,
the hip is at a normal dynamic pelvic inclination and the hip flexion angle is 45° or less.

**Straight Leg Raise Against Resistance:** Historically, the straight leg raise against resistance test is also known as the Stinchfield test.4 The patient performs an active straight leg raise to 45°; the examiner’s hand is then placed proximal to the knee while applying downward force. The straight leg raise against resistance test is an assessment of hip flexor psoas strength and is a sign of an interarticular problem as the psoas places pressure on the labrum in active resistance. A positive test is noted with recreation of the patient’s pain or weakness.

**Strength Testing:** Muscular strength about the hip joint including the hip abductors, adductors, flexors and extensors is tested during the hip examination. The examiner applies a force to the leg, and the patient is instructed to resist the force. Each muscle group is graded in the traditional fashion on a 5-point scale. These tests can be performed in a supine, seated, or lateral position. To test the gluteus medius, the iliobibial band must be released by flexing the knee.

**Passive Supine Rotation Test:** Historically, the passive supine rotation test has been known as the log roll.20 In a supine position, with the patient’s legs extended and relaxed on the table, each leg is separately internally and externally rotated by the examiner, and differences are noted in terms of guarding or laxity. A restriction or pain may indicate interarticular or extra-articular pathology.

**Posterior Rim Impingement:** To assess posterior rim impingement, the patient is positioned at the edge of the examination table so that the legs hang freely at the hip, and the patient draws up both legs toward the chest, thus eliminating lumbar lordosis. The affected leg is then extended off the table, allowing for full extension of the hip, and is abducted and externally rotated (Fig 3). The posterior rim impingement test takes the hip into extension, allowing assessment of the congruence of the posterior acetabular wall and femoral neck. A variation of this test is the lateral FABER test, or lateral rim impingement test, performed in the lateral position. The examiner cradles the patient’s lower leg with one arm and monitors the hip joint with the opposing hand. The examiner passively brings the affected hip through a wide arc from flexion to extension in continuous abduction. Reproduction of the patient’s pain indicates a positive test. The supine position with the contralateral leg flexed eliminates lumbar lordosis, whereas the lateral position is used to test the normal dynamic pelvic inclination. Pelvic inclination may affect testing, and both positions are helpful in evaluation.

**Flexion/Adduction/Internal Rotation:** The flexion/adduction/internal rotation (FADDIR) test is traditionally performed in the supine position with passive movement of the thigh into full flexion, adduction, and internal rotation21; however, the FADDIR test can also be performed in the lateral position. With the patient in the supine position, the hip is passively brought into 90° of flexion, adduction, and internal rotation (Fig 4). Re-

![Figure 3](image1.jpg)

**Figure 3.** Posterior rim impingement test. The patient is positioned at the edge of the examination table and holds the contralateral leg in flexion. The examiner passively brings the affected hip into extension, abduction, and external rotation.

![Figure 4](image2.jpg)

**Figure 4.** FADDIR test. With the patient in the supine position, the examiner passively brings the hip into 90° of flexion, adduction, and internal rotation. This test can also be performed in the lateral position.
production of the patient’s pain indicates a positive test, and the degree of flexion and internal rotation is noted.

Lateral Assessment

Passive Adduction Tests: Passive adduction tests are historically similar to Ober’s test performed with the hip in extension.4 The patient is positioned on the unaffected hip with the shoulders at 90° to the table. The examiner stands behind the patient, cradles the patient’s lower leg, and assesses full passive adduction of the hip using the following 3 tests (Fig 5): (1) The tensor fascia lata contracture test is performed with the hip and knee in extension, thus placing tension on the tensor fascia lata when the hip is adducted. (2) The gluteus medius contracture test is performed with 0° of hip extension and 45° to 90° of knee flexion thus releasing the iliotibial band and placing tension on the gluteus medius with hip adduction. (3) The gluteus maximus contracture test is performed with the shoulders rotated back toward the table with hip flexion and knee extension, thus placing tension on the gluteus maximus with hip adduction. Any restrictions of these motions are recorded. A healthy patient should be able to perform passive adduction past the midline of the body.

Prone Assessment

Femoral Anteversion Test: The femoral anteverision test is historically similar to Craig’s test.4 With the patient in the prone position, the knee is flexed to 90° and the examiner manually rotates the leg while palpating the greater trochanter. The examiner rotates the limb so that the lateral prominence of the greater trochanter is felt to be maximal, thereby placing the femoral head into the center portion of the acetabulum.4 Femoral anteversion/retroversion is assessed by noting the angle between the axis of the tibia and an imaginary vertical line.4 Normally, femoral anteverision is between 8° and 15°.4 If there is a significant difference in internal rotation in the extended and seated flexed position, the examiner should differentiate between osseous and ligamentous causes.

Data Analysis

The physical examination tests performed by each examiner were recorded separately for each patient. All data are reported as mean ± SD. Pearson correlation coefficient were calculated to determine significant relations. The level of significance was set at P < .05.

RESULTS

All examiners began each examination by reviewing the patients’ written history and by asking questions regarding mechanism, time of onset of pain, location of pain, and severity of pain. The mean length of time spent with the patient by the examiners was 6.6 minutes (range, 4.6 to 9.1 minutes). The mean number of clinical tests performed by each examiner was 15.6 ± 2.5 (examiner 1), 12.5 ± 2.6 (examiner 2), 13 ± 2.5 (examiner 3), 33.8 ± 1.5 (examiner 4), 18.8 ± 2.9 (examiner 5), and 12.4 ± 2.5 (examiner 6). Each examiner’s routine physical examination of the hip is shown in Table 1.
It was determined that 18 tests were most frequently performed (≥40%) by the examiners, 3 standing, 11 supine, 3 lateral, and 1 prone (Fig 6). Of the tests most frequently performed, 10 were performed more than 50% of the time. The tests performed in the supine position were as follows: flexio ROM (percentage of use, 98%), flexio internal rotation ROM (98%), flexio external rotation ROM (86%), passive supine rotation test (76%), FADDIR test (70%), straight leg raise against resistance test (61%), and FABER test (52%). The tests performed in the standing position were the gait test (86%) and the single-leg stance phase test (77%). The 1 test performed in the prone position was the femoral anteverision test (58%).

Table 2 presents the agreement between examiners...
for obtaining positive tests. The number of positive finding per test performed are separated by patient for the 10 most frequently used tests (where reproduction of the patient’s pain or fir endpoint in ROM indicated a positive test). Included in the table is the posterior rim impingement test, which was included because of high agreement between examiners but was performed less than 30% of the time.

There was a significant \( (P < .01) \) positive moderate relation \( (r = 0.46, n = 66) \) of positive tests to tests performed with all patients included (Fig 7). Relations varied greatly when calculated based on individual patients. These data are shown in Table 3.

**DISCUSSION**

The examiners observed in this study followed a very consistent pattern within their own physical examination of the hip. Examiners exhibited little variation from their average chosen tests by using 2 to 3 additional tests. All examiners structured their physical examination in the same manner, beginning with...
standing evaluations followed by seated, supine, lateral, and prone positions. Between examiners, however, the chosen tests differed. Presented here are the most common tests performed by the 6 hip specialists. The main finding in this study was the observation of the 10 most commonly performed tests (>50%); 7 in the supine position (flexion ROM, internal rotation ROM, external rotation ROM, passive supine rotation test, FADDIR test, straight leg raise against resistance test, and FABER test), 2 in the standing position (gait test and single-leg stance phase test), and 1 in the prone position (femoral anteversion test). Eight additional tests were also performed 40% to 50% of the time. The consistent use of these tests stresses the importance of physical examination techniques and tests to be routinely used. Incorporation of these 18 tests into a structured protocol of standing, seated, supine, lateral, and prone examinations should be considered.

An improperly performed test could constitute a false-positive or false-negative finding. This fact calls for standardization of how tests are performed. True agreement or reliability between examiners could not be calculated because not all tests were specifically used by all examiners for all patients; however, there was good agreement between examiners (whether the test was positive or negative) for the most frequently performed tests. Interestingly, there was 1 test (posterior rim impingement test) that showed good agreement but was not frequently used (performed in <30% of patients). Fair levels of agreement have been reported for the FABER test ($\kappa = 0.63$), FADDIR test ($\kappa = 0.58$), and passive supine rotation test ($\kappa = 0.61$).

Although the tests described are used by the 6 hip specialists studied, the specificity, sensitivity, and validity require further documentation and study. Future studies need to include a comprehensive physical examination with detailed findings associated with the presentation of hip disorders. A recent report specific to the clinical presentation of patients with anterior hip impingement reported the physical examination finding of ROM (flexion, extension, abduction,

**Table 2. Agreement for Positive Tests Between Examiners**

<table>
<thead>
<tr>
<th>Test</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion ROM</td>
<td>6/6</td>
<td>6/6</td>
<td>6/6</td>
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<tr>
<td>Internal rotation ROM</td>
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<td>6/6</td>
<td>6/6</td>
<td>6/6</td>
<td>6/6</td>
<td>5/5</td>
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<td>5/5</td>
<td>4/4</td>
<td>6/6</td>
<td>6/6</td>
<td>4/4</td>
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<tr>
<td>Passive supine rotation test</td>
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<td>1/4</td>
<td>0/4</td>
<td>1/4</td>
<td>1/6</td>
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<td>1/4</td>
<td>0/4</td>
<td>0/4</td>
<td>0/4</td>
</tr>
<tr>
<td>Gait</td>
<td>0/4</td>
<td>1/5</td>
<td>0/5</td>
<td>1/5</td>
<td>2/5</td>
<td>1/6</td>
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<td>Single-leg stance phase test</td>
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<td>0/5</td>
<td>3/4</td>
<td>0/5</td>
<td>0/5</td>
<td>1/5</td>
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<tr>
<td>Straight leg raise against resistance test</td>
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<td>3/3</td>
<td>1/4</td>
<td>1/3</td>
<td>2/4</td>
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<tr>
<td>FADDIR test</td>
<td>2/3</td>
<td>3/4</td>
<td>4/4</td>
<td>4/4</td>
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<td>2/4</td>
<td>1/5</td>
<td>0/4</td>
<td>0/5</td>
<td>1/4</td>
</tr>
<tr>
<td>Posterior rim impingement test</td>
<td>1/2</td>
<td>1/1</td>
<td>1/2</td>
<td>1/2</td>
<td>2/3</td>
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<td>0/2</td>
<td>1/2</td>
<td>1/1</td>
<td>2/2</td>
<td>2/2</td>
</tr>
</tbody>
</table>

Note: Data are presented as positive tests/number of tests performed.
adduction, internal rotation in neutral position, internal rotation at 90° of flexion external rotation in neutral position, and external rotation at 90° of flexion) and provocative tests (FADDIR, FABER, straight leg raise against resistance, passive supine rotation, and posterior rim impingement). Our finding are limited to the specific population of patients studied. It is assumed that all examiners performed the tests that they believe are the most effective in evaluating healthy individuals with hip pain. However, for a comprehensive evaluation of the hip, it is necessary to rule out lumbar spine, abdominal, and neurovascular conditions in each patient.

Not every test can or should be administered for every given patient. Our data show that performing a high number of tests yields a high number of positive tests (examiner 4 performed a mean of 34 tests with a mean of 7 positive tests [20%]). However, performing a high number of tests does not yield the highest percentage of positive tests (examiner 2 performed a mean of 13 tests with a mean of 4 positive tests [36%]). The relation between the number of tests performed and the number of positive tests across all patients was positive and moderate in strength ($r = 0.44$) yet varied greatly depending on the patient.

There are basic tests that need to be performed when examining the painful hip (skin inspection, neurovascular assessment, palpation, ROM assessment, and strength assessment), as with other joints. An experienced examiner will be guided by the finding of the presenting patient; however, the inexperienced examiner must not be too quick to omit tests from an examination. Therefore the most comprehensive and

### Table 3. Relation of Number of Positive Tests and Number of Tests for Each Patient

<table>
<thead>
<tr>
<th>Patient</th>
<th>$r$ Value</th>
<th>$P$ Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.60</td>
<td>0.20</td>
</tr>
<tr>
<td>B</td>
<td>0.90*</td>
<td>0.02</td>
</tr>
<tr>
<td>C</td>
<td>0.86*</td>
<td>0.03</td>
</tr>
<tr>
<td>D</td>
<td>0.94†</td>
<td>0.01</td>
</tr>
<tr>
<td>E</td>
<td>0.74*</td>
<td>0.09</td>
</tr>
<tr>
<td>F</td>
<td>0.08</td>
<td>0.88</td>
</tr>
<tr>
<td>G</td>
<td>0.66</td>
<td>0.15</td>
</tr>
<tr>
<td>H</td>
<td>0.77</td>
<td>0.07</td>
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<tr>
<td>I</td>
<td>0.55</td>
<td>0.26</td>
</tr>
<tr>
<td>J</td>
<td>-0.39</td>
<td>0.45</td>
</tr>
<tr>
<td>K</td>
<td>0.33</td>
<td>0.52</td>
</tr>
</tbody>
</table>

* $P < .05$.
† $P \leq .01$.

### Table 4. Comprehensive Physical Examination of Hip

#### Physical examination
- Height (cm)
- Weight (kg)
- Temperature (°F)
- Respiration
- Pulse (bpm)
- Blood pressure (mm/Hg)

#### Gait/posture
- **Gait**
  - Normal
  - Antalgic
  - Adductor deficiency (Trendelenburg)
  - Pelvic wink
  - Arm swing
  - Short stride length
  - Short stance phase
  - Foot progression angle
  - External
  - Neutral
  - Hyperpronation
- **Single-leg stance phase test** (Trendelenburg test)
  - Right
  - Left
- Shoulder height (equal/not equal) (cm)
- Iliac crest height (equal/not equal) (cm)
- Active forward bend (°)
- Spine
  - Straight
  - Scoliosis (structural/nonstructural)

#### Laxity
- Thumb
- Elbows
- Knees
  - > 5°
- Lordosis
  - Normal
  - Increased
- Paravertebral muscle spasms

#### Seated examination
- Neurologic finding
  - Motor
  - Sensory
  - DTR
  - Achilles
  - Patella
- Circulation
  - Dorsalis Pedis
  - Posterior Tibialis
- Skin inspection
- Lymphatic
  - Lymphedema
  - No lymphedema
- Pitting edema (1+/2+)
- Straight leg raise
  - R
  - L

#### ROM
- **Internal rotation**
  - R
  - L
Presented in Table 4 is a comprehensive list of physical examination tests by position, including the tests described in this article. These tests are the common

<table>
<thead>
<tr>
<th>TABLE 4. Continued</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>External rotation</strong></td>
</tr>
<tr>
<td>R</td>
</tr>
<tr>
<td>L</td>
</tr>
<tr>
<td><strong>Supine examination</strong></td>
</tr>
<tr>
<td>Leg lengths (cm)</td>
</tr>
<tr>
<td>R</td>
</tr>
<tr>
<td>L</td>
</tr>
<tr>
<td>Equal/not equal</td>
</tr>
<tr>
<td><strong>ROM</strong></td>
</tr>
<tr>
<td>Right leg</td>
</tr>
<tr>
<td>Flexion (80/100/110/120/130/140)</td>
</tr>
<tr>
<td>Abduction (10/20/30/45/50)</td>
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<tr>
<td>Adduction (0/10/20/30)</td>
</tr>
<tr>
<td>Left leg</td>
</tr>
<tr>
<td>Flexion (80/100/110/120/130/140)</td>
</tr>
<tr>
<td>Abduction (10/20/30/45/50)</td>
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<td>Adduction (0/10/20/30)</td>
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<tr>
<td><strong>Hip flexion contracture test</strong></td>
</tr>
<tr>
<td>R (+/-)</td>
</tr>
<tr>
<td>L (+/-)</td>
</tr>
<tr>
<td><strong>FADDIR</strong></td>
</tr>
<tr>
<td>R (+/-)</td>
</tr>
<tr>
<td>L (+/-)</td>
</tr>
<tr>
<td><strong>DIRI</strong></td>
</tr>
<tr>
<td>R (+/-)</td>
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<tr>
<td>L (+/-)</td>
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<tr>
<td><strong>DEXRIT</strong></td>
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<tr>
<td>R (+/-)</td>
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<tr>
<td>L (+/-)</td>
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<tr>
<td>Posterior rim impingement test</td>
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<tr>
<td>R (+/-)</td>
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<tr>
<td>L (+/-)</td>
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<tr>
<td>Apprehension sign</td>
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<tr>
<td>R (+/-)</td>
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<tr>
<td>L (+/-)</td>
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<tr>
<td><strong>Palpation</strong></td>
</tr>
<tr>
<td>R (+/-)</td>
</tr>
<tr>
<td>L (+/-)</td>
</tr>
<tr>
<td><strong>Tinel’s Test—femoral nerve</strong></td>
</tr>
<tr>
<td>R (+/-)</td>
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<tr>
<td>L (+/-)</td>
</tr>
<tr>
<td><strong>G. Max insertion into ITB (tender/nontender)</strong></td>
</tr>
<tr>
<td>R (+/-)</td>
</tr>
<tr>
<td>L (+/-)</td>
</tr>
<tr>
<td><strong>Sciatic nerve (tender/nontender)</strong></td>
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<td>G. Max contracture test</td>
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<td>Gluteus maximus contracture test</td>
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<td><strong>Lateral rim impingement test</strong></td>
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<tr>
<td>R (+/-)</td>
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<tr>
<td>L (+/-)</td>
</tr>
<tr>
<td><strong>FADDIR test</strong></td>
</tr>
<tr>
<td>R (+/-)</td>
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<tr>
<td>L (+/-)</td>
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<tr>
<td><strong>Femoral anteversion test</strong></td>
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<td>(° anteversion)</td>
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<td><strong>Palpation</strong></td>
</tr>
<tr>
<td>Spinous processes (+/-)</td>
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<tr>
<td>SI joints</td>
</tr>
<tr>
<td>R (+/-)</td>
</tr>
<tr>
<td>L (+/-)</td>
</tr>
<tr>
<td>Bursae ischium</td>
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<tr>
<td><strong>Specific tests</strong></td>
</tr>
<tr>
<td>Philippon internal rotation test</td>
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<tr>
<td>McCarthy’s sign</td>
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<tr>
<td>Scours test</td>
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<tr>
<td>Foveal distraction test</td>
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<tr>
<td>Bicycle test</td>
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<td>Fulcrum test</td>
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<tr>
<td>Freiberg’s test</td>
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<tr>
<td>Pace sign</td>
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<tr>
<td>ABDEER test</td>
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<tr>
<td>Dynamic Trendelenburg test</td>
</tr>
<tr>
<td><strong>Supine abduction external rotation test</strong></td>
</tr>
</tbody>
</table>

NOTE. The tests most frequently used by the 6 hip specialists are indicated in bold.

Abbreviations: DTR, deep tendon reflex of patella and Achilles tendons; ABDEER, abduction/extension/external rotation test; SI, sacroiliac joint; ASIS, anterior superior iliac spine; G. Max, gluteus maximus; ITB, iliotibial band.

efficien physical examination must be determined.
denominator among the examiners in this study, and our recommendations can be a useful guide to ensure that the hip is not overlooked. These suggestions are neither definitive nor final; however, these data provide a foundation for the development of a standardized protocol.

CONCLUSIONS

There are variations in the testing that hip specialists perform to examine and evaluate their patients, but there is enough commonality to form the basis to recommend a battery of physical examination maneuvers that should be considered for use in evaluating the hip.

Acknowledgment: The authors thank Ian J. Palmer, Ph.D., for his assistance in preparing the manuscript, and Dr. Freddie Fu for his guidance and direction.

REFERENCES

Physiological Changes as a Result of Hip Arthroscopy Performed With Traction


Purpose: To evaluate the physiological effects of hip arthroscopy using traction on venous blood flow nerve conduction, soft-tissue injury, fibrinolysis and patient pain. Methods: Thirty subjects were prospectively analyzed in an institutional review board–approved study. The visual analog scale pain score, creatine phosphokinase (CPK)–MM level, and D-dimer test were obtained preoperatively, postoperatively, and 5 days postoperatively. Doppler ultrasound (group A) (n = 15) of femoral and popliteal venous blood flow and somatosensory evoked potentials (SSEPs) (group B) (n = 15) of the posterior tibial nerve and superficial peroneal nerve were monitored intraoperatively. Results: Mean operation and traction times were 131.7 and 27.3 minutes, respectively. During traction (mean, 57.7 lb), decreased blood flow was determined at the popliteal vein (15 of 15 subjects) and femoral vein (4 of 15 subjects). Blood flow returned to baseline after traction in all subjects. Mean CPK-MM levels were 86.0 ± 29.6 mU/mL preoperatively, 232.1 ± 224.6 mU/mL postoperatively, and 138.1 ± 109.3 mU/mL at 5 days postoperatively. The number of subjects positive for D-dimer was 7 preoperatively, 12 postoperatively, and 21 at 5 days postoperatively. SSEPs showed a greater than 50% decrease in amplitude on the operative (8 of 15) and nonoperative (9 of 15) limbs. No significant correlations were determined between visual analog scale pain score, body mass index, CPK-MM level, traction time, or operating room time. Conclusions: Doppler ultrasound showed decreased blood flow of the popliteal vein with traction, which returned to normal after traction. SSEPs showed changes with and without traction on operative and nonoperative legs. Consideration should be given for knee flexion of the contralateral leg after traction to protect nerve function. Hip arthroscopy resulted in an increase in a positive D-dimer test from immediately postoperatively to postoperative day 5. There is variability in the soft-tissue damage with hip arthroscopy, which is independent of time (<2 hours), body mass index, or pain. Traction affects the vascular and neurologic structures of the operative and nonoperative extremity independent of time. Level of Evidence: Level IV, therapeutic case series.

Hip distraction is required for access to the central compartment of the hip joint during hip arthroscopy. The use of traction forces (50 to 60 lb) is necessary to achieve adequate joint space separation (10 to 12 mm) confirmed by use of fluoroscopy.1-5 To minimize the risk of iatrogenic complications, traction time is kept under 2 hours and/or intermittently released and the least amount of traction force is used to achieve adequate distraction.5 The frequency of complications reported for hip arthroscopy for all indications is typically less than 1.5%, with a range of 0.5% to 5% of procedures performed.6,7 Transient neurapraxia of the pudendal, sciatic, and peroneal nerves is the most common injury and has been attributed to prolonged and/or excessive traction on the hip joint.7,8
Deep vein thrombosis (DVT) and pulmonary embolism (PE) are generally believed to be complications that are not specifically associated with hip arthroscopy. In a literature review of over 5,500 hip arthroscopy cases performed over a 20-year period, Bushnell et al. concluded that the reported rate of DVT and PE in hip arthroscopy was 0%. The incidence of these complications in hip arthroscopy may be under-reported to date. With the rapidly increasing prevalence of hip arthroscopy procedures being performed in the United States, it is probable that case reports of these rare but potentially devastating complications could become more common.

Intraoperative monitoring of somatosensory evoked potentials (SSEPs) is routinely performed during spinal surgery to detect and prevent damage to the brain, spinal cord, and nerve roots. Several reports of its use to detect and prevent damage in the upper and lower extremities, secondary to positioning, in spinal surgery and other types of operative procedures also exist.

Intraoperatively, Doppler ultrasonography may be used as a rapid, noninvasive means of determining whether diminution or occlusion of venous blood flow has occurred due to excessive/prolonged traction forces or patient positioning. By monitoring the change in flow relative to the application of traction and time under traction, the surgeon may gather useful information about how and when blood flow is reduced. Such information will be valuable in developing evidence-based guidelines on how traction should be safely used in hip arthroscopy or to direct prophylactic care. In addition, the use of a D-dimer test along with intraoperative blood flow monitoring may be useful for the early detection of thrombi.

There are no reports in the literature regarding the extent of soft-tissue stress/damage associated with hip arthroscopy procedures. The procedure necessitates establishing several portals through which instruments are repeatedly passed to gain access to the central compartment, either through cannula or directly through the tissue channels. In addition, application of prolonged/excessive traction forces may cause direct trauma or compression injury. The extent of tissue/muscle damage resulting from these maneuvers may be significant and thus contribute to postoperative pain. Serum levels of muscle enzymes, such as creatine phosphokinase (CPK)–MM, are elevated during muscle injury and can be quantitatively measured as a marker of muscle damage.

The purpose of this study was to evaluate the physiological effects of hip arthroscopy using traction on the lower extremity by intraoperative monitoring of venous blood flow nerve conduction; and markers of soft-tissue injury, fibrinolysis and patient pain. We hypothesized that venous and neurologic structures would be affected during hip arthroscopy with traction.

METHODS

This was a prospective, institutional review board–approved, 2-cohort exploratory study of the utility of multimodal monitoring of patients undergoing hip arthroscopy procedures using a traditional fracture table and distraction attachments. A total of 30 patients were recruited and enrolled in the study at a single institution. In the first cohort of patients (group A) (n = 15), venous blood flow in the leg under traction was evaluated by use of noninvasive duplex Doppler ultrasound in the operating room before and after application/removal of hip/leg positioning equipment. In the second cohort (group B) (n = 15), intraoperative SSEP monitoring was performed to evaluate peripheral nerve function in the leg under traction. In addition, the following assessments/laboratory tests were performed on all patients in both cohorts: baseline medical history, preoperative/postoperative narcotic use, motor/neurologic physical examination, CPK-MM and D-dimer serum assay tests, and patient-reported pain evaluation. Patient data were collected at baseline screening (preoperatively), intraoperatively, during postoperative recovery, and at routine follow-up 5 days postoperatively.

Subjects

The study population consisted of male and female subjects who elected to undergo hip arthroscopy surgery and were aged 18 years or older. Thirty patients who met the study eligibility criteria were enrolled at a single clinical site. There are no data published in the medical literature on which to base an estimate of the proportion of hip arthroscopy patients expected to exhibit significant venous/nerve/tissue compromise due to the effects of hip/leg positioning equipment. Lancaster et al. have suggested that, when conducting a pilot study to determine sample size requirements in larger trials, at least 30 patients should be enrolled. Thus a sample size of 30 patients was chosen to meet the objectives of this study.

The inclusion criteria were as follows:

1. Male or female patient aged 18 years or older
2. Patient elected to undergo a standard hip ar-
throscopic procedure that required access to the central compartment of the hip joint
3. Patient was able to give voluntary, written informed consent to participate and signed an informed-consent document

The exclusion criteria were as follows:

1. Any major systemic or lower extremity trauma or any pre-existing medical condition/illness that represented a contraindication for hip arthroscopy surgery
2. Significant peripheral vascular disease characterized by diminished dorsalis pedis or tibial pulse
3. Significant peripheral neuropathy shown by nerve conduction velocity test
4. Preoperative serum CPK-MM levels outside the bounds of normal limits as defined by the reference laboratory
5. Preoperative use of statins or other medications known to elevate serum CPK-MM levels within 1 week of surgery
6. History of substance abuse within the past 12 months
7. Any significant psychological disturbance in the past or present, psychotic or neurotic, that could impair the informed-consent process

Procedures

All procedures performed per standard of care or for research purposes are described herein. The schedule of assessments is summarized in Table 1.

Baseline Assessment

The demographic and medical history data obtained were age, gender, weight, height, and body mass index (BMI). Pertinent medical history included data relevant to predisposing risk factors for venous thromboembolism (VTE) (i.e., personal/family history of VTE, prolonged immobilization, tobacco use, cancer, hormone therapy, varicose veins, heart failure, respiratory failure, inflammatory bowel disease, myeloproliferative disorders, nephritic syndrome, and paroxysmal nocturnal hemoglobinuria) and the use of pain medication (narcotics and non-narcotic analgesics). All subjects underwent a comprehensive physical examination of the hip, and the patient was asked to rate his or her hip-related pain using a visual analog scale (VAS) pain assessment questionnaire. During routine preoperative blood sampling, an additional amount of blood was taken for CPK-MM and D-dimer assay tests.

Intraoperative Assessments

After induction of general anesthesia in the operating room, the patient was positioned on the fracture table in the standard supine position. A perineal post and tensioning element were affixed to the ipsilateral extremity and standard traction forces applied to achieve adequate hip distraction. Required access portals were established with standard surgical instrumentation. Diagnostic arthroscopic examination and therapeutic treatment/repair were carried out as indicated by the patient’s presenting condition. On completion of the indicated procedure(s), traction forces and distraction attachments were removed. Once surgery was complete, the patient was moved to the postoperative recovery unit.

All Patients: In the operating room, circumferential hip and thigh measurements were taken with a tape measure before the application of a traction apparatus and once again upon removal of the apparatus. The quantitative measure of traction force applied to the lower extremity was recorded. Blood sampling for CPK-MM and D-dimer assay was performed in the postoperative recovery unit. Before discharge, the patient was asked to rate his or her hip pain using a VAS questionnaire.

Group A: Before application of traction, blood flow in the popliteal and common femoral veins was monitored with Doppler ultrasound.

**Table 1. Schedule of Patient Assessments**

<table>
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<tr>
<th>Interval</th>
<th>Assessment</th>
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<td>Baseline</td>
<td>IC, history, medication use, physiological examination of motor and sensory reflexes, VAS score for pain, CPK level, D-dimer</td>
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<td>Thigh circumference</td>
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<tr>
<td>Operative</td>
<td>DUS with traction off, DUS with traction on</td>
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<tr>
<td>Group A</td>
<td>DUS with traction off, DUS with traction on</td>
</tr>
<tr>
<td>Group B</td>
<td>SSEPs</td>
</tr>
<tr>
<td>Postoperative</td>
<td>Thigh circumference, medication use, physiological examination of motor and sensory reflexes, VAS score for pain, CPK level, D-dimer; DUS in group A only</td>
</tr>
<tr>
<td>5 d postoperatively</td>
<td>Medication use, physiological examination of motor and sensory reflexes, VAS score for pain, thigh circumference, CPK level, D-dimer</td>
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Abbreviations: DUS, Doppler ultrasound; IC, informed consent.
measured by Doppler ultrasound. Popliteal and common femoral venous blood flow in the contralateral extremity was also measured as a control. Ultrasound blood flow measurements in the extremity under traction were repeated immediately after traction force was applied. The time of the start of traction, the amount of tension applied to the lower extremity, and the time of ultrasound measurements were recorded. A marked diminution of flow (>50%) was considered a significant alteration from baseline. In the postoperative recovery room, a final Doppler blood flow measurement was recorded. Group A comprised 15 subjects with traction by use of a non-cannulated approach.

**Group B:** Baseline SSEP tracings were obtained by stimulating the superficial peroneal nerve (SPN) and posterior tibial nerve (PTN). The contralateral extremity was monitored as a control. After application of the traction apparatus, intraoperative SSEPs were monitored routinely throughout the procedure of the SPN and PTN and tracings were obtained every 5 to 15 minutes. A 50% decrease in amplitude or a 10% increase in latency relative to baseline was considered a significant alteration from baseline. Group B comprised 15 subjects with traction by use of a cannulated approach.

**Postoperative Follow-up: Day 5**

Patients returned for routine postoperative follow-up on the fifth postoperative day. During this visit, the following assessments/procedures were performed: CPK-MM; D-dimer; physiological examination of neurologic and motor function; measurements of thigh circumference; VAS pain questionnaire; and use of narcotics, non-narcotic analgesics, and anticoagulants.

**Data Analysis**

Because this is a 2-cohort exploratory study, all variables were tabulated and descriptive summary statistics were presented by cohort and for the entire population. Baseline, intraoperative, and postoperative assessment data were compared and summarized. All data presented as mean ± standard deviation.

**RESULTS**

There were no known complications within the study population. Thirty patients were part of the study; however, 1 patient was lost at 5-day follow-up. There were 8 men and 22 women with a mean height of 67.6 in, weight of 178.3 lb, and BMI of 27.4. Intraoperative arthroscopic procedures included femoroplasty (29), acetabuloplasty (26), labral fixation (10), bursectomy (11), piriformis release (6), peritrochanteric space inspection (4), and ligamentum teres debridement (3). The mean operating room time was 131.7 minutes. Traction was applied for a mean of 27.3 minutes at a mean of 57.7 lb. With the application of traction, 13 of 15 subjects in the Doppler ultrasound group had greater than 50% decreased blood flow of the popliteal vein, with all 15 showing occlusion. Of 15 subjects, 4 had decreased blood flow of the femoral vein. Blood flow returned to baseline after removal of traction in all subjects (1 patient had only moderate femoral flow in recovery). Mean CPK-MM levels were 86.0 ± 29.6 mU/mL preoperatively, 232.1 ± 224.6 mU/mL postoperatively, and 138.1 ± 109.3 mU/mL at 5 days postoperatively (Fig 1). At the time of baseline examination, 5 patients were positive for D-dimer. This increased to 12 patients on the day of surgery, and 21 patients were positive for D-dimer at the 5-day follow-up (Fig 2). SSEP monitoring showed a greater than 50% decrease in amplitude on the operative limb in 8 of 15 patients (5 PTN only, 1 SPN only, and 2 PTN and SPN). Nine patients showed a greater than 50% decrease in amplitude on the contralateral limb (5 PTN only, 2 SPN only, and 3 PTN and SPN). There were no significant correlations determined between VAS, BMI, CPK-MM level, traction time, or operating room time. The mean VAS score preoperatively, postoperatively, and at 5 days postoperatively was 53.7 cm, 52.8 cm, and 39.3 cm, respectively.

**DISCUSSION**

At the time of this study, there were no published studies on venous blood flow nerve conduction, and tissue damage in the lower extremity during hip arthroscopic procedures with traction. The purpose of this study was to evaluate the effects of hip arthroscopy using traction on the lower extremity by intraoperative monitoring of venous blood flow nerve conduction; and markers of soft-tissue injury, fibrinolysis, and patient pain.

To access the central compartment of the hip, traction is required, and the amount of traction force necessary can vary.5 Eriksson et al.3 reported that the traction force needed to achieve sufficient visualization of the hip joint was 300 to 500 N (67 to 112 foot-pounds) in an anesthetized patient and up to 900 N (202 lbf) in an unanesthetized patient. Smart et al.8 suggest that 223 to 275 N (50 to 75 lbf) of traction is sufficient. To minimize the risk of iatrogenic complications, traction time is kept under 2 hours and/or
intermittently released and the least amount of traction force necessary to achieve adequate distraction is used. Demers et al. reported that a tourniquet time greater than 60 minutes was found to be a statistically significant factor associated with the development of VTE and therefore suggested that traction time should be minimized to under 1 hour. In this study a fairly conservative amount of traction (57.7 lb) was applied for a relatively short period (27.3 minutes). The mean operative time was 131 minutes.

The most common injuries associated with prolonged and/or excessive traction of the hip joint include transient neurapraxia of the pudendal, sciatic, and peroneal nerves. However, the prolonged traction necessary to achieve adequate hip distraction may be a potentially significant risk factor for the development of DVT or VTE because of the restriction of blood flow within the leg under traction. The incidence of DVT or VTE in lower extremity arthroscopy has been reported to be very small, but it remains a concern for the arthroscopic surgeon. In 2005 McCarthy and Lee described a DVT complication that developed 1 month after hip arthroscopy surgery in a patient who had factor V Leiden deficiency. In the same year, Byrd also reported a possible case of DVT in a professional athlete who began to have gastrocnemius muscle discomfort 2 months after arthroscopic hip surgery. Although a venous Doppler study showed no evidence of occlusion or flow obstruction, there was evidence of thrombus in the deep calf noted on magnetic resonance imaging. In early 2009, Bushnell and Dahners reported a case of fatal

![Figure 1](image1.png)

**Figure 1.** CPK test results in hip arthroscopy. (5 day, 5 days postoperatively; PERI-OP, perioperatively; PRE-OP, preoperatively.)

![Figure 2](image2.png)

**Figure 2.** D-dimer test results in hip arthroscopy. (5-day post, 5 days postoperatively; NEG, negative; Peri-OP, perioperatively; POS, positive; Pre-OP, preoperatively.)
current medical condition. Other risk factors are related to an individual patient's medical history and should be placed on identifying those risk factors important in minimizing this potential risk, and emphasis on careful patient screening and selection is important. A single risk factor for VTE. Nevertheless, in a previous history of VTE was the only statistically significant single risk factor for VTE. Nevertheless, careful patient screening and selection are important in minimizing this potential risk, and emphasis should be placed on identifying those risk factors related to an individual patient’s medical history and current medical condition. Other risk factors are thought to include advanced age, major systemic trauma, lower extremity trauma, prolonged immobilization, obesity, tobacco use, cancer, hormone therapy, varicose veins, and various systemic illnesses.

Intraoperative monitoring of SSEPs is regularly performed during spinal surgery to detect and prevent damage to the brain, spinal cord, and nerve roots. Jones et al. reported on 3 cases in which SSEP monitoring of the bilateral upper extremities during lumbar spine surgery provided early warnings of vascular and neural compression that led to prompt intraoperative intervention with patient repositioning and resulted in no adverse neurologic sequelae. In a prospective study of 230 lumbosacral spinal procedures, Chung et al. also performed upper limb SSEP monitoring to detect position-related ulnar neuropathy. Significant changes in SSEP amplitude occurred in 5.2% of the patients (10 of 230) intraoperatively, and in all cases the SSEP reading returned to baseline with patient repositioning. No postoperative upper extremity paresis was documented. Pereles et al. used intraoperative SSEP monitoring in 52 total hip arthroplasty procedures to identify those surgical maneuvers that place the sciatic nerve at risk for injury and reported that significant SSEP changes occurred in 15% of their cases (8 of 52), all of which involved the common peroneal nerve. They concluded that routine lateral or anterior retraction of the proximal femur was the most common surgical maneuver associated with temporary nerve compromise. Baumaertner et al. monitored 20 patients undergoing pelvic and acetabular fracture surgery, of whom 6 showed SSEP changes. In 5 of these patients, these changes resolved during surgery with no postoperative deficit whereas in 1 patient the SSEP was not resolved and the patient awoke with peroneal palsy. In our study a greater than 50% decrease in amplitude on the operative limb was observed in 8 of 15 patients (5 PTN only, 1 SPN only, and 2 PTN and SPN). However, SSEP changes were noted on the contralateral limb in both nerves. All SSEP degradations resolved within 5 to 10 minutes, and no patients had postoperative neurosensory deficit. SSEP changes were observed with no postoperative deficit but what effects this might have on postoperative rehabilitation warrants further study. The position of traction, with the extremity in slight flexion, adduction, and internal rotation, tensions the piriformis muscle, which could have an effect on the inferior gluteal nerve and thus gluteus maximus during rehabilitation.

There are no reports in the literature regarding the extent of soft-tissue stress/damage associated with hip arthroscopy procedures. In a small-scale randomized controlled trial, Shin et al. obtained serial CPK-MM serum levels preoperatively and at 1, 3, and 5 days postoperatively in 2 groups of patients undergoing either microendoscopic discectomy or microscopic discectomy to evaluate the degree of invasiveness of each procedure and correlate the results to patient-reported VAS pain scores. They reported that mean CPK-MM levels and VAS scores were significantly lower postoperatively in the group of patients who underwent the microendoscopic discectomy procedure and concluded that it was less invasive than microscopic discectomy and caused less muscle damage and back pain. These results suggest that CPK-MM level can be used as a valid marker of tissue damage in studies of other surgical procedures. Our study showed an increase from 86 mU/mL at baseline to 232 mU/mL postoperatively, with a decrease to 138 mU/mL 5 days postoperatively (the normal value range is 21 to 215 mU/mL). There was variability in soft-tissue damage with hip arthroscopy, which was independent of time (<2 hours), BMI, or correlation with VAS.
Additional observations concerning the entire procedure of hip arthroscopy were made during the course of this study suggesting interesting further study. Patient body weight was obtained preoperatively and postoperatively, with a mean weight gain of 10 lb in the absence of peritoneal and retroperitoneal fluid gain, suggesting that the fluid is dominantly intravascular and local. In 15 patients in whom a non-cannulated technique was used, 2 cases of heterotopic ossification (1 with indomethacin and 1 with no prophylaxis) were noted on standard 6-week postoperative radiographic analysis routinely ordered within our practice (Fig 3). No heterotopic ossification was found in an established permanent cannula group. Higher CPK-MM levels were seen in the non-cannulated approach. The length of pain was variable, and no additional narcotic use was noted.

A limitation to the study may be the short traction time. The data are specific to a mean 27 minutes of traction with intermittent traction. This low traction time is a reflection of our technique that has evolved over time. Future studies should include individuals who undergo longer traction times. Another limitation was the small sample size of 15 patients per group. In addition, SSEPs of the SPN were unobtainable for 4 patients because of increased adiposity at the level of SPN electrode placement. Although the blood flow and nerve conduction monitoring could be more closely related to the effects of traction, the soft-tissue damage and fibrinolysis markers are due to the surgical procedure itself. A redesign of the study specific to traction should include a blood draw after traction but before incision.

CONCLUSIONS

Doppler ultrasound showed decreased blood flow of the popliteal vein with traction, which returned to normal after traction. SSEPs showed changes with and without traction on operative and nonoperative legs. Consideration should be given for knee flexion of the contralateral leg after traction to protect nerve function. Hip arthroscopy resulted in an increase in a positive D-dimer test from immediately postoperatively to postoperative day 5. There is variability in the soft-tissue damage with hip arthroscopy, which is independent of time (<2 hours), BMI, or pain. Traction affects the vascular and neurologic structures of the operative and nonoperative extremity independent of time.

REFERENCES


Figure 3. Heterotopic ossification of a right hip (A) and left hip (B) after hip arthroscopy with a non-cannulated approach.
Postoperative Imaging of the Hip

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Cross-sectional Imaging of the hip
- MR arthrography
- MR imaging without contrast
- Multidetector CT evaluation
- Postoperative imaging evaluation
  - Acetabular labral repair
  - Femoral head-neck junction osteoplasties
    - Open surgical technique
    - Arthroscopic technique
    - Hip fracture repair
    - Core decompression
- Total hip arthroplasty
  - Imaging of total hip arthroplasty
  - Common pathology in total hip arthroplasty
    - Soft tissue abnormalities
    - Loosening
    - Infection
    - Particle inclusion disease
- Summary
- References

Postoperative imaging of the hip has received much less attention than postoperative imaging of the knee or shoulder but is equally important if persistent pathology, surgical complications, or recurrent disease is to be detected. Even preoperatively, the hip is not recognized as the source of symptoms in 60% of patients, and the average length of time from onset of symptoms to diagnosis is approximately 7 months [1]. Postoperative imaging of the hip often requires the use of multiple modalities. There are many surgical procedures that may require imaging follow-up, including acetabular labral repair, head-neck junction osteoplasties, hip fracture repair, core decompression (CD), and total hip arthroplasty (THA) [2–4] [Table 1].

The cross-sectional imaging modalities are among the most useful techniques in the evaluation of a postoperative hip. Possibly the most useful modality in this armamentarium of the hip is magnetic resonance (MR) arthrography [Table 1]. This imaging technique involves the injection of saline mixed with a small amount (0.1–0.2 mL) of gadolinium (ie, gadopentetate dimeglumine) into the hip joint via a small-bore needle. This method, known as direct MR arthrography, is most useful in the evaluation of the acetabular labrum and of the capsule.
Table 1: Protocol for MR imaging of the hip: gadolinium arthrogram

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<th>Plane</th>
<th>Sequence</th>
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<th>FOV</th>
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<td>6</td>
<td>Localizer—</td>
<td>GRE</td>
<td>Body</td>
<td>40</td>
<td>7/2</td>
<td>288/128</td>
<td>175</td>
<td>MIN-FULL</td>
<td>70</td>
<td>64</td>
<td>—</td>
<td>N</td>
<td>2D, GRE, S/I AUTO</td>
</tr>
<tr>
<td>knees</td>
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</table>

Special instructions:
- Sequence #1: both hips and surrounding soft tissues in view.
- Sequence #2–7: small FOV over hip of interest.
- Sequence #6: oblique axial plane oriented parallel to the femoral neck. Coverage is from superior portion of the greater trochanter to the inferior portion of the lesser trochanter.
- Sequence #7: oblique sagittal plane oriented perpendicular to the femoral neck. Coverage is from femoral head to intertrochanteric line.
- Localizer #2: done through the knees using the body coil.
- Note: orient sequences 6 & 7 parallel and perpendicular to the orientation of the femoral neck.
- Employ respiratory compensation if breathing artifact is present.

Abbreviations: 2D, two-dimensional; A/P, anterior to posterior; ETL, echo train length; FC, flow compensation; FSE, fast spin echo; GRE, gradient echo; I, inferior; Min-Full, range of minimum to full TEs; NPW, no phase wrap; S, superior; Sat, saturation band; SE, spin echo; S/I, superior to inferior; Supp, suppressed; TE, echo time; TR, repetition time.
liligamentous structures, and for the determination of the presence of loose bodies [5]. The most important advantage of direct MR arthrography is the ability to achieve adequate capsular distension, which allows the intra-articular anatomy to be delineated optimally by the contrast mixture that is injected into the hip joint.

MR arthrography increasingly is used to evaluate the hip, especially in young patients who have hip pain and in patients who have had prior hip surgery. MR imaging is limited by the magnetic susceptibility artifact produced by metal but is used increasingly in postoperative situations, including after THA [6]. Although most investigators advocate the use of direct arthrography when evaluating a hip joint (especially to detect acetabular labral and articular cartilage abnormalities), noncontrast MR imaging of a hip is useful diagnostically, is noninvasive, and, if optimized for detection of intra-articular pathology, may be comparable diagnostically to direct MR arthrography [7].

Multidetector CT (MDCT) also is useful for evaluating the anatomy of the hip and pelvis, including the osseous structures and surrounding soft tissue. The strength of MDCT relates to its multiplanar isotropic scanning capability, its ability to display the osseous structures optimally, and its relative resistance to metallic streak artifact compared with single-slice CT.

Conventional radiography remains an important modality for the evaluation of pre- and postoperative hips. The global view of postsurgical constructs, such as THAs or lag screws and side plates, is useful for assessing component breakage or displacement, and the ability of conventional radiography to demonstrate soft tissue calcifications and various osseous abnormalities is optimal [8,9].

Radionuclide imaging is helpful for detecting a variety of postoperative complications, including infection (soft tissue infection and osteomyelitis), periprosthetic fracture, and loosening of a THA. Although these pathologic processes may be evaluated well with other modalities, radionuclide imaging is helpful especially in cases of THA loosening that may be equivocal by other forms of imaging [10].

Surgical procedures in and around hip joints increased during the past decade and the annual number of THAs is in excess of 800,000, with more than 120,000 performed in the United States [11,12]. The incidence of hip surgery, including hip arthroscopy, also is increasing, and techniques of acetabular labral repair, joint capsule plication, and femoral head-neck junction osteoplasty are more prevalent [13,14]. This article focuses primarily on imaging of the postoperative hip, the most common types of procedures performed, and the scenarios encountered most commonly after these procedures.

**Cross-sectional Imaging of the hip**

**MR arthrography**

The joint distension achieved with direct MR arthrography allows for optimal evaluation of the intra-articular structures of the hip. The hip joint is accessed by placing the lower extremity in neutral rotation and targeting the subcapital region of the femoral neck [Fig. 1]. The primary indications for MR arthrography are evaluation of the capsuloligamentous structures, the acetabular labrum, and intra-articular loose bodies. Direct arthrography provides an optimal evaluation of the integrity of the repaired acetabular labrum and the status of the articular cartilage [13].

Although direct MR arthrography is an optimal imaging technique for the indications described previously, by definition, this procedure is invasive. It also is more expensive than routine MR imaging of the hip and should be reserved for situations in which it has clear usefulness. Additionally, patients are exposed to ionizing radiation during the fluoroscopic placement of the needle, and the examination requires coordinating the fluoroscopy and MR imaging schedules to allow an effective transition of patients to the MR imaging unit after the hip injection. The fluoroscopic suite also must be located near the MR imaging unit to accomplish this study logistically.

The pitfalls of hip joint injection are not as common as with the injection of some other joints. The needle tip must be present within the joint itself rather than in another potential space, such as the iliopsoas bursa; intra-articular confirmation may be obtained with the injection of 1 to 2 mL of iodinated contrast material. Care must be taken in
order not to overdistend the hip joint, as this can result in extra-articular contrast leaks. Additionally, the injection of air into the joint also occasionally may lead to diagnostic confusion, because air bubbles can mimic loose bodies within the joint. The air bubbles, however, are antidependent in their position within the joint, whereas loose bodies usually are located within the dependent portion of the joint. Other ways to differentiate air from loose bodies is that air bubbles tend to be smaller and have an associated magnetic susceptibility artifact. If the injected gadolinium is not diluted appropriately, a susceptibility artifact also can arise from the injected contrast material. An inadequately diluted gadolinium solution appears as low signal intensity material within the joint. This low signal tends to obscure the surrounding anatomic structures and can limit the overall anatomic assessment severely.

**MR imaging without contrast**

The majority of the literature supports the use of direct MR arthrography for the evaluation of the acetabular labrum and articular cartilage. Many investigators disparage the use of noncontrast MR imaging and cite sensitivities and specificities as low as 30% and 36%, respectively, versus values of over 90% as determined at arthroscopy and graded correctly (within 1 grade) by expert readers detected 94% to 95% of the tears on noncontrast MR imaging without intra-articular contrast when attempting to detect damage to the acetabular labrum or the articular cartilage, the use of noncontrast MR imaging with parameters optimized for the hip joint seems to have the potential to be as effective as MR arthrography without the invasive component. Additional studies are necessary to determine if this is the case and to show that the results can be replicated at other institutions. Mintz and colleagues provide compelling evidence that diagnostically accurate MR imaging of the hip can be performed without intra-articular contrast.

**Multidetector CT evaluation**

MDCT can provide a high-resolution, multiplanar examination of postoperative hips. The isotropic voxels allow patients’ anatomy to be viewed in any plane and MDCT is far less susceptible to the adverse effects of metallic artifact than single-slice CT. The hip may be scanned from the superior portion of the iliac crest to the tibial tubercles, thereby allowing the degree of femoral or acetabular anteversion to be measured along with other important anatomic characteristics, such as the femoral caput collum diaphysis angle, the center edge angle, and the femoral length. MDCT allows the area to be scanned in one volume and patients can be scanned in any position. 3-D reconstructions also may be helpful for evaluation of complex skeletal diseases and for assessing postoperative alignment.

MDCT is useful in assessing postoperative anatomy in patients who undergo treatment for developmental dysplasia of the hip (DDH), slipped capital femoral epiphysis (SCFE), and femoroacetabular impingement (FAI) [Fig. 2]. The multiplanar formatting provides an effective assessment of alignment of the proximal femur and acetabulum and optimal assessment of the osseous anatomy. The labrum, articular cartilage, and intra-articular contents also may be assessed with CT arthrography. The CT arthrogram also can be performed in conjunction with MR arthrography, because 1 to 2 μL of iodinated contrast material usually is used to confirm an intra-articular placement during MR arthrography. This amount of iodinated contrast
material provides an appropriate dilute contrast solution that may be examined by CT immediately after the injection of the contrast material. The MDCT examination of the hip requires only a few minutes from the time patients enter the CT suite until the end of an examination, thereby making it possible to scan patients quickly before obtaining the MR imaging examination. When using a protocol that scans through to the knees [Table 2], various anatomic characteristics may be measured (ie, femoral and acetabular version) and calculated (ie, McKibbin index) [23].

In addition to its high-resolution, multiplanar capabilities, MDCT also may be used to map the anatomy three dimensionally. This mapping may be used in THA and hip arthroscopy. Surgical goals generally involve conserving bone stock, optimizing the implant position and fit, appropriately sizing osteochondroplasties, equalization of leg length, creating normal biomechanical orientation, and minimizing complications. CT is useful especially when the hip is prominently dysplastic or when the combined femoral neck and external rotation is greater than 15° [24]. 3-D presentations of anatomy, as can be produced by multislice CT, are effective especially at demonstrating the intricacies of the anatomy [Fig. 3]. MDCT not only is effective for guiding surgical therapy, but it can be useful for postoperative assessment of the osseous anatomy.

### Postoperative Imaging Evaluation

**Acetabular Labral Repair**

The acetabular labrum is a fibrocartilaginous rim around the acetabulum that is triangular in cross-section and extends around the periphery of the

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**Table 2: Protocol for CT scanning of the hip**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Bone algorithm</th>
<th>Soft tissue algorithm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kilovoltage</td>
<td>140</td>
<td>140</td>
</tr>
<tr>
<td>Milliamperes seconds</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>Rotation time (s)</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Collimation (mm)</td>
<td>1.3</td>
<td>2.5</td>
</tr>
<tr>
<td>Section thickness (mm)</td>
<td>1.3</td>
<td>2.5–3.0</td>
</tr>
<tr>
<td>Reconstruction interval (mm)</td>
<td>0.625</td>
<td>2.5–3.0</td>
</tr>
<tr>
<td>Intravenous contrast material</td>
<td>Dilute iodinated contrast (1–2:20) and dilute gadolinium injection (concentration 1:200)</td>
<td>Dilute iodinated contrast (1–2:20) and dilute gadolinium injection (concentration 1:200)</td>
</tr>
</tbody>
</table>

Special Instructions:
- Series #1: scan hips and surrounding soft tissues from superior iliac crests to tibial tubercles (FOV, 36 cm).
- Series #2: small FOV over hip of interest (FOV, 20 cm).
- Series #3 & 4: sagittal and coronal reconstructions.
- Series #5: performed at the workstation or the console: oblique axial reconstruction along the axis of the femoral neck.
- Series #6: performed at the workstation or the console: oblique sagittal plane oriented perpendicular to the femoral neck.

Note: orient series 5 and 6 parallel and perpendicular to the femoral neck, respectively.

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**Fig. 2.** FAI. Coronal reconstruction after injection of a 3% iodinated contrast mixture shows a bony prominence at the inferior portion of the femoral head-neck junction (arrow). This bony prominence was not seen at the time of the initial surgery (osteoplasty of the anterior and superior head neck junction performed because of FAI).

**Fig. 3.** 3-D volume CT scan of the pelvis shows optimal demonstration of the osseous anatomic relationships.
acetabulum, with the exception of the acetabular notch (where it merges with the transverse acetabular ligament) [Fig. 4]. The labrum is bulkier superiorly and posteriorly and thinner at the opposite corner [25,26]. The fibrocartilage of the acetabular labrum is attached directly to the osseous acetabulum and is composed of heterogeneous fibrocartilage (relative to the fibrocartilage meniscus of the knee) [15].

The acetabular labrum is believed to preserve the hydrostatic pressure within the hip joint and prevent articular cartilage consolidation and dessication [27]. Consolidation of the hyaline cartilage is defined by the compression of cartilage layers with expression of interstitial fluid from the proteoglycan-rich matrix of tissue. The acetabular labrum also contributes to maintaining stability of the femur relative to the acetabulum [27]. The joint capsule inserts onto the acetabular rim at the base of the labrum. At the junction between the labrum and the capsule, there is a perilabral recess [26].

Imaging of the acetabular labrum may be accomplished best with MR arthrography [28]. Knowledge of the arthroscopic classification of acetabular tears also helps match the arthroscopically described abnormality to the MR equivalent appearance [Fig. 5]. With MR arthrography, labral tears are diagnosed when the injected fluid extends into the substance of the acetabular labrum through a surfacing signal abnormality [Fig. 6]. This is applicable regardless of whether or not patient status is preoperative or postoperative. Fluid also may extend between the attachment of the labrum to the transverse acetabular ligament or undermine the labral attachment to the bony acetabulum [Fig. 7]. One of the pitfalls when evaluating the acetabular labrum (postoperative or otherwise) is the posteroinferior labral sulcus [Fig. 8] [29]. This sulcus or groove is common and can be mistaken for a labral avulsion if not recognized as a normal variant. Other regions of separation between the labrum and the acetabulum should be interpreted as tears, as most investigators recognize the posteroinferior labral sulcus as the only normal variant of its type [16,30].

Repair of the acetabular labrum may involve partial resection of the labrum, débridement of the torn portion of the labrum, or suture repair with

![Fig. 4. Diagram of an en face view of the acetabulum and acetabular labrum. The labrum extends around the periphery of the bony acetabulum (arrows) with the exception of the acetabular notch where it merges with transverse acetabular ligament (arrowheads). (Adapted from Primal Pictures Ltd., London, UK; with permission. © Primal Pictures Ltd.)](image)

![Fig. 5. Acetabular labral tears. An en face view of the acetabulum shows the transverse ligament (arrowheads) joining the lunate shaped articular surface of the acetabulum (lighter gray shaded structure) and the two edges of the acetabular labrum (darker gray structure). Some of the various types of acetabular labral tears are illustrated on this image including the peripheral or longitudinal type tear (small arrow), the radial fibrillated tear (large arrow), and the radial flap tear (curved arrow). (Adapted from Lage LA, Patel JV, Villar RN. The acetabular labral tear: an arthroscopic classification. Arthroscopy 1996;12:269–72.)](image)

![Fig. 6. Labral tear. Sagittal T1-weighted fat-suppressed MR arthrogram shows intra-articular gadolinium and a region of increased signal in the anterosuperior acetabular labrum, consistent with an acetabular labral tear (arrow).](image)
marginal convergence of the torn components of the labrum. The majority of labral tears are treated by resection or débridement and although the short-term results are favorable, the long-term results are not yet known [31]. Given that the most common method of repairing the acetabular labrum is to remove a portion of it, the normal postoperative MR appearance after partial resection or débridement of the labrum must be considered. The labrum may appear truncated or partially or completely absent after surgical treatment for an acetabular tear [Fig. 9]. Fluid that either undercuts the labrum or extends into its substance, however, is indicative of a persistent tear or a repeat injury to the labrum.

Inflammatory changes in and around the perilabral recess manifest as an anatomic adherence between the perilabral joint capsule and the labrum itself [Fig. 10A]. Normally, this recess is present and is defined on MR arthrography with fluid extending between the acetabular labrum and the joint capsule [see Fig. 10B]. The adhesion of the joint capsule to the labrum is common in the superolateral perilabral recess and the capsule may appear scarred and adherent to the labrum on MR imaging and arthroscopy. Adhesion of the capsule to the labrum may have an effect on the ability of the labrum to maintain its hydrostatic seal and thereby could expose the articular cartilage to increased stress. In patients who have perilabral adhesions that are examined by arthroscopy, the joint capsule can be seen as adherent to the labrum. This is associated commonly with erythema and limited capsule motion across the labrum in the region of adhesions.

Focal separation of the acetabular labrum from the bony acetabulum rarely may be seen after a hip arthroscopy procedure. This can be seen on follow-up MR imaging and with follow-up arthroscopy, as a focal perforation in the base of the acetabular labrum may result from the placement of the portal through the substance of the labrum. Although other complications of arthroscopy, such as injury to the lateral femoral cutaneous nerve or chondral injuries, are more common, radiologists should be aware of this iatrogenic cause of labral perforation.

Normal variant appearances of the acetabular labrum also should be taken into consideration during postoperative imaging of the hip. The acetabular labrum has a triangular appearance in most people. This typically transitions to a rounded appearance then to an irregular appearance and may appear absent in a certain portion of older patients [32]. Signal alteration within the acetabular labrum also may be seen. Signal changes typically start in the anterior and superior portion of the acetabular labrum and progress to other parts of the labrum as patients age [32]. Variation in the typical appearance of the acetabular labrum relates partially to patient age and to traumatic pathology, and this should be taken into consideration when interpreting imaging studies of patients who have hip discomfort.

### Femoral head-neck junction osteoplasties

#### Open surgical technique

Proximal femoral osteoplasty is performed to correct osseous abnormalities that cause impingement of structures in or around the hip joint. There are open and arthroscopic techniques for performing these osteoplasties [14]. Open procedures involve...
**Fig. 9.** Débrided labral tear. Axial (A), coronal (B), and sagittal (C) T1-weighted fat saturated MR images obtained after the direct administration of a dilute (1:200) gadolinium solution shows truncation and irregularity of the anterosuperior portion of the acetabular labrum (arrows). This is consistent with prior arthroscopic débridement of a labral tear in this region.

**Fig. 10.** Superolateral hip joint capsule. (A) Coronal T2-weighted fat suppressed image obtained after the injection of 10 cc of dilute gadolinium into the hip joint shows that the superolateral hip joint capsule is adherent to the lateral portion of the superior acetabular labrum (arrow). (B) Coronal T1-weighted fat suppressed image obtained after the injection of 10 cc of dilute gadolinium into the hip joint shows a normal perilabral recess with fluid extending between the medial border of the superior hip joint capsule and the lateral portion of the superior acetabular labrum (arrow).
placing patients in the lateral decubitus position with the hip exposed anteriorly and dislocated in the same direction. Care is taken not to disrupt the external rotator muscles and the vascular supply (medial circumflex femoral artery) that parallel these muscles. This technique also allows a complete view of the femoral head and the acetabulum. After the hip is dislocated, the femoral head-neck junction may be inspected for prominent regions and decreased head-neck cutback zones, and cartilage surfaces are inspected for damage. The treatment for osseous impingement is to remove the nonspherical portions of the femoral head and neck via an open surgical osteochondroplasty [Figs. 11 and 12]. Acetabular sources of impingement, such as acetabular retroversion, prominence of the lateral acetabular rim, and acetabular protrusio, also may be treated either by osteochondroplasty of the lateral acetabular rim or acetabular osteotomy. In many cases, it is necessary to address both sites of impingement [see Figs. 11 and 12] [14]. After surgical resection, it is important to observe the full range of motion of the hip to ensure that there are no residual regions of impingement.

Fig. 11. “Cross-over” sign of FAI. (A) Preoperative anteroposterior radiograph of a patient who had clinical signs of FAI syndrome shows a cross-over of the superior aspect of the posterior acetabular wall (arrow). The acetabular margin is outlined (white dashed line), delineating normal mid and inferior acetabular relationships. The superior aspect of the acetabulum reverses its orientation, however, such that the posterior acetabulum lies medial to the anterior wall. (B) Preoperative lateral radiograph demonstrates abnormal prominence of the anterior femoral head neck junction (arrows).

Fig. 12. Status post osteoplasties for FAI. (A) Anteroposterior conventional radiograph of the patient shown in Fig. 11 is obtained postoperatively after undergoing a surgical hip dislocation with osteoplasties of the femoral head-neck junction (black arrow) and superolateral anterior acetabular rim (white arrows) and a greater trochanteric osteotomy (white arrowhead) with screw fixation (done as part of the surgical dislocation procedure). The acetabular rim again is demonstrated by the white dashed line. Note the lack of cross-over along the superior margin of the osseous acetabulum after the prominent anterosuperior acetabular rim has been resected. (B) Lateral postoperative radiograph shows decreased prominence of the anterior femoral head neck junction because of the prior osteoplasty (arrows). The acetabular rim osteoplasty also has been performed and the labrum tacked down (arrowheads).
Arthroscopic technique

Hip arthroscopy may be used for resection of prominent portions of the femoral head-neck junction and is less invasive than hip arthrotomy. Although effective in many circumstances, hip arthroscopy has contraindications, including patient obesity, the presence of open wounds or cellulitis, arthrofibrosis, and very advanced disease states. The arthroscopic procedure is performed in patients who are in a modified supine position on a fracture table. Patients' feet are placed in traction boots and traction is applied to distract the hip joint [Fig. 13]. This usually results in 8 to 10 mm of distraction and enables the internal portions of the joint to be examined [Fig. 14]. The anterolateral portal is placed 1.0 cm anterior and 1.0 cm superior to the greater trochanter and the anterior portal is placed 2.0 cm lateral to the anterior superior iliac spine at the same superior/inferior level as the anterolateral portal. Through the arthroscopic portals, the anatomy is inspected [Fig. 15] and regions of abnormal osseous prominence are identified. The arthroscopic bur is used to resect the osteocartilaginous prominence associated with patients' FAI [Fig. 16]. Once the arthroscopic osteochondroplasty is performed, the range of motion at the hip joint is examined to ensure that the osseous prominences have been resected adequately [Fig. 17]. If residual osseous impingement is identified by arthroscopic examination during range of motion movements, additional osteoplasty or osteochondroplasty may be necessary to remove the regions of impingement. Evidence of the head-neck junction osteoplasty may be seen with postoperative conventional radiography and with cross-sectional imaging [Fig. 18].

Many patients presenting with osseous impingement also have other pathology, such as acetabular labral tears and flexion contractures at the hip joint. The labral tears are repaired or debrided in conjunction with the osteoplasty, and an iliopsoas tendon release also can be performed in patients who have flexion contractures of the hip or signs of femoral nerve entrapment. The imaging appearance of the iliopsoas release should be recognized to avoid misinterpretation. Acutely, the iliopsoas...
release can result in edema and fluid around the distal portion of the tendon. The fluid commonly tracks from the point of release (adjacent to the joint) superiorly and may surround the entire distal tendon [Fig. 19]. The fluid also may track superiorly to be located between the medial iliopsoas tendon and the external iliac artery and vein [see Fig. 19]. The chronic appearance of an iliopsoas release is characterized by an absence of fluid and the presence of iliopsoas muscle atrophy [Fig. 20]. This is a normal postoperative appearance and should not be confused with disuse atrophy, denervation, or postmyositis atrophy.

**Hip fracture repair**

The two primary elements that should be present for adequate fracture healing to occur are adequate reduction and internal fixation [33]. Inadequate reduction increases the risk of avascular necrosis (AVN) and unstable fixation [34]. After fracture fixation, the intraoperative fluoroscopic anteroposterior view should demonstrate a caput collum diaphysis angle ranging between 130° and 150° [Fig. 21] [35]. This angulation purposefully is valgus to reduce the risk of AVN and maximize the stability of the fixation. On the lateral view, the alignment of the femoral head to the shaft should be linear [see Fig. 21] [35]. On the lateral view, the screw should be placed in the center of the femoral neck and through the center (or slightly posterior) portion of the femoral head [36]. A 1995 study by Baumgaertner and coworkers support a distance from the tip of the dynamic hip screw to the femoral head apex of 25 mm or less [37]. The femoral head apex is determined by the junction of the subchondral femoral head and a line drawn parallel along the center of the femoral neck. Care must be taken to scrutinize the position of the distal tip of the screw on the lateral view adequately as the proximal femur can be difficult to visualize adequately and the interobserver agreement as to the determination of this position is reported as poor [9].

The goal of a hip fracture repair is to place the proximal femur and the femoral fixation construct in such a position that the repair is stable and the fracture heals without resultant deformity. The complications of a femoral neck fracture in children are similar to complications seen in other
types of proximal femoral stabilization, such as DDH repair and pinning for SCFE [38]. Postsurgical deformities may occur after fixation and additional manipulation may be necessary to treat these regions of altered anatomy. In addition to the deformities that may cause biomechanical compromise resulting from abnormal femoral or acetabular version, other processes, such as leg length discrepancies, abnormal varus, or valgus angulation, and disruption of the proximal femoral epiphysis may give rise to proximal femoral deformities [Figs. 22 and 23] [39]. The post-traumatic alteration in anatomy can give rise to early-onset degenerative arthritis. Additionally, acetabular labral tears rarely occur in the absence of bony abnormalities and this combination of pathology can contribute to a painful post-traumatic or postsurgical hip [40].

**Core decompression**

AVN is a common condition affecting between 10,000 and 20,000 individuals in the United States annually [41]. Various risk factors for AVN are identified, including trauma, steroid medications, systemic lupus erythematosis, and pancreatitis. The primary method of treating AVN is early identifica-
tion by MR imaging and CD of the femoral head. The effect of CD is to decrease the intraosseous pressure and to promote the revascularization of the femoral head. Overall, there is controversy about the role of CD in the treatment of early AVN [42]. Compared with conservative management, however, there are some reports that CD produces better treatment results in early stage AVN [43].

There are different techniques that are used for CD, all of which involve accessing the femoral head to create a void within the cancellous bone [Fig. 24]. Accessing the femoral head with a Kirschner wire, hollow trephine, or screw is used and some procedures are performed in conjunction with bone grafting into the void. These techniques are used with varying results but, in combination with early detection with MR imaging, the results of CD generally are improved.

The postoperative status of the CD with or without the grafting procedure can be monitored and the degree of involvement of the articular surface of the femur can be measured. The degree of involvement of the articular surface is used as a preoperative predictor for subchondral collapse. In 1990, Beltran and colleagues divided the degree of articular involvement of the femoral head into four categories: (A) no AVNs, (B) less than 25% involvement of weight-bearing portion of the femoral head, (C) involvement of 25% to 50%, and (D) involvement of more than 50%. The rate of collapse varied from no collapse in categories A and B to collapse seen in 43% of the hips in category C to 87% of the hips in category D [44].

Fig. 18. Osteochondroplasty for FAI. Anteroposterior (A) and frog-leg lateral (B) views of the left hip show a blade plate and screw construct within the left proximal femur (black arrows), greater trochanteric screw fixation (white arrows), and postoperative evidence of the femoral head neck junction osteochondroplasty (white arrowheads).

Fig. 19. Iliopsoas tendon release. (A) Axial fast spin-echo T2-weighted image just superior to the left hip joint in a patient who recently has had an iliopsoas tendon release shows fluid surrounding the anterior and medial portions of the iliopsoas tendon (black arrows). The fluid also lies immediately adjacent to and lateral to the external iliac neurovascular bundle (white arrow). (B) Axial fast spin-echo T2-weighted image just inferior to the image shown in (A) shows fluid surrounding the anterior, medial and lateral portions of the iliopsoas tendon (black arrows).
The amount of edema associated with the double line sign seen in AVN also may be used as a predictor for the chance of success in CD of the femoral head [45]. In a 2004 study, Radke and coworkers find that the presence of edema associated with the double line sign of AVN is a predictor for progression to THA. The findings of extent of involvement of the articular surface and the presence of edema along with the double line sign may or may not have similar prognostic usefulness in postoperative hips. This needs to be examined by additional studies that strive to relate the postoperative appearance after CD to the time course and degree of disease progression. The deformity of the femoral head along with the presence of subchondral collapse, joint space narrowing, osteophyte formation, and the progression of degenerative arthritis may be visualized clearly on follow-up radiographic or cross-sectional imaging. These various modalities may be used as a method of monitoring patients and, in conjunction with the clinical examination, contribute substantially in determining whether or not a patient's treatment regimen should progress to surgical replacement of the involved joint.

**Total hip arthroplasty**

As discussed previously, the number of THA procedures has increased to the point where this is a routine treatment for patients who have severe hip joint arthritis or in patients who have sustained an irreparable hip fracture. The complications of THA generally are well recognized and include loosening of the prosthesis, periprosthetic fracture, heterotopic bone formation, postoperative infection, trochanteric bursitis, and osteolysis from foreign body granulomatosis. These complications may vary in severity and often necessitate revision arthroplasty.

**Imaging of total hip arthroplasty**

The imaging evaluation of symptomatic patients who have undergone THA includes primarily con-
ventional radiography, nuclear medicine studies with technetium and gallium scanning, joint aspiration, and arthrography [46–49]. Traditionally, cross-sectional imaging was not used because of imaging artifacts caused by the metal prostheses (beam hardening and streak artifacts with CT and metal susceptibility artifacts with MR imaging). Various strategies have been used to decrease the MR imaging artifacts caused by a variety of metal orthopedic devices [10,50–53]. These are discussed in more detail later.

MT imaging also may be useful in the imaging evaluation for loosening of hip arthroplasties. Lower field-strength MR imaging units (ie, less than 1.0 Tesla) may be the most advantageous in this evaluation, because less susceptibility artifact results from lesser gradient strengths [54]. Low-field MR imaging is shown to be able to depict loosening around the femoral component of a THA, but the visualization around the acetabular component is less optimal [54,55]. Higher magnetic field strengths often are associated with proportionately more prominent artifacts [Fig. 25]. This contributes to the common belief that MR imaging is not appropriate for detecting periprosthetic pathology, such as loosening or particle inclusion disease in patients who have arthroplasties, especially THAs. Various MR imaging techniques, however, have been developed to combat the susceptibility artifacts seen with MR imaging.

MR imaging is shown to be accurate in detecting and sizing areas of osteolysis [56] and in evaluating the surrounding soft tissue structures [Fig. 26] [6]. As discussed, MR imaging after arthroplasty poses particular challenges because of the prominent artifact from the metal prostheses. The different types of metal used in hip arthroplasty demonstrate variations in the severity of artifact—stainless steel causes severe distortion and titanium or oxidized zirconium causes less severe distortion [57].

Because the artifact from metal partly is the result of incorrect spatial encoding resulting from frequency misregistration, widening the receiver bandwidth decreases the apparent size of artifact. This occurs because the widened bandwidth allows a broader range of frequencies to be sampled, so that the difference between any two frequencies is a smaller percentage of the total range. In one study, widening the receiver bandwidth from 16 kHz to 64 kHz reduces metal artifact by 60% [58]. In addition to sampling over a broader range of frequencies, widening the receiver bandwidth also serves to decrease interecho spacing. A shorter echo time allows less time for intravoxel dephasing than a long echo time, and is, therefore, less sensitive to metal artifact. The downside of widening the receiver bandwidth is that it causes a decrease in SNR [59]. To compensate for the loss of SNR, increasing the number of excitations (NEX) may be necessary.

The echo train length (ETL) also is shown to be a factor in the severity of artifacts [59]. Increasing the number of refocusing pulses (increasing ETL) decreases the time for intravoxel dephasing to occur.

The misregistration from metal implants occurs between slices (in the z-plane) and in the frequency encoding direction (y-plane). Similar to the receiver
bandwidth, the slice-select bandwidth can be widened by increasing the magnitude of the gradient and decreasing the time in which the gradient is applied. For example, a 20% increase in bandwidth can be achieved by multiplying the gradient magnitude by a factor of 1.2 and decreasing the time the gradient is applied by a factor of 1.2 [58]. This decreases misregistration between slices.

An additional technique used by some investigators to reduce metal artifact is called view angle tilting (VAT) [58,60,61]. This is achieved by re-applying the slice-select gradient at time of readout, so that the slice-select gradient and the frequency-encoding gradient are applied simultaneously. VAT causes the spins to be aligned essentially tangential to the frequency plane at time of readout and is shown to reduce susceptibility artifact [56,60,61]. Image blurring is a problem resulting from this technique, and different methods are attempted to reduce blurring [56,61,64]. In one study, a combination of widening the receiver bandwidth, widening the slice-select bandwidth, and applying VAT resulted in decreased artifact compared with either widening the receiver bandwidth or VAT alone [58].

Overall, with use of a few modifications, MR imaging can be useful and accurate in evaluating the periprosthetic osseous and soft tissue structures.

Fig. 23. Nonspheric femoral head secondary to childhood fracture fixation. (A) Coronal T1-weighted MR image from a left hip MR arthrogram shows the metallic artifact from the fixation screw (white arrow) along with widening of the medial hip joint space (black arrow). (B) Sagittal T1-weighted MR image again demonstrates the metallic artifact (white arrow) but shows that the joint space is widened posteriorly (black arrow). (C) Axial T1-weighted MR image shows the joint space widening posteriorly (large black arrow), femoral head flattening, and degenerative change anteriorly (small black arrows). This axial image also provides an optimal view of the nonspherical femoral head that resulted from the childhood fracture fixation. This nonsphericity produced an asymmetric position of the femoral head within the acetabulum that resulted in atypical degenerative changes. These findings were corroborated by a hip arthroscopic examination. An anterosuperior labral tear that was identified at MR imaging and arthroscopy is not shown.
after hip arthroplasty. In the future, MR imaging may become the image modality of choice for the painful hip prosthesis.

**Common pathology in total hip arthroplasty**

**Soft tissue abnormalities**

Although the imaging work-up usually is directed toward detecting hardware failure, various soft tissue abnormalities may be the actual cause of hip pain. MR imaging may be used to assess processes that occur around a metal implant, including adductor tendon rupture and trochanteric bursitis [62]. These soft tissue abnormalities may be the cause of pain, especially if a transgluteal approach is used [63]. MR angiography also is used to detect deep venous thrombosis in patients who have undergone THA [51].

**Loosening**

Loosening of a metallic hip prosthesis is the most common indication for revision arthroplasty and typically is determined based on the radiographic appearance of the prosthesis relative to the surrounding bone or polymethyl methacrylate. A loose prosthesis is characterized either by a progressively increasing radiolucency at the bone-cement or prosthesis-cement/bone interface or by a change in the position of the prosthesis. A subtle increase in the radiolucent interface zone, however, is not necessarily a sign of loosening [64].

When patients present with a painful prosthetic hip, the prospect of loosening should be suspected immediately, but before this diagnosis can be made, it should be corroborated by the appropriate imaging examinations. In addition to conventional radiography, other modalities may be used, including arthrography, bone scintigraphy, and MR imaging [65,66].

On conventional radiographs, a lucent zone greater than 2 mm around the prosthesis or at the cement/bone interface is a common manifestation of loosening [Fig. 27] and lucent zones of less than 2 mm cannot be dismissed completely as normal postoperative changes. Caution must be used when invoking the possibility of loosening and the most important diagnostic tool in an armamentarium is the prior comparison radiographs. Some lucent zones seem too wide but do not change over time. Revision arthroplasties also may have a wider...
radiolucent zone than primary arthroplasties. The possibility of loosening in the absence of clinical symptoms must be considered with skepticism. Other signs of loosening on conventional radiographs include fracture of a prosthesis itself, fracture of the cement around a prosthesis, and the development of osseous sclerosis adjacent to the distal tip of a prosthesis. Occasionally, a prosthesis may move or have various degrees of rotation from one radiograph to another. Prosthetic wear also may be apparent on conventional radiography when there is particle inclusion disease [Fig. 28] or when there is increasing number of metallic fragments in and around the joint.

The imaging investigation for loosening also includes arthrography. This may be performed in isolation or in conjunction with joint aspiration or synovial biopsy when the possibility of infection is present. A loose prosthesis typically demonstrates contrast below the intertrochanteric line between the prosthesis and the bone or cement. Although arthrography previously has been shown to be accurate in the determination of prosthetic loosening, false negative examinations may occur when inflammatory debris prevents contrast material from entering the interface between the prosthesis and the adjacent bone or cement.

**Infection**

Along with loosening, infection is one of the most common complications in patients who have hip arthroplasties. Imaging findings in patients who have a low-grade infection may mimic loosening. When the infection is more severe, it often is associated with a hip effusion, prominent bone destruction or sclerosis, and pain. Infection also may mimic aggressive granulomatosis (particle inclusion disease), because osseous resorption may

**Fig. 27.** Loosened acetabular component. Anteroposterior conventional radiograph of the pelvis shows bilateral THAs with cemented prostheses. Note lucency (small black arrows) surrounding a displaced and rotated right acetabular cup (large black arrow). By comparison, note the normal left acetabular cup (black arrowheads). Incidentally noted is sacroiliac joint fusion (white arrows) and confluent ossification of the spine in this patient who has ankylosing spondylitis.

**Fig. 28.** Loosened acetabular component. (A) Anteroposterior radiograph demonstrates bilateral THAs (arrowheads). The right hip prosthesis is normal in appearance, but there are multiple lucencies surrounding the acetabular and femoral components (arrows). There also is loosening and lateral subluxation of the left acetabular component. (B) Anteroposterior radiograph of the left hip taken 6 months later shows progression of the lucencies surrounding the femoral component (black arrows). There also is progressive lateral subluxation of the acetabular component, so that the lateral portion of the articulated femoral head is aligned with the lateral ilium (white arrow).
occur around the prosthesis and can simulate the scalloped appearance of resorption seen in peri-prosthetic granulomatous involvement.

In the imaging evaluation of a suspected arthroplasty infection, conventional radiography is used and can show findings, such as periprosthetic resorption of bone, loosening of the prosthesis, and osseous changes consistent with osteomyelitis. Cross-sectional imaging can be used to confirm or refute findings seen on radiographs, assess for soft tissue involvement, define the degree of bony destruction better, and evaluate more definitively the osseous structures for evidence of osteomyelitis. Radionuclide bone scans may demonstrate findings in infection that are similar to those found in aseptic loosening of the prosthesis. Correlation with dedicated scans designed to assess for infection may be helpful in differentiating infection and loosening. The combination of technetium and gallium scanning may not always be helpful in differentiating infection from joint arthroplasty loosening, because periprosthetic bone can exhibit uptake with both scenarios. This results from gallium’s proclivity to be taken up in bone in a similar

![Figure 29](image_url)

**Fig. 29.** Infected THA. (A) Anteroposterior view of the pelvis and proximal femora taken after a 3-hour delay during a bone scan performed with technetium Tc 99m methylene diphosphonate shows increased radiotracer uptake around the femoral component of the THA (black arrows). (B) Anteroposterior view of the pelvis and proximal femora in the same patient as demonstrated in (A) taken during a gallium citrate Ga 67 citrate scan shows radiotracer accumulation around the region of the right hip joint (white arrows). The presence of the radiotracer within the joint is indicative of infection. (Courtesy of Christopher J. Palestro, MD, Long Island Jewish Medical Center, New Hyde Park, NY).

![Figure 30](image_url)

**Fig. 30.** Infected THA. (A) Anteroposterior view of the pelvis and proximal femora in a patient who had a right THA taken after administration of indium In 111–labeled WBCs shows a faintly increased region of uptake in the region of the right proximal femur (arrow). (B) Anteroposterior view of the pelvis and proximal femora in a patient who had a right THA taken after administration of technetium Tc 99m sulfur colloid shows no uptake in the region of the right hip (arrowhead). Therefore, the presence of increased radiotracer uptake on the WBC scan and absence of radiotracer uptake on the sulfur colloid scan are consistent with the presence of infection. (Courtesy of Christopher J. Palestro, MD, Long Island Jewish Medical Center, New Hyde Park, NY).
distribution as the agents (ie, methylene diphosphonate) used for bone scanning. Occasionally, gallium scanning may show uptake within the joint itself, which is highly indicative of infection [Fig. 29]. A standard way of analyzing the combination of bone scan and gallium studies includes considering the scenario negative for infection when the gallium scan is normal, when the radiotracers are congruent, or the intensity of the gallium is less than that of the bone scanning agent. The scenario is considered positive for infection when the intensity of gallium exceeds that of the bone agent or when they are spatially incongruent [67].

Radionuclide scanning using sulfur colloid imaging combined with technetium- or indium-labeled white blood cells (WBCs) may be helpful adjuncts to the anatomic imaging techniques for differentiating between loosening and infection. Because neutrophils are present with an infection, labeled WBC imaging is the most sensitive technique for detecting neutrophil-mediated inflammatory changes. The radiotracer labeled neutrophils collect in the region of infection but not in the normal marrow to nearly the same degree. The labeled sulfur colloid is present in the normal marrow but not in the regions of infection. The degree of radiotracer uptake along with the type of radiotracer that collects in the specific location of interest provide important clues to the cause of the patient's symptoms or the findings on the anatomic imaging studies [Figs. 30 and 31].

Regardless of the findings on any particular examination, the information derived from an imaging evaluation must be evaluated collectively along with any available clinical information, because some conditions, such as cellulitis or inflammatory arthritis, may mimic the presence of infection [68]. In equivocal cases, fluoroscopic or sonographically guided joint aspiration or synovial biopsy may be used to assess for infection further.

**Particle inclusion disease**

Focal osteolysis around the prosthesis was described first by Charnley in the 1960s [73], was believed caused by the cement used to stabilize the prosthesis, and originally was referred to as cement disease. This process subsequently has been called particle inclusion disease or histiocytic response. Any small particles, such as cement, metallic fragments, or small particles of polyethylene, can cause this osteolytic response and this process can occur around any arthroplasty. Any process that accelerates the wear of the prosthesis (ie, an eccentric position of the prosthetic femoral head within the acetabular component) can put patients at risk for particle inclusion disease [69]. With an increase in the use of cementless fixation, polyethylene wear debris is now the most common cause of particle inclusion disease.

The histiocytic response incited by the small foreign particles results from the macrophage reaction to these particles. These granulomatous lesions present as radiolucencies that surround the arthroplasty components. This condition typically occurs 1 to 5 years after surgery and is characterized by

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**Fig. 31.** Noninfected THA. (A) Anteroposterior view of the pelvis and proximal femora obtained during an indium In 111–leukocyte-labeled radionuclide scan shows the presence of a focal region of decreased radiotracer uptake corresponding to the patient’s THA (arrowheads). There also is increased radiotracer uptake around the acetabular component of the prosthesis (arrows) that is slightly more than the contralateral side. (B) Anteroposterior view of the pelvis and proximal femora on the same patient during a technetium Tc 99m sulfur colloid scan shows the slightly asymmetric increased uptake around the acetabular component of the right THA (arrows). This uptake indicates the presence of normal marrow in the region and supports the presence of an aseptic process. (Courtesy of Christopher J. Palestro, MD, Long Island Jewish Medical Center, New Hyde Park, NY).
scalloped areas of bony resorption around the prosthesis rather than linear areas around the prosthesis seen with mechanical loosening [see Fig. 28]. Soft tissue masses or fluid representing pseudobursae also may be present around the joint prosthesis.

The bone surrounding the regions of osseous resorption is at increased risk of fracture and the disease process should be followed with serial radiographs or cross-sectional imaging to determine the rate of growth of the granulomatous regions and to assess the degree of fracture risk. Although the degree of involvement is assessed effectively and rapidly with conventional radiography, cross-sectional imaging, such as MR and CT, may be used to monitor progression of the bony resorption [see Fig. 26]. Particle inclusion disease typically is seen on MR imaging as having low intensity signal on the T1-weighted images, intermediate signal intensity on the T2-weighted images, and irregular peripheral enhancement after contrast administration [70]. Periprosthetic fractures also are detected effectively with MR imaging [71].

**Summary**

The hip often is a diagnostic quandary preoperatively and, relative to other large joints, has received much less attention in terms of postoperative imaging. A complete postoperative evaluation may include the use of many modalities, such as conventional radiography, MDCT, MR imaging, and radionuclide imaging. Many types of surgical procedures are performed on the hip, including acetabular labral repair, osteoplasties, osteotomies, fracture fixation, CD, and THAs. Some of these procedures (ie, fracture fixation and THA) can cause prominent postoperative imaging artifact on certain imaging modalities and, until the advent of MDCT and dedicated MR imaging protocols, cross-sectional imaging of these prostheses was of limited value. The increasing prevalence of open hip surgery and hip arthroscopy has given rise to an increasing variety of procedures and an increased need for postoperative imaging. As with other types of postoperative imaging, knowledge of the type and technical details of the surgical procedure help prescribe which imaging modality demonstrates the findings of interest best. Each type of procedure has certain intricacies associated with it and certain postoperative anatomy that is within the accepted range of normal. Patients’ clinical examination and type of surgical procedure that has been performed determine which imaging strategy to use to investigate patient postoperative condition. The ability to direct this workup and to determine what pathology exists, if any, is the task of the individuals directing the imaging evaluation. The more knowledge these individuals have about the procedures performed and which imaging modalities to use when, the more accurate a work-up is.

**References**


Preemptive Analgesia in Hip Arthroscopy: A Randomized Controlled Trial of Preemptive Periacetabular or Intra-articular Bupivacaine in Addition to Postoperative Intra-articular Bupivacaine

Amir Shlaifer, M.D., Zachary Tuvya Sharfman, M.S., Hal David Martin, D.O., Eyal Amar, M.D., Efi Kazum, M.D., Yaniv Warschawski, M.D., Matan Paret, B.S., Silviu Brill, M.D., Michael Drexler, M.D., and Ehud Rath, M.D.

Purpose: To evaluate and compare the efficacy of intra-articular and periacetabular blocks for postoperative pain control after hip arthroscopy. Methods: Forty-two consecutive patients scheduled for hip arthroscopy were randomized into 2 postoperative pain control groups. One group received preemptive intra-articular 20 mL of bupivacaine 0.5% injection, and the second group received preemptive periacetabular 20 mL of bupivacaine 0.5% injection. Before closure all patients received an additional dose of 20 mL of bupivacaine 0.5% intra-articularly. Data were compared with respect to postoperative pain with visual analog scale (VAS) and analgesic consumption, documented in a pain diary for 2 weeks after surgery. Results: Twenty-one patients were treated with intra-articular injection, and 21 patients with peri-acetabular injection. There were no significant differences with regards to patient demographics or surgical procedures. VAS scores recorded during the first 30 minutes postoperatively and 18 hours after surgery were significantly lower in the periacetabular group compared with in the intra-articular group (0.667 ± 1.49 vs 2.11 ± 2.29; P < .045 and 2.62 ± 2.2 vs 4.79 ± 2.6; P < .009). There were no differences between the groups with regard to analgesic consumption. Conclusions: Periacetabular injection of bupivacaine 0.5% was superior to intra-articular injection in pain reduction after hip arthroscopy at 30 minutes and 18 hours postoperatively. However, total analgesic consumption over the first 2 postoperative weeks and VAS pain measurements were not significantly affected. Level of Evidence: Level I, randomized controlled trial.

Hip arthroscopy is a well-established therapeutic intervention with good outcomes for an increasing number of indications. The use of hip arthroscopy has increased in recent years' as new indications and techniques are learned. However, this procedure, like other orthopaedic surgeries, causes moderate to severe pain and therefore requires effective pain management protocols. In addition to facilitating patient comfort, postoperative pain management allows day case surgery. Furthermore, effective postoperative pain management has been shown to decrease pain-associated complications of surgery such as pneumonia and blood clots. Postoperative pain management has implications for the overall well-being and rehabilitation of the patient as well as financial implications associated with decreased length of stay.

Multiple pain management protocols are used for hip arthroscopy. Lumbar plexus blocks, fascia iliaca blockade, femoral nerve block, intra-articular analgesia infiltration, and paravertebral L1-2 blocks have all been used successfully to manage postoperative pain. Each protocol has its advantages and disadvantages, and to the best of our knowledge based on an extensive literature review, no technique has been proven superior to the others. The various nerve blocks used in hip arthroscopy may be associated with various
complications such as muscle weakness, postoperative falls, and direct vascular injection. Furthermore, these techniques are often time consuming and require the assistance of an anesthesiologist. Periacetabular and intra-articular bupivacaine injection for postoperative pain management may offer advantages when compared with nerve blocks as they can be performed without an anesthesiologist’s assistance and are associated with limited complications. A recent survey of surgeons who perform a high volume of hip arthroscopy procedures regarding their operative technique, type of procedure, and postoperative management showed that only 56% inject local anesthetic into the joint.13

This study aimed to evaluate and compare the efficacy of preemptive intra-articular and periacetabular blocks, in addition to postoperative intra-articular injection, for postoperative pain control after hip arthroscopy. We hypothesized that preemptive periacetabular blockade would reduce postoperative pain to a higher degree than intra-articular blockade for patients within the first 24 hours after surgery.

Methods
The study protocol was reviewed and approved by the local institutional review board. We conducted a prospective, randomized, double blind clinical trial at a single center. Patients scheduled for hip arthroscopy to treat symptomatic femoroacetabular impingement (FAI), older than 18 years of age, with the ability to give informed consent were eligible for inclusion in the study. FAI was diagnosed clinically based on the combination of anterior groin pain and a positive anterior impingement test on flexion adduction internal rotation. All patients had anteroposterior and frog view radiographs as well as magnetic resonance imaging arthrogram of the involved hip. Radiographic criteria for FAI were alpha angle > 55°, lateral central edge angle > 40°, acetabular crossover sign, and low anterior inferior iliac spine.

FAI was diagnosed clinically and radiographically. Patients were randomly assigned to receive either intra-articular or periacetabular bupivacaine. Both the patient and the evaluators remained blinded for the entire follow-up period. Demographic data were collected from patient charts and included gender, age, body mass index, height, and operated side. Criteria for exclusion were age younger than 18 years of age, osteoarthritis of the involved hip, revision surgery, sciatic back pain, and known allergy to bupivacaine. The inclusion criteria were age older than 18 and the ability to give informed consent, as well as clinical and radiographic signs of FAI. Intraoperative findings, procedures, and data were recorded from the operative report. These data included the number of anchors used, operation length, and intraoperative analgesic use.

All patients received general anesthesia, and a single surgeon (E.R.) performed all operations using a standard arthroscopy technique. The surgeon (E.R.) was only informed of the preemptive analgesia protocol after the patient arrived to the operating room. The patient was not informed of the type of analgesia given. Hip arthroscopy was performed in the supine position. After sterilization and draping, the anesthetic block was performed and the case was started after 5 minutes time. An 18-G spinal needle was used to administer 20 mL of bupivacaine 0.5% with epinephrine (1:200,000) either intra-articularly or periacetabularly under fluoroscopy. The protocol for the periacetabular block was needle insertion 1 cm proximal to the joint line anteriorly. The bupivacaine was discharged into the periacetabular space in 3 boluses (approximately 7 mL each) at the anterior, lateral, and posterior aspect of the joint (Fig 1A-C). To perform this block, the needle is first inserted under fluoroscopy until making contact with the lateral aspect of the hip 1 cm above the acetabulum (Fig 1A). The needle is then withdrawn slightly, and the first bolus is injected. The needle is then repositioned within the hip under fluoroscopy, without completely withdrawing the needle, into the anterior and lateral positions for administration of the second and third boluses (Fig 1A and B). The protocol for the intra-articular injection was as follows. The needle was inserted halfway between the anterior inferior iliac spine (AIIS) and the greater trochanter and slightly anteriorly (Fig 2A). The needle was inserted at a 45° angle and directed just anteriorly to the neck of the femoral head. Once the needle contacted the femoral neck, it was withdrawn slightly and repositioned just anteriorly to the femoral neck. Capsular fluid drawback ensured that the injection was properly placed within the intra-articular space (Fig 2B).

After administration of the blockade, traction was applied to the ipsilateral lower limb. Osteoplasty on the femoral or acetabular side, chondroplasty, and labral repair were performed according to the preoperative plan and the intraoperative findings. Before closure, all patients received an additional dose of 20 mL of bupivacaine 0.5% intra-articularly. The length of surgery was measured from the administration of preemptive analgesic to closure. The second dose was administered to accommodate for possible washout of the first dose in the intra-articular group, to standardize procedure for the periacetabular group, and to ensure adequate postoperative pain management in both groups.

Postoperative pain was assessed using visual analog scale (VAS) pain scores. VAS pain scores were conducted by the ward staff who remained blinded to the patient’s intervention. VAS scores were recorded in the first 30 minutes and then hourly in the postoperative anesthesia suite. The head nurse managed pain control in the postoperative anesthesia suite. Pain control was
Fig 1. Periacetabular bupivacaine administration fluoroscopy on the left hip. The bupivacaine was discharged into periacetabular space in 3 boluses at the anterior, lateral, and posterior aspect of the joint. To perform this block, the needle is first inserted under fluoroscopy until making contact with the lateral aspect of the hip 1 cm above the acetabulum (A). The needle is then withdrawn slightly, and the first bolus is injected. The needle is then repositioned within the hip under fluoroscopy, without completely withdrawing the needle, into the anterior and lateral positions for administration of the second and third boluses (B, C).

Fig 2. Protocol for the intra-articular injection is as follows. The needle is inserted half way between the anterior inferior iliac spine (AIIS) and the greater trochanter and slightly anteriorly on the left hip (A). The needle is inserted at a 45° angle and directed just anteriorly to the neck of the femoral head. Once the needle contacted the femoral neck, it was withdrawn slightly and repositioned just anteriorly to the femoral neck. Capsular fluid draw back ensured that the injection was properly placed within the intra-articular space (B).
Table 1. Demographic Data

<table>
<thead>
<tr>
<th></th>
<th>Periacetabular</th>
<th>Intra-Articular</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender, male/female</td>
<td>14/7</td>
<td>11/10</td>
<td>.340</td>
</tr>
<tr>
<td>Age, years</td>
<td>39.6 ± 16.1</td>
<td>36 ± 15.6</td>
<td>.458</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>74.17 ± 15.9</td>
<td>72.4 ± 15.0</td>
<td>.727</td>
</tr>
<tr>
<td>Height, cm</td>
<td>171.69 ± 10.53</td>
<td>169.29 ± 11.03</td>
<td>.553</td>
</tr>
<tr>
<td>Body mass index</td>
<td>26.1 ± 5.6</td>
<td>25.2 ± 5.43</td>
<td>.717</td>
</tr>
</tbody>
</table>

provided via the departmental VAS-based pain protocol, taking medication contraindications into account. Upon request of pain control, patients received analgesics based on VAS score (1 to 4, paracetamol 100 mg; 5 to 7, tramadol 100 mg; 8 to 10 morphine 5 mg). Patients were released from the postoperative analgesia recovery based on the practice guidelines for post-anesthetic care14 and after having achieved adequate pain management. Adequate pain management was defined as VAS less than 4. VAS scores were then recorded at 6, 12, and 18 hours postoperatively. Analgesic medications were administered according to the following pain protocol: patients reporting VAS scores of 0 to 4 received paracetamol 500 mg, those with VAS scores from 5 to 7 received tramadol 100 mg, and those with VAS scores of 8 to 10 received oxycodone with acetaminophen 5 mg.

Patients were discharged from hospital 1 day after their hip arthroscopy. It is the common practice in this hospital to discharge simple knee arthroscopies on the day of surgery; in all other arthroscopic sports medicine interventions patients are discharged after the first postoperative day. However, this study was conducted to address pain management and the viability of day case surgery in hip arthroscopy.

The ward physician (E.K., also blinded to the intervention) assessed patient pain using VAS on the day of discharge and performed a physical examination to rule out early complications. Patients were asked to complete a pain diary for 14 days postoperatively. In the diary patients were asked to describe their pain using a VAS score (0 to 10). Patients were instructed to record their pain prior to taking medication. Patients returned for postoperative follow-up at 14 days, and the operating physician examined the patients in the outpatient clinic to assess for early complications and satisfaction. The medical assistant responsible for preoperative care used an automated, Internet-based randomization system to ensure concealed randomization from the author and patients. The flowchart for randomization and treatment is shown in Figure 3.

Statistical Analysis

Statistical analysis was carried out with $\chi^2$ or Fisher exact test for categorical variables and Student $t$-test for scaled variables at a significance level of .05. IBM SPSS

Table 2. Intraoperative Findings and Procedures

<table>
<thead>
<tr>
<th></th>
<th>Periacetabular</th>
<th>Intra-Articular</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labral repair/RF recon (%)</td>
<td>14(82)/3(18)</td>
<td>19(85%)/1(5%)</td>
<td>.169</td>
</tr>
<tr>
<td>Number of anchors</td>
<td>2.61 ± 1.19</td>
<td>2.48 ± 0.81</td>
<td>.679</td>
</tr>
<tr>
<td>Femoral osteoplasty</td>
<td>20</td>
<td>17</td>
<td>.153</td>
</tr>
<tr>
<td>Acetabular osteoplasty</td>
<td>19</td>
<td>19</td>
<td>1</td>
</tr>
<tr>
<td>Operation length, hours (range)</td>
<td>01:37 ± 00:31 (00:43-02:28)</td>
<td>01:29 ± 00:22 (00:38-02:19)</td>
<td>.373</td>
</tr>
<tr>
<td>Intraoperative morphine, mg</td>
<td>6.7 ± 2.6</td>
<td>8.15 ± 2.0</td>
<td>.117</td>
</tr>
<tr>
<td>Intraoperative fentanyl, µg</td>
<td>173.5 ± 60.9</td>
<td>180.5 ± 62</td>
<td>.738</td>
</tr>
<tr>
<td>PACU morphine, mg</td>
<td>1.9 ± 2.9</td>
<td>4.1 ± 5.5</td>
<td>.2</td>
</tr>
<tr>
<td>PACU tramadol, mg</td>
<td>12.5 ± 34.1</td>
<td>31.25 ± 47.8</td>
<td>.01</td>
</tr>
</tbody>
</table>

PACU, postanesthesia care unit; RF recon, labral reconstruction using the reflected head of the rectus femoris tendon.

Table 3. VAS Scores in the First 18 Hours and Analgesis Data

<table>
<thead>
<tr>
<th></th>
<th>Periacetabular</th>
<th>Intra-Articular</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recovery length, hours</td>
<td>02:05 ± 00:49</td>
<td>03:33 ± 01:59</td>
<td>.007</td>
</tr>
<tr>
<td>Recovery morphine, mg</td>
<td>5 ± 2.53</td>
<td>6.5 ± 5.74</td>
<td>.558</td>
</tr>
<tr>
<td>VAS 30 minutes</td>
<td>0.667 ± 1.49</td>
<td>2.11 ± 2.29</td>
<td>.045</td>
</tr>
<tr>
<td>VAS 1 hour</td>
<td>1.25 ± 1.7</td>
<td>1.93 ± 1.9</td>
<td>.128</td>
</tr>
<tr>
<td>VAS 2 hours</td>
<td>0.76 ± 1.4</td>
<td>1.64 ± 1.6</td>
<td>.146</td>
</tr>
<tr>
<td>VAS 6 hours</td>
<td>0.99 ± 1.2</td>
<td>1.61 ± 1.2</td>
<td>.146</td>
</tr>
<tr>
<td>VAS 12 hours</td>
<td>3.08 ± 2.53</td>
<td>3.00 ± 4.24</td>
<td>.960</td>
</tr>
<tr>
<td>VAS 18 hours</td>
<td>2.62 ± 2.2</td>
<td>4.79 ± 2.6</td>
<td>.009</td>
</tr>
</tbody>
</table>

NOTE. Bold denotes significant P value.

VAS, visual analog scale.
21 (IBM, Armonk, NY) for windows was used for all analyses. Power analysis was carried out via IBM SPSS Sample Power 3.0 and demonstrated that 20 patients per group with an effect size of 0.91 and alpha of 0.05 would yield test power of 0.8 for evaluation of post-operative VAS scores.

Results

Between February 2015 to August 2015, 43 consecutive patients who underwent hip arthroscopy for FAI were recruited to the study. Forty-two patients met the inclusion criteria, and one patient was excluded after refusing to participate in the study. Twenty-one patients were included in each group. There were no significant differences between the periacetabular and intra-articular groups in terms of demographic data or intraoperative findings and procedures performed (Tables 1 and 2).

The first VAS scores recorded postoperatively at 30 minutes in the postoperative analgesia recovery room differed significantly (peri-acetabular, 0.667 ± 1.49; intra-articular, 2.11 ± 2.29; P = .045). Post-anesthesia care unit morphine use was not significant between groups however; the intra-articular group received significantly more tramadol (Table 2). The average length of stay in the postoperative analgesia recovery room was 123 ± 49 minutes (range, 64 to 220 minutes) for the periacetabular group and 213 ± 119 minutes (range, 85 to 425 minutes) for the intra-articular group, which was significant (P = .007). The 1-, 2-, 6-, and 12-hour VAS scores did not differ. However, the VAS score recorded at 18 hours was statistically different (peri-acetabular, 2.62 ± 2.2; intra-articular, 4.79 ± 2.6; P = .009; Table 3).

After the first postoperative day there was no significant difference between the groups in terms of VAS-reported pain scores during the following 14 days (Fig 4). Additionally, there was no significant difference between groups in terms of narcotic analgesic consumption per day (percocet 5 mg) or doses of non-narcotic analgesic consumption per day (paracetamol 500 mg or tramadol 100 mg; Figs 5 and 6). There were no complications (falls, weakness, paresthesia, clinical signs of deep vein thrombosis, or pulmonary embolism) during the first 2 weeks postoperatively reported in either the periacetabular or intra-articular groups.

Discussion

The chief outcome of this study showed that periacetabular bupivacaine was superior to intra-articular administration in pain reduction during at least one time point during the first 18 hours after hip arthroscopy. Todd et al. found that a difference of 1.3 on a VAS pain scale should be considered clinically significant for acute traumatic pain. DeLoach et al. concluded that a single VAS measurement should be considered accurate within 2 points during the immediate postoperative period. Based on these studies, there are one or 2 statistically significant time points during the first 18 hours postoperatively in the current study. The clinical relevance of these findings, however, is difficult to interpret as there was not a continuous significant decrease in the VAS pain scores throughout the first 18 hours. Although there was a significant reduction in the VAS score, this reduction was not translated to reduction in analgesic consumption during the first 18 hours. In the following 13 days
PREEMPTIVE ANALGESIA IN HIP ARTHROSCOPY

there were no significant differences in the VAS scores or analgesic consumption between the 2 groups.

The need for effective postoperative pain control after hip arthroscopy has led to the development of multiple analgesic techniques. These techniques include lumbar plexus block, femoral nerve block, fascia iliaca block, and intra- and periarticular administration of bupivacaine. Each of these techniques presents various advantages and challenges. The use of lumbar plexus block for postoperative pain control can often be time consuming, requires the assistance of a skilled anesthesiologist, and has the potential for complications. Femoral nerve blocks may be used for postoperative pain control, however, Lovdal et al. and Sharma et al. have shown that it is associated with a temporary strength reduction in the quadriceps muscle, which can lead to falls and delayed rehabilitation.

Fascia iliaca block is considered a safe procedure and may be used for postoperative pain control, however, this technique often requires ultrasound guidance and an anesthesiologist.

The possible advantages of preemptive periacetabular bupivacaine over preemptive intra-articular bupivacaine that were found in this study can be partially explained by the complex innervation of the hip joint that was described by Birnbaum et al. Articular branches of the femoral nerve innervate the anterior joint capsule. Articular branches of the obturator nerve innervate the anteromedial aspect of the joint capsule. Branches of the sciatic nerve provide innervation of the posterior aspect of the joint, whereas articular branches from the nerve to the quadratus femoris (a branch of the sacral plexus) innervate the posteromedial aspect.

In addition, articular branches of the superior gluteal nerve (a branch of the sacral plexus) innervate the posterolateral section of the joint capsule. The administrations of bupivacaine in 3 points around the hip joint as per the protocol in this study appeared to adequately block the complex innervation of the hip joint. The improved coverage of blockade with periacetabular blocks when compared with intra-articular blocks may explain some of the early advantages of periacetabular blocks in pain management. The onset of action for intra-articular bupivacaine has been reported to be less than 5 minutes. Thus, adequate time between the injection and the beginning of irrigation would have been allowed for. However, longer onsets of actions have been reported (1 to 17 minutes), and it is possible that some portion of the first dose of intra-articular bupivacaine is washed from the joint and rendered ineffective. The second dose of intra-articular bupivacaine, administered at the end of surgery, is not washed out but may be distributed outside the joint, as the capsule is not closed.

Hip arthroscopy is ideally conducted as day case surgery. Increased length of stay has implications for the health and recovery of a patient. Postoperative pain management has been shown to be an important factor in determining length of stay and may have implications for improved surgical outcomes. Juenger et al. studied the factors determining length of stay in surgical day case patients and found postoperative pain to be a good predictor of prolonged stay in the day case unit and unplanned hospital admissions. Reducing postoperative pain for the first 18 hours may be an advantage of periacetabular bupivacaine blockade over intra-articular blockade. The half-life of bupivacaine is approximately 2.7 hours in adults, however, the duration of action is route and dose dependent and ranges from 2 to 9 hours. The significant difference in VAS scores cannot be explained by the direct analgesic effect of bupivacaine, but it may be influenced by superior initial pain management, a more effective pain management loading dose, psychological factors related to the initial level of pain experienced after surgery, or other unknown factors. Additionally, previous studies have shown the effectiveness of intra-articular bupivacaine ranges up to 24 hours postoperatively.

After the first 18 hours pain management, narcotics consumption remains important. Although the result was not significant, patients in the periacetabular group reported lower VAS pain scores consistently for the entire study period and used less narcotic and non-narcotic medications. In the analysis of postoperative VAS and medication consumption, significance was determined per day and not for the entire time period. Thus, the decreased VAS scores during follow-up and lower overall use of narcotics may still be an important finding for reducing overall patient discomfort and analgesic use.

Limitations

The limitations of this study include the lack of a saline control group to establish a baseline postoperative pain level. Furthermore, the 5-minute working time for bupivacaine injection in the intra-articular group may not allow adequate time for the anesthetic to fully exert its effect. The lack of capsular closure allows for potential extravasation of the intra-articular bupivacaine outside the joint. Using a postoperative pain management protocol that offered different pain medications after surgery may have complicated the reporting of VAS scores. The statistical difference in VAS scores between groups may not represent a significant clinical difference at all time points. Employing only one pain medication would simplify analysis of VAS scores; however, it would also result in the undermedication of patients in severe pain and the overmedication of marginally painful patients. Although VAS scores are objective measures, multiple recorders may influence scores. Further study of this topic with an additional control group is warranted to clarify the effects of different postoperative pain management techniques.
Conclusions

Periacetabular injection of bupivacaine 0.5% was superior to intra-articular injection in pain reduction after hip arthroscopy at 30 minutes and 18 hours postoperatively. However, total analgesic consumption over the first 2 postoperative weeks and VAS pain measurements were not significantly affected.

References

Reliability of clinical diagnosis in intraarticular hip diseases

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Received: 4 September 2009 / Accepted: 4 December 2009 / Published online: 8 January 2010
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Abstract This study investigated the ability of experienced orthopedic surgeons to agree on a diagnosis of labral tear, femoroacetabular impingement (FAI), and capsular laxity using clinical examination. Eight patients under the care of an experienced hip arthroscopist underwent independent clinical evaluations by six orthopedic surgeons who specialized in management hip pain. No attempt was made to regulate the evaluation process as surgeons performed their examination as they would in their own practice. Average subject age was 27 years (19–47 years) with five females and three males. Subjects subsequently underwent arthroscopic surgery by the treating surgeon. Surgical findings were recorded with respect to the presence or absence of a labral tear, FAI, and/or capsular laxity. The percent agreement between the surgical findings and clinical examinations were determined. Surgical findings noted four subjects had a labral tear, five FAI, and three laxity. Based on clinical examination, surgeons agreed 63, 65 and 58% of the time with the surgical diagnosis of labral tear, FAI, and capsular laxity, respectively. The level of agreement did not seem to be dependent on the size or type of labral tear. Also, the ability to detect FAI did not seem to depend on whether the lesion was a cam, pincer, combined cam/pincer or size of the cam lesion. This study offers support that clinical examination techniques used for making a diagnosis needs to be improved and standardized if they are to be useful in diagnosing specific pathologies found with arthroscopic hip surgery.

Keywords Hip arthroscopy · Hip pain · Agreement · Clinical examination

Introduction

There is limited research supporting the clinical evaluation process for potential hip arthroscopy candidates. If information collected from a clinical evaluation is to be useful, evidence to support this evaluation process should be provided. This includes defining the ability of examiners to agree on a diagnosis. Currently there is no information to describe if clinicians can agree on the presence or absence of a labral tear, femoroacetabular impingement (FAI), and/or capsular laxity based on examination in individuals with non-arthritic musculoskeletal hip pain.
Advancements in hip arthroscopy have made clinicians more aware of labral tears and the abnormal hip morphology associated with these tears. This includes FAI and capsular laxity [14, 20, 22, 24]. Femoral head–neck junction deformities leading to cam-type FAI and acetabular deformities leading to pincer-type FAI have been implicated as causes of labral lesions [5, 9, 11]. It is also thought that forceful excessive hip external rotation may be linked to focal rotational iliofemoral ligament laxity [21, 25]. The labrum may not only be subjected to abnormal stress when ligament laxity is present but a labral tear, which may have resulted from FAI, can potentially lead to increased stress on the anterior capsule and promote iliofemoral ligament laxity [22, 23].

The evaluation process for individuals with non-arthritic musculoskeletal hip has not been well defined or standardized which may compromise the ability to correctly diagnose specific sources of intra-articular hip pathology. The purpose of this study was to investigate the ability of experienced orthopedic surgeons to agree on a diagnosis of labral tear, FAI, and capsular laxity using clinical examination. It was hypothesized that the evaluation process would be suboptimal, and the agreement between even experienced surgeons in identifying those with and without these disorders would be low when compared to surgical findings.

### Materials and methods

Subjects consisted of eight volunteer patients with musculoskeletal hip-related pathologies under the care of an experienced hip arthroscopist. This surgeon has 18 years of clinical experience treating individuals with hip pain and a majority of current patients that are potential hip arthroscopy candidates. Each subject underwent a comprehensive evaluation by this surgeon that included a complete history, clinical examination, and standard series of plain radiographs views (standing anterior–posterior (AP) of pelvis, AP of the involved hip, and cross-table lateral) taken at the time of their initial examination. Subjects also had a conventional small field of view unilateral direct magnetic resonance imaging (MRI) arthrogram using long acting anesthetic and gadolinium contrast. These subjects were determined to be appropriate arthroscopy candidates and had surgery performed shortly before the completion of this study. Surgical findings and subject demographics are provided in Table 1. This study was approved by the institutional review board. All subjects gave their consent for participation in this study, and the rights of the subjects were protected.

Six orthopedic surgeons who specialized in management of individuals with musculoskeletal hip pain participated as examiners. Clinical experience of these examiners averaged 15 years (range 7–24 years).

### Table 1 Demographic, diagnostic information, and surgical findings

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age</th>
<th>Gender</th>
<th>Labral tear</th>
<th>Femoroacetabular impingement</th>
<th>Laxity</th>
<th>Other findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>Male</td>
<td>7 mm anterior superior Labral chondral separation</td>
<td>Cam and pincer (Profunda) Alpha angle 66° Cross over sign</td>
<td>No</td>
<td>N/A</td>
</tr>
<tr>
<td>2</td>
<td>25</td>
<td>Female</td>
<td>No</td>
<td></td>
<td>No</td>
<td>Iliotibial band (Bursitis)</td>
</tr>
<tr>
<td>3</td>
<td>27</td>
<td>Female</td>
<td>1.2 cm anterior superior Labral chondral separation</td>
<td>Cam and pincer Alpha angle 54° Cross over sign</td>
<td>No</td>
<td>Iliofemoral ligament laxity Ligamentum teres hypertrophy</td>
</tr>
<tr>
<td>4</td>
<td>22</td>
<td>Male</td>
<td>9 mm anterior superior flap tear</td>
<td>Cam and pincer Alpha angle 54° Cross over sign</td>
<td>No</td>
<td>N/A</td>
</tr>
<tr>
<td>5</td>
<td>19</td>
<td>Female</td>
<td>4 mm anterior superior Degenerative labral tear and partial labral chondral separation</td>
<td>Cam and pincer (Profunda) Alpha angle 40°</td>
<td>No</td>
<td>Capsular adhesion</td>
</tr>
<tr>
<td>6</td>
<td>47</td>
<td>Female</td>
<td>3 mm anterior superior partial labral chondral separation</td>
<td>Cam Alpha angle 63° Cross over sign</td>
<td>No</td>
<td>Hamstring tear grade III</td>
</tr>
<tr>
<td>7</td>
<td>37</td>
<td>Male</td>
<td>No</td>
<td>Cam Alpha angle 63° Cross over sign</td>
<td>No</td>
<td>Psoas tendinitis</td>
</tr>
<tr>
<td>8</td>
<td>36</td>
<td>Female</td>
<td>1 cm anterior superior degenerative labral tear</td>
<td>Pincer (Protrusio) Cross over sign</td>
<td>No</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Data collection and data analysis

The eight subjects underwent an independent evaluation by each of the six examiners in a previously determined random order. A brief written summary outlining the subject’s history was provided. However, each examiner could ask the subject questions as they felt appropriate. Subjects were instructed not to reveal the known results of any previous evaluation procedure done by the treating surgeon or reveal information offered by any other examiner during this process. The examiners were instructed to perform their clinical examination as they would in their own practice. No attempt was made to regulate the evaluation process, and examinations were performed isolated in separate clinical examination rooms in a university orthopedic clinic. The examiners recorded the results of their examination and made a diagnosis with respect to the specific pathology (ies) involved. Each examiner was blinded to the findings and diagnosis of the other examiners as well as the finding and diagnosis of the treating surgeon.

After this data collection process, the eight subjects underwent hip arthroscopy by the treating surgeon with surgical findings recorded. Specifically, the presence or absence of a labral tear, FAI, and/or capsular laxity was noted. Diagnoses were made based on the results of the treating surgeon’s history, clinical examination, and surgical findings. When a labral tear was identified during surgery, its size and location were recorded. To assess for FAI, each subject’s involved hip was moved through complete range of motion while under anesthesia with intraoperative assessment. This included combined motions of hip flexion, adduction, and internal rotation as well extension with external rotation. The presence of FAI was noted if at any time the femur abutted the labrum with notable secondary changes of FAI, such as chondral softening or delamination in the location of impingement.

Capsular laxity was identified intraoperatively when increased external rotation range of motion was noted compared to contralateral side, the hip was distracted with minimal traction force, and capsular redundancy with excessive volume was noted.

The clinical diagnoses made by the examiner as were dichotomized as to whether a labral tear, FAI, or laxity were present or not. The number of clinical diagnoses that were in agreement with the surgical findings and treating surgeon’s diagnosis were tallied.

Results

With eight subjects and six surgeons, a total of 48 evaluations were performed. The percent agreement between treating surgeon’s diagnosis and clinical examination in identifying the presence or absence of labral tear, FAI, or laxity are presented in Table 2. Based on clinical examination, surgeons were in agreement 63, 65 and 58%, respectively in diagnosing a labral tear, FAI, and capsular laxity. Diagnosing FAI had the highest level of agreement with the diagnosis as determined by arthroscopy (31 out of 48 evaluations), while diagnosing capsular laxity had the lowest level of agreement with surgical findings (28 out of 48 exams). Overall, diagnoses obtained by these experienced surgeons with clinical examination had a poor agreement to surgical findings.

Discussion

The most important finding of the present study was that there was a low level of agreement between a diagnosis based on a pre-operative clinical examination and surgical findings for the presence or absence of labral tear, FAI, and

<table>
<thead>
<tr>
<th>Labral tear</th>
<th>Clinical exam</th>
<th>FAI</th>
<th>Clinical exam</th>
<th>Laxity</th>
<th>Clinical exam</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Right</td>
<td>Wrong</td>
<td>Right</td>
<td>Wrong</td>
<td>Right</td>
</tr>
<tr>
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<td>Yes</td>
<td>4</td>
<td>2</td>
<td>Yes</td>
<td>5</td>
</tr>
<tr>
<td>Subject 4</td>
<td>No</td>
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<td>0</td>
<td>No</td>
<td>2</td>
</tr>
<tr>
<td>Subject 5</td>
<td>Yes</td>
<td>4</td>
<td>2</td>
<td>Yes</td>
<td>5</td>
</tr>
<tr>
<td>Subject 6</td>
<td>Yes</td>
<td>4</td>
<td>2</td>
<td>No</td>
<td>3</td>
</tr>
<tr>
<td>Subject 7</td>
<td>Yes</td>
<td>3</td>
<td>3</td>
<td>Yes</td>
<td>3</td>
</tr>
<tr>
<td>Subject 8</td>
<td>Yes</td>
<td>2</td>
<td>4</td>
<td>No</td>
<td>5</td>
</tr>
<tr>
<td>Subject 9</td>
<td>No</td>
<td>5</td>
<td>1</td>
<td>Yes</td>
<td>4</td>
</tr>
<tr>
<td>Subject 10</td>
<td>Yes</td>
<td>2</td>
<td>4</td>
<td>Yes</td>
<td>4</td>
</tr>
</tbody>
</table>

FAI Femoroacetabular impingement

Table 2 Surgical diagnosis compared with clinical examination only and clinical examination plus diagnostic imaging in correctly identifying the presence or absence of labral tear, FAI, or laxity
capsular laxity. These findings were noted despite the level of expertise of the surgeons performing the evaluation. This study offers support that the evaluation process used for making a diagnosis with history and clinical needs to be improved and standardized if the obtained information is to help identify the specific pathologies noted with hip arthroscopy.

This study is needed because a clinical examination for individuals with non-arthritic intra-articular hip pain is felt to provide critical information [3, 8, 17]; however, evidence to support the accuracy of the examination has not been thoroughly defined [14]. One study noted that a clinical examination could not determine the specific intra-articular pathology but could differentiate between intra- and extra-articular pathology [3]. Byrd and Jones noted when identifying the nature of the intra-articular abnormality, clinical assessment was accurate in 32% of surgical cases [3]. In potential surgical candidates, it was found that history and clinical examination could not differentiate those with primarily intra-articular from those with primarily extra-articular sources of hip pain based on the results of an anesthetic intra-articular injection [15]. When considering intervention options, accurate diagnoses as to the presence or absence of a labral tear, FAI, and/or capsular laxity is necessary for appropriate treatment planning.

The results of study are consistent with previous work in that the examination process is suboptimal when attempting to indentify the specific intra-articular pathology in those with non-arthritic musculoskeletal hip pain [3, 19]. While a cross over sign and angle alpha are radiographic means to assess for FAI [6, 7], there is little work done to describe the accuracy of diagnosing FAI in a clinical setting. Also, evidence to describe the accuracy in diagnosing capsular laxity of the hip is not available. In this current study, the agreement with the diagnoses of a labral tear, FAI, and/or capsular laxity using clinical examination (ranging from 58 to 65%) is consistent with other studies.

When specifically looking at identifying those with and without surgically confirmed labral tears, the subjects without a labral tear were identified with clinical examination in 11 out of 12 (92%) evaluations, while those with a labral tear were identified in only 19 of 36 (53%) evaluations. The level of agreement for those with a labral tear did not seem to be dependent on the size of the tear or type of tear. It should be noted that tears in this current study were relatively small (<1.5 cm) and were associated with FAI in four out of the five cases. These subject characteristics may have contributed to the poor level of agreement in identifying those with a labral tear using clinical examination. Studies have shown large variability in MRI appearance of the labrum in asymptomatic individuals [4, 10] as well as a high prevalence of labral tears in cadaveric studies [18, 26]. Additionally, it was noted that a labral tear identified on MRI arthrography may not be the major source of patient’s pain complaints [15]. Martin et al. [15] noted only 57% (27 of 47) of those with definite or possible labral tears had greater than 50% relief of pain and only 15% (7 of 47) had greater than 90% relief with an intra-articular anesthetic injection. Given this information, it seems clear that relationship between a labral tear and patient symptoms needs to be better defined.

Similar to the findings with regard to evaluation of a labral tear, the level of agreement in identifying those patients with or without surgically documented FAI was low. This study defined FAI to be present during surgery when the femur abutted the labrum during range of motion assessment from cam and/or pincer lesions. A cam FAI is noted when the shape of the femoral head was not round, suggesting a bump on the femoral head-neck junction [13]. Pincer lesions are defined as an acetabular disorder with protrusio, profunda and/or relative acetabular retroversion [6]. Both cam and pincer lesions have been implicated in the etiology of labral and chondral lesions [1, 2, 5, 9, 11, 12]. Subjects without FAI were identified with clinical examination in 10 out of 18 (55%) evaluations, while those with FAI were accurately identified in 21 of 30 (70%) evaluations. The ability to detect FAI did not seem to depend on whether the lesion was a cam, pincer, or combined cam/pincer. Also the size of the cam lesion, as determined by the alpha angle, did not seem to contribute in the ability to detect FAI. As with labral tears, the level of agreement between clinical evaluation and the surgical presence or absence of FAI was low.

While there is evidence to link FAI and intra-articular pathology, the relationship between hip capsular laxity and intra-articular pathology is less defined. Forceful excessive hip external rotation may be linked to focal rotational iliofemoral ligament laxity [21, 25]. The labrum may not only be subjected to abnormal stress when ligament laxity is present but a labral tear may also lead to increased stress on the anterior capsule and promote iliofemoral ligament laxity [22, 23]. While there are some objective means to define labral tears (i.e. size of lesion) and FAI (i.e. alpha angle), there is no such methods to objectively assess for laxity. The clinical tests, such as the log roll, used to diagnosis laxity are subjective in nature. There has been a study to assess the reliability of the log roll test [16]; however, no information was provided regarding its accuracy. Even determining the presence of laxity at the time of surgery is still without clear objective measure and may not be consistent from surgeon to surgeon. A clinical exam was able to correctly identify one individual with laxity (subject 3) and one individual without laxity (subject 9) at 100% accuracy. In the case of subject 3 who had capsular laxity, this patient seemed to fit a typical profile for someone who may have laxity, being a young female with a history of
instability. In the case of subject 9, this patient fit typical profile for someone without capsular laxity as this person was a male who complained stiffness. Other symptoms did not seem to contribute to making a correct diagnosis in any of these eight surgical subjects.

There are several limitations with this study. Diagnostic imaging plays a critical role in the patient management process and was not included in this analysis. Further assessment needs to be done as to how the level of agreement would change with the addition of the information obtained with imaging. This study was a small case series that was not meant to provide conclusive answers regarding the accuracy of a clinical examination but to serve as platform for larger studies to consider. The gold standard was felt to be appropriate as one experienced surgeon who had access to all patient information was involved in all aspect of patient care, though he did not participate in the “blinded” examinations. The gold standard was arthroscopic confirmation. However, it must be noted that it is possible that the treating surgeon’s diagnosis could be incorrect, even after arthroscopic assessment. The study group was considered appropriate, as these were all surgeons with interest, experience and expertise in treating patients with non-arthritic hip problems. While the presence or absence of a labral tear and FAI could be objectively noted, the issue of laxity is more subjective. Also, more research is needed to determine at what point, with regard to size or severity, the findings of a labral tear, FAI, and/or laxity noted at surgery should be addressed to successfully resolve the patient symptoms.

Conclusion

The agreement of experienced surgeon’s on the diagnosis of labral tear, FAI, and laxity, based clinical examination was low. This study offers support that clinical examination techniques used for making a diagnosis needs to be improved and standardized if they are to be useful in diagnosing specific pathologies found with arthroscopic hip surgery.

Acknowledgments Multi-Center Arthroscopy of the Hip Outcomes Research Network (MAHORN) has received a grant from Smith and Nephew.

References


A Short Version of the International Hip Outcome Tool (iHOT-12) for Use in Routine Clinical Practice


Purpose: The purpose of this study was to develop and validate a shorter version of the 33-item International Hip Outcome Tool (iHOT-33) that could be easily used in routine clinical practice to measure both health-related quality of life and changes after treatment in young, active patients with hip disorders. Methods: A development dataset (104 patients) was explored with forward-selection linear regression analysis to choose a reduced item set for the new scale. This was tested in a validation dataset (1,833 patients) and responsiveness subset (80 patients) to measure agreement between the shorter and longer versions and to test the sensitivity of the shorter instrument to change after treatment. Results: Twelve items were chosen for a short version of the International Hip Outcome Tool (iHOT-12). The iHOT-12 showed excellent agreement with the long version (iHOT-33). It captured 95.9% (95% confidence interval, 95.0% to 96.8%) of the variation of the iHOT-33 and showed equivalent sensitivity to change with a standardized effect size of 0.98 (95% confidence interval, 0.67 to 1.28). Conclusions: A short version of the International Hip Outcome Tool (iHOT-12) has been developed. It has very similar characteristics to the original rigorously validated 33-item questionnaire, losing very little information despite being only one-third the length. It is valid, reliable, and responsive to change. We suggest that it be used for initial assessment and postoperative follow-up in routine clinical practice.

The International Hip Outcome Tool (iHOT-33) is a 33-item patient-reported measure of health-related quality of life.1 It was designed to measure the impact of hip disease in young, active patients and to measure the effect of treatment of this disease. Patients were extensively involved in both item genera-

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The authors report the following potential conflict of interest or source of funding in relation to this article: Professor Griffin is a paid consultant or employee for ConMed Linvatec and receives research or institutional support from Wright Medical. Dr. Mohtadi is on the Membership and Scientific Committees of the International Society of Arthroscopy, Knee Surgery & Orthopaedic Sports Medicine and is an Editorial Board Member of the American Journal of Sports Medicine, Clinical Journal of Sport Medicine, Physician and Sportsmedicine, and Journal of Sport-Orthopaedic-Sport-Traumatologie. Dr. Safran is on the Executive Committee of the American Shoulder and Elbow Surgeons; is Treasurer and a Board Member of the International Society of Arthroscopy, Knee Surgery & Orthopaedic Sports Medicine; is Chair of the Council of Delegates and a member of the Education Committee and Board Member of the American Orthopaedic Society for Sports Medicine; is an Editorial Board Member of the American Journal of Sports Medicine; and is President and a Board Member of the Society for Tennis Medicine and Science. He receives royalties from Stryker Medical (shoulder anchor), Lippincott Williams & Wilkins, and Elsevier/Saunders; is a paid consultant or employee for ArthroCare; is an unpaid consultant for Biomimedica and Cradle Medical; receives fellowship support from Smith & Nephew, ConMed Linvatec, Ossur, and Zimmer; and owns stock or stock options in Biomimedica and Cradle Medical.

The members of the Multicenter Arthroscopy Arthroscopy of the Hip Outcomes Research Network (MAHORN) are listed in the Acknowledgments section at the end of this article.

Received July 26, 2011; accepted February 26, 2012.
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© 2012 by the Arthroscopy Association of North America
0749-8063/11/475/$36.00
doi:10.1016/j.arthro.2012.02.027
tion and assessment of item importance. This patient involvement and extensive international testing during the development process led to a valid and reliable instrument for use in this particular group of patients.

The iHOT-33 includes 33 questions or items, each answered by marking a visual analog scale between 2 anchor statements. This can be done on a paper form (with a 100-mm scale) or as part of a computer-based system. The total score is calculated as a simple mean of these responses ranging from 0 to 100, with 100 representing the best possible quality-of-life score.

The iHOT-33 is most likely to be used in the research setting, for example, in randomized controlled trials to compare treatment strategies in young, active patients with hip pathologies such as femoroacetabular impingement or articular cartilage degeneration. In these studies the wide range of symptoms and problems covered by the 33 items will provide a sensitive measure of treatment-related change, and the resources associated with such studies will facilitate the use of this relatively large instrument. In routine clinical practice, most clinicians look for an instrument with similar characteristics of validity, reliability, and responsiveness to the iHOT-33, but with a smaller number of items to reduce patient burden and administrative effort. For example, the universal PROMs (Patient Reported Outcome Measures) program introduced by the National Health Service in England made use of the 12-item Oxford Hip Score in patients undergoing total hip arthroplasty. A similar strategy was followed for the conversion of the Short Form 36 to the shorter Short Form 12.

The purpose of this study was to develop and validate a shorter version of the International Hip Outcome Tool (iHOT) that could be easily used in routine clinical practice to measure both health-related quality of life and changes after treatment in young, active patients with hip disorders.

**METHODS**

**Development of Short Version of iHOT**

The feasibility of a short version of the iHOT was explored during a development study. During January and February 2008, active, English-speaking adults, aged 18 to 60 years, who presented as new patients to a young adult hip clinic or who were undergoing follow-up after hip-preserving treatment of hip problems were invited to take part. One hundred and four such patients completed the iHOT-33. Characteristics of these patients are shown in Table 1. A principal component analysis was used to assess the dimensionality of the iHOT-33 as a prelude to item subset selection. Eigenvalues greater than 1 were retained, on the basis that any single factor should be dropped unless it contains at least as much information as any one of the original questionnaire items. Regression analysis was then used to select a reduced number of items from the 33-item set. A forward-selection procedure was used to select items that accounted for the greatest part of the variation in the overall mean of the 33 items for each patient. The variance accounted for by each item can be interpreted as a measure of how much information is captured by that item and, in a regression model, how much more information is provided by that item over that which has already been cumulatively provided by previously included items. The variance accounted for by individual regression models was assessed by the coefficient of determination, the adjusted $R^2$ value from the regression output, and expressed as a percentage where, for instance, 50% indicated that half the variance in the iHOT-33 was accounted for by the selected subset of items. This gave a rating of the importance of the items for each administration of the questionnaire. The specific ordering of the importance of individual items was viewed with some caution: As usual in such statistical modeling, the process to reach the most parsimonious linear regression model and the selection of which terms to include in that model allowed several choices. However, the results gave a strong indication as to the composition of an optimal subset of items for inclusion in a shortened form of the iHOT.

The final selection of items for inclusion in a shortened questionnaire was based on the regression analysis ranking of the relative contribution to variance of each item, a pre hoc decision to span the 4 domains of the iHOT (symptoms and functional limitations; sport and recreational activities; job-related concerns; and social, emotional, and lifestyle concerns), the item frequency-importance product, and a pragmatic intent for there to be somewhere between 10 and 15 items on the shortened questionnaire.

**Validation of Short Version of iHOT**

The shortened iHOT was validated using a separate large dataset of completed iHOT-33 questionnaires from 1,833 patients, recorded between March 2008 and September 2010. The characteristics of these patients are shown in Table 1. The mean iHOT-33 score for these patients was 44.3 (95% confidence interval [CI], 43.1 to 45.5).
For a subsample of 80 patients, both preoperative and 3-month postoperative iHOT scores were also collected. These data were used to assess responsiveness of the shortened iHOT (i.e., the sensitivity to change after treatment). Preoperative assessment of these patients was performed on the day of surgery. The median time between the preoperative and postoperative assessments for these patients was 96 days (interquartile range, 121 to 178 days).

The shortened iHOT was validated by scatterplot against the iHOT-33 and by comparison of the adjusted $R^2$ value for the validation data with that reported for the development data. A paired t test was used to compare change scores (postoperative score – preoperative score) between the shortened iHOT and the iHOT-33 in the subsample of 80 patients. Responsiveness of the shortened instrument was determined using standardized effect sizes. The 104 patients from the development dataset were asked to undertake an additional administration of the iHOT-33, a mean of 24 days after the first assessment (range, 14 to 90 days); these data were used to assess test-retest reliability for the shortened instrument using an intraclass correlation coefficient.

### RESULTS

#### Development

Principal component analysis of the iHOT-33 for the development data showed that there were at least 4 important components (with eigenvalues $>1$) that we can loosely associate with the 4 domains of the iHOT-33. This analysis showed that there was some scope to shorten the iHOT-33 while retaining the main properties of the instrument. This was expected, because the iHOT-33 has been deliberately developed with a degree of innate redundancy to provide a measure that is both responsive to change and stable across possibly highly heterogeneous populations. Figure 1 shows the variance accounted for in the regression analysis by the inclusion of increasing numbers of items from the development data, expressed as a percentage of the total variance captured by the iHOT-33. Approximately 100% of the variance was accounted for after 20 items were included in the regression models, so the process was curtailed at this point. The very rapid rise in proportion of variance shows that a small number of items accounted for nearly all the variability in the overall mean iHOT-33 scores.
Four items, in order of importance, accounted for 99% of the variability in the overall mean of the 33 items: (1) Overall, how much pain do you have in your hip/groin? (2) How concerned are you about picking up or carrying children because of your hip? (3) How concerned are you about cutting/changing directions during your sport or recreational activities? and (4) How much trouble do you have pushing, pulling, lifting, or carrying heavy objects at work? Reassuringly, these 4 selected items represented 1 item from each of the 4 domains identified in the full iHOT-33 questionnaire.

To decide on the final selection of items, the regression analysis results, domain memberships, and frequency-importance products were considered together (Table 2). This resulted in the selection of a further 8 items to give a final selection of 12 items, detailed in Table 3, that had good frequency-importance products, covered each of the 4 domains, and accounted for greater than 99% of the variance of the iHOT-33. We called this new, shortened instrument the iHOT-12 (Appendix).

Validation

Overall iHOT-33 and iHOT-12 scores were calculated as the mean visual analog scale score for the individual items for each questionnaire for each patient. These are shown for the full validation dataset for each patient in Fig 2. There is good agreement between the 2 sets of scores, with regression analysis showing that the iHOT-12 accounted for 95.9% (95% CI, 95.0% to 96.8%) of the variation in the iHOT-33. This is close to the result of analysis of the development dataset with a value of greater than 99%.

For the subsample of patients in the validation dataset with both preoperative and postoperative scores (n = 80), change scores (postoperative score – preoperative score) were determined for both the iHOT-33 and iHOT-12. Figure 3 shows that there was excellent agreement between the iHOT-33 and iHOT-12 for these patients, with a paired t test indicating that there was no significant difference (P = .241) in change scores between the original questionnaire and the shortened questionnaire. Standardized effect sizes were 1.03 (95% CI, 0.70 to 1.36) and 0.98 (95% CI, 0.67 to 1.28) for the iHOT-33 and iHOT-12, respectively, indicating almost exact equivalence in responsiveness to clinical change for the 2 questionnaires. Test-retest reliability for the iHOT-12 was good, with an intraclass correlation coefficient of 0.89 (95% bootstrapped CI, 0.83 to 0.93).

Table 2. iHOT-33 Item Domain Membership, Cumulative Variance Accounted for During Model Development Regression Analysis, and By Frequency-Importance Products

<table>
<thead>
<tr>
<th>iHOT-33 Questions</th>
<th>iHOT-33 domain</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-16</td>
<td>I: Symptoms and functional limitations</td>
</tr>
<tr>
<td>17-22</td>
<td>II: Sports and recreational activities</td>
</tr>
<tr>
<td>23-26</td>
<td>III: Job-related concerns</td>
</tr>
<tr>
<td>27-33</td>
<td>IV: Social, emotional, and lifestyle</td>
</tr>
<tr>
<td></td>
<td>Variance (importance)</td>
</tr>
<tr>
<td>80%-99% (strong)</td>
<td>16,* 21,* 23,* and 32*</td>
</tr>
<tr>
<td>99%-99.9% (intermediate)</td>
<td>1, 3,* 6,* 8, 11, 14,* 15, 17,* 18,* 24, 25, 26, 28,* 29,* 30, and 33*</td>
</tr>
<tr>
<td>&gt;99.9% (weak)</td>
<td>2, 4, 5, 7, 9, 10, 12, 13, 19, 20, 22, 27, and 31</td>
</tr>
<tr>
<td></td>
<td>Frequency-importance product</td>
</tr>
<tr>
<td>&gt;60%</td>
<td>3,* 17,* 18,* 19, 20, 21,* 27, 29,* and 33*</td>
</tr>
<tr>
<td>50%-60%</td>
<td>1, 2, 5, 6,* 7, 8, 9, 16,* 22, 30, and 31</td>
</tr>
<tr>
<td>35%-50%</td>
<td>4, 10, 11, 12, 13, 14,* 15, 23,* 24, 25, 26, 28,* and 32*</td>
</tr>
</tbody>
</table>

*Items selected for inclusion in iHOT-12.
DISCUSSION

The iHOT was developed to provide an evaluation tool for the management of nonarthritic hip problems in young, active patients. Excellent instruments already exist for patients with hip fractures, those with hip arthritis, or those undergoing hip arthroplasty. The iHOT-33 was designed using a rigorous methodology with a large number of active, young patients being considered for, or receiving, hip-preserving surgery, to capture their different problems, goals, and expectations of treatment.

The iHOT-33 is reliable; shows face, content, and construct validity; and is highly responsive to clinical change. However, it is a lengthy instrument comprising 33 separate questions in 4 domains. This is unlikely to be a problem in the context of clinical trials but might limit the usefulness of the instrument in routine clinical practice. Concerns about the practicality of the original questionnaire during pilot studies, particularly from clinicians who wanted to use it in all of their patients at first contact and on every follow-up.

<table>
<thead>
<tr>
<th>iHOT-12 Question</th>
<th>iHOT-12 Question</th>
<th>iHOT-33 Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall, how much pain do you have in your hip/groin?</td>
<td>Question 16</td>
<td></td>
</tr>
<tr>
<td>How difficult is it for you to get up and down off the floor/ground</td>
<td>Question 6</td>
<td></td>
</tr>
<tr>
<td>How difficult is it for you to walk long distances?</td>
<td>Question 3</td>
<td></td>
</tr>
<tr>
<td>How much trouble do you have with grinding, catching, or clicking in your hip?</td>
<td>Question 14</td>
<td></td>
</tr>
<tr>
<td>How much trouble do you have pushing, pulling, lifting, or carrying heavy objects at work?</td>
<td>Question 23</td>
<td></td>
</tr>
<tr>
<td>How concerned are you about cutting/changing directions during your sport or recreational activities?</td>
<td>Question 21</td>
<td></td>
</tr>
<tr>
<td>How much pain do you experience in your hip after activity?</td>
<td>Question 18</td>
<td></td>
</tr>
<tr>
<td>How concerned are you about picking up or carrying children because of your hip?</td>
<td>Question 32</td>
<td></td>
</tr>
<tr>
<td>How much trouble do you have with sexual activity because of your hip?</td>
<td>Question 28</td>
<td></td>
</tr>
<tr>
<td>How much of the time are you aware of the disability in your hip?</td>
<td>Question 33</td>
<td></td>
</tr>
<tr>
<td>How concerned are you about your ability to maintain your desired fitness level?</td>
<td>Question 17</td>
<td></td>
</tr>
<tr>
<td>How much of a distraction is your hip problem?</td>
<td>Question 29</td>
<td></td>
</tr>
</tbody>
</table>
The iHOT-12 uses 12 items from the original 33. Regression analysis of a development dataset identified these 12 items that accounted for greater than 99% of the total variation in the full score. In a separate, large group of patients used for a validation study, the iHOT-12 showed excellent agreement with the iHOT-33 and captured at least 96% of the variation in the full questionnaire. The iHOT-12 extends across all 4 domains identified in the work to develop the iHOT-33 and showed almost identical sensitivity to change after treatment in a mixed group of patients with a variety of pathologies and treatment modalities. Standardized effect size for both the iHOT-12 and iHOT-33 was smaller than in our previous study (around 1.0 compared with 1.8). We believe that this probably reflects differences in the case mix of patients presenting for hip-preserving surgery, although both patient groups had a wide variety of diagnoses and were treated with a variety of techniques.

The decision to use 12 items is, to some extent, arbitrary. As few as 4 items could be expected to capture most of the variation available with a longer questionnaire. However, it is desirable that each attribute (or dimension) that one wishes to measure has adequate representation on the questionnaire, that is, more than 1 item asking about the attribute, for 2 main reasons: (1) multiple items decrease the variability in the overall response by increasing the measure resolution for each item, and (2) multiple items minimize the impact of idiosyncratic responses to individual items. In other words, a short questionnaire may perform well on average to discriminate between groups of patients, but it will not always capture the subtle idiosyncrasies that allow the instrument to evaluate changes in individual patients. Guyatt et al. recommended that 3 or 4 items should be included for each attribute. We suggest that 12 items is a reasonable compromise between a very short, simple instrument and a longer and more evaluative instrument best suited to prospective clinical research. Thus the iHOT-12 is likely to be most useful in routine clinical practice: Subtle differences within individual patients may not be identified but this will be outweighed by the ease and speed of administration, as well as the responsiveness of the instrument on average across a practice. The iHOT-12 has excellent psychometric properties and correlates well with the iHOT-33. We suggest that the iHOT-33 will be preferred for prospective clinical studies, unless these are very large and pragmatic, where the shorter iHOT-12 may again provide an advantage.

**CONCLUSIONS**

A short version of the iHOT, the iHOT-12, has been developed. It has very similar characteristics to the original 33-item questionnaire, losing very little information despite being only one-third the length. It is valid, reliable, and responsive to change. We suggest that it be used for initial assessment and postoperative follow-up in routine clinical practice.


**REFERENCES**


APPENDIX

SHORT VERSION OF INTERNATIONAL HIP OUTCOME TOOL

QUALITY OF LIFE QUESTIONNAIRE FOR YOUNG, ACTIVE PEOPLE WITH HIP PROBLEMS

INSTRUCTIONS
• These questions ask about the problems you may be experiencing in your hip, how these problems affect your life, and the emotions you may feel because of these problems.

• Please indicate the severity by marking the line below each question with a slash.

   » If you put a mark on the far left, it means that you feel you are significantly impaired. For example:

   SIGNIFICANTLY IMPAIRED _____________________________ NO PROBLEMS AT ALL

   » If you put a mark on the far right, it means that you do not think that you have any problems with your hip. For example:

   SIGNIFICANTLY IMPAIRED _____________________________ NO PROBLEMS AT ALL

   » If the mark is placed in the middle of the line, this indicates that you are moderately disabled, or in other words, between the extremes of ‘significantly impaired’ and ‘no problems at all’. It is important to put your mark at either end of the line if the extreme descriptions accurately reflect your situation.

   TIP: If you don’t do an activity, imagine how your hip would feel if you had to try it.

• Please let your answers describe the typical situation in the last month.

Q1 Overall, how much pain do you have in your hip/groin?

EXTREME PAIN _____________________________ NO PAIN AT ALL

Q2 How difficult is it for you to get up and down off the floor/ground?

EXTREMELY DIFFICULT _____________________________ NOT DIFFICULT AT ALL

Q3 How difficult is it for you to walk long distances?

EXTREMELY DIFFICULT _____________________________ NOT DIFFICULT AT ALL
Q4  How much trouble do you have with grinding, catching or clicking in your hip?

SEVERE TROUBLE ___________________________ NO TROUBLE AT ALL

Q5  How much trouble do you have pushing, pulling, lifting or carrying heavy objects?

SEVERE TROUBLE ___________________________ NO TROUBLE AT ALL

Q6  How concerned are you about cutting/Changing directions during your sport or recreational activities?

EXTREMELY CONCERNED ___________________________ NOT CONCERNED AT ALL

Q7  How much pain do you experience in your hip after activity?

EXTREME PAIN ___________________________ NO PAIN AT ALL

Q8  How concerned are you about picking up or carrying children because of your hip?

EXTREMELY CONCERNED ___________________________ NOT CONCERNED AT ALL

Q9  How much trouble do you have with sexual activity because of your hip?

☐ This is not relevant to me

SEVERE TROUBLE ___________________________ NO TROUBLE AT ALL

Q10 How much of the time are you aware of the disability in your hip?

CONSTANTLY AWARE ___________________________ NOT AWARE AT ALL

Q11 How concerned are you about your ability to maintain your desired fitness level?

EXTREMELY CONCERNED ___________________________ NOT CONCERNED AT ALL

Q12 How much of a distraction is your hip problem?

EXTREME DISTRACTION ___________________________ NO DISTRACTION AT ALL
Letter to the Editor

Surgical and Histologic Confirmation of Psoas Regeneration After Arthroscopic Tenotomy

To the Editor:

In 2013 we had the high honor of publishing an article in *Arthroscopy*, entitled “Regrowth of the psoas tendon after arthroscopic tenotomy: A magnetic resonance imaging study.” One of the limitations, pointed out by the reviewers, was the lack of histologic confirmation of tendinous tissue regeneration. Confirming this histologic regrowth in a research protocol would involve a new procedure, which would be an obvious unethical scenario.

However, 15 months after we finished the original project, one of the patients required revision surgery due to recurrence of impingement symptoms and capsular adhesions that failed to respond to conservative treatment during a period of 4 months. To confirm the histologic regrowth of the psoas tendon after tenotomy, and with previous institutional review board approval and the patient’s informed consent, the psoas tendon was explored during the revision hip arthroscopy and the presence of regenerated tissue was surgically confirmed, whence a histologic sample of the tendon at the level of the labrum was collected. With no previous information about the origin of the tissue, a senior pathologist assessed the sample using H&E stain and reported “tendinous tissue, with hypocellular collagen bundles, and occasional lymphocytes and macrophages with hemosiderin” (Fig 1).

Although our previous MRI study in 19 patients reported psoas regrowth after tenotomy, and other authors have reported a clinically exaggerated re-formation of the tendon in athletes, there have been no previous surgical or histologic reports of psoas tendon regeneration in the literature. Histologic corroboration of tendon regrowth has been reported previously in animals and humans. Turhan et al. performed an anatomic and histologic study in sheep and found a regeneration potential of the musculus extensor digitalis lateralis tendon 6 months after tenotomy.

In humans, the studies have been directed mainly to hamstring tendon regrowth after use as an autograft for anterior cruciate ligament (ACL) reconstruction. Ahlen et al. reported histologic re-formation of the semitendinosus (ST) tendon at a minimum 6-year follow-up in 18 patients who underwent ACL reconstruction using ipsilateral ST tendon autograft. Interestingly, they found no significant differences between the regenerated and non-harvested tendon in terms of fiber structure, cellularity, vascularity, and level of glycosaminoglycans. By contrast, in this case, the architecture of the tissue was different when compared with a normal psoas tendon. The regenerated tendon had disorganized fibers and more cellularity.

This case study finally proved that the psoas tendon regenerates after tenotomy and supports the clinical and

![Fig 1](image_url) (A) Histologic sample of regenerated psoas tendon (H&E stain, original magnification ×200). Bundles of hypocellular collagen with occasional lymphocytes were observed. The more cellular area in the upper left portion of the image corresponds to a zone adjacent to muscle. (B) Normal psoas tendon from a 30-year-old male cadaver (H&E stain, original magnification ×200). Organized collagen architecture and cellularity can be observed.
observation of a regrowth phenomenon reported in our previous study. The re-formation phenomenon is important to understand the natural history of psoas tenotomy by disturbing and apparently recovering the function of the psoas tendon without recurrence of the impingement or snapping phenomenon.

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Note: The authors report the following potential conflict of interest or source of funding: H.D.M. receives support from Smith & Nephew and Pivot Medical.
The regional microvascular density of the gluteus medius tendon determined by immunohistochemistry with CD31 staining: a cadaveric study

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2 Baylor University Medical Center, Dallas, Texas - USA
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ABSTRACT

Background and Purpose: There are no studies to date about the vascularisation into the gluteus medius tendon. The purpose of this study was to define the microvessel density of the gluteus medius in 3 zones through a special staining with CD31 and to identify regional differences in microvascular density that may have implications for the healing.

Methods: We obtained 12 complete gluteus medius tendons from cadavers who had been an average age of 30.3 years old (range 18 to 55). All the donors were males with no known history of hip abnormalities. Following a rigorous protocol, each gluteus medius tendon was divided in 3 portions. Each gluteus medius tendon was divided in 3 portions (I: musculotendinous, II: Tendon, III: Tendon-Bone junction).

Results: There were regional differences between all anatomic zones in both the transverse section (p<0.001) and the longitudinal section (p = 0.007). Furthermore, a significant difference was found between zones II and I (mean difference -23.45 IC95% -38.77 to -8.13, p<0.001) and between zones II and III (mean difference -26.08 IC95% -41.39 to -10.76, p<0.001) in transverse section. In longitudinal sections, this difference was found as well between zones II and I (mean difference -29.48 IC95% -51.54 to -7.43, p = 0.01), but not between zones II and III (mean difference -10.87 IC95% -32.93 to 11.18, p = 0.67).

Conclusions: The microvessel density was significantly lower in the length of the tendon (central portion) compared to the other 2 regions.

Keywords: Gluteus medius tendon, Microvascular density, CD31 staining

Introduction

The vascular supply of tendon is variable, the majority have 3 sources: 1) the musculotendinous junction; 2) the length of the tendon; and 3) the tendon-bone junction (1). Both the musculotendinous junction and the tendon-bone junction have vessels coming from muscular and periosteal arteries respectively. The main blood supply to the middle portion of the tendon is exclusively via the paratenon (2).

The ratio of blood supply from the intrinsic to extrinsic systems varies from tendon to tendon. For example, the central third of the rabbit Achilles tendon receives 35% of its blood supply from the extrinsic system (3). In the absence of a synovial sheath, the paratenon provides the extrinsic component of the vasculature. Vessels entering the paratenon course transversely, and branch repeatedly to form a complex vascular network (4).

Tendon vascularity is compromised at junctional zones and sites of torsion, friction or compression, a finding particularly notable in the tibialis posterior, supraspinatus, and achilles tendons demonstrated in cadaveric studies using intravascular injection of India ink-gelatin mixture (5, 6). In the Achilles tendon, angiographic injection techniques have demonstrated a zone of hypovascularity 2-7 cm proximal to the tendon insertion (7).

There is a characteristic vascular pattern with avascular zones identified in the rotator cuff tendons of the shoulder (6), and those conclusions could be analogically used
for the gluteus medius tendon based on their similarities. Nevertheless, the anatomy, position, and biomechanics of the gluteus medius tendon is highly different (8) and no published studies to date have determined if there is a real hypovascular zone in the gluteus medius tendon.

On another hand, the studies about vascular supply of the tendons are mainly performed in the external vascular structures (e.g. angiography, etc.) (9, 10). But there are few studies to date about the vascularisation into the tendon through histological or immunohistochemical techniques.

The objective of this study was to determine the microvesSEL density into the gluteus medius tendon in 3 zones through a special staining with CD31 antibody in order to identify regional differences in microvascular density that may have implications for the healing.

Patients and Methods

In accordance with the ethical standards of the responsible committee on human experimentation and with the Helsinki Declaration, the Department of Pathology of the University of Antioquia in Medellin (Colombia) provided the specimens for this study. A pathologist supervised the selection and preparation of the cadavers.

A total of 12 complete gluteus medius tendons (including bone from the greater trochanter) from 12 fresh human cadavers with a mean age of 30.3 years old (range 18 to 55) were obtained through a postero-lateral approach (Fig. 1). All the donors were males with no known history of hip abnormalities. The samples were processed only if they came from cadavers without inflammatory or arthritic changes on gross inspection.

The entire gluteus medius tendon was dissected with its bone and muscle attachment, and all adipose tissue was carefully removed. Then, each sample was divided in 3 similar transverse portions as follows: the musculotendinous junction (zone I), the length of the tendon (zone II), and the tendon-bone junction (zone III). Then, from each transverse section a longitudinal portion from each zone was obtained as well (Fig. 2).

Each specimen was immersion-fixed in 10% formalin for 24 hours, and paraffin-embedded. 4 µm thick sections were stained with hematoxylin-eosin. The vessels were detected by immunohistochemistry (IHC) using a commercial antibody against the endothelial antigen CD31 (PECAM-1 Ab-6, clone 1A10, Thermo Fisher Scientific, Fremont, CA, USA; 1:100 dilution, 40-min incubation). The reason for choosing this immunohistochemistry technique was the aim to provide a real data about the vascular supply inside the tendon.

For IHC labelling, each section (4 µm) was deparaffinised in xylene during 30 minutes and rehydrated by using graded ethanol concentrations. Endogenous peroxidase activity was blocked with hydrogen peroxide. Antigen retrieval was carried out by the steam tris buffer EDTA (ethylene-diaminetetra-acetic acid) treatment, pH 7.0 (30 minutes). The detection system used was polymer-based (Ultravision Quanto, Thermo Fisher Scientific, Fremont, CA, USA).

Specimens were examined at x400 and x200 with H&E staining (Fig. 3) and at x100 magnification (objective 10X) with CD31 standing, every powered field at x100 meaning an area of 2 mm². The capillaries per mm² were counted for each specimen (only including the tendon itself and septal structures) (Fig. 4).

Microvessel was defined as any blood vessel that average less than 0.3 mm in diameter. The comparison of the microvessel density between zones I, II and III (transverse and longitudinal) was performed using an Analysis of Variance (ANOVA). Furthermore, a multiple comparison between groups was performed using a Bonferroni correction. For data analysis we used SPSS, version 21.0 with an alpha error of 5% was considered.

Results

In all specimens, a septal vascular tree supplied the gluteus medius tendon. All specimens were adequate for the analysis.

The vascular density was not uniform when comparing the 3 zones. There were regional differences between all anatomic zones both in the transverse section (p<0.001) and the longitudinal section (p = 0.007) (Tab. I). Furthermore, a significant
difference was found between zone II (length of the tendon) and I (mean difference -23.45 IC95% -38.77 to -8.13, p<0.001) as well as between zones II and III (mean difference -26.08 IC95% -41.39 to -10.76 p<0.001) in transverse section. In the longitudinal sections, this difference was also found between zone II and zone I (mean difference -29.48 IC95% -51.54 to -7.43, p = 0.01), but not between zone II and zone III (mean difference -10.87 IC95% -3.29 to 11.18, p = 0.67) (Tab. II).

**Discussion**

This study suggests that the vessel density of the gluteus medius tendon is significantly lower within the central portion of the tendon compared to the other 2 regions, and therefore becomes the first evidence to support the presence of a critical zone in this tendon.

During development, tendons are highly cellular and metabolically active, and are thus supplied with a rich capillary network (11). Mature tendons, in contrast, are poorly vas-

**TABLE II** - Multiple comparisons between zones I, II and III (transverse and longitudinal section), bonferroni correction

<table>
<thead>
<tr>
<th>Section</th>
<th>Zone (A)</th>
<th>Zone (B)</th>
<th>Mean difference (A-B)</th>
<th>IC 95%</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse</td>
<td>Zone III</td>
<td>Zone I</td>
<td>2.63</td>
<td>-12.36</td>
<td>17.61</td>
</tr>
<tr>
<td></td>
<td>Zone II</td>
<td>Zone III</td>
<td>-2.63</td>
<td>-17.61</td>
<td>12.36</td>
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<tr>
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<td>Zone II</td>
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<td>-40.67</td>
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<td>Zone III</td>
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<td>-51.54</td>
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</table>

**Fig. 3 - Left:** Longitudinal section in the central portion of the tendon. Dense connective tissue formed by parallel fibres of collagen densely packed. Fusiform cells appear among collagen fibres. The connective tissue surrounding fibre bundles (endotenon) contains the capillaries. **Right:** Transversal section of the tendon on the musculotendinous junction. There are rounded fibre bundles with capillaries among them. Groups of muscle cells are mixed with bundles of collagen of the tendon. There are also adipocytes. Both images: hematoxylin-eosin, left x400, right x200.

**Fig. 4** - All vessels are stained in brown colour (CD31 staining). Specimens were examined at ×100 magnification (objective 10X, area of 2 mm²). The capillaries per mm² were counted in the best-vascularised area for each specimen. Red arrow: vessel stained with CD31.

**TABLE I - Global differences in vascular density between zones I, II and III (transverse and longitudinal section) -anova.**

<table>
<thead>
<tr>
<th>Section</th>
<th>Zone I</th>
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<th>Zone III</th>
<th>p value</th>
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<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Transverse (vessels/mm²)</td>
<td>77.6</td>
<td>9.9</td>
<td>54.1</td>
<td>14.4</td>
</tr>
<tr>
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<td>87.2</td>
<td>25.5</td>
<td>57.9</td>
<td>20.1</td>
</tr>
</tbody>
</table>
cularised (12). With vessels generally arranged longitudinally within the tendon, passing around the collagen fibre bundles within the endotenon (11, 13).

To date, there are no reported studies about the specific microvascular supply of the gluteus medius tendon. Most of the conclusions about this issue have been extrapolated from studies performed in the Achilles tendon, the rotator cuff of the shoulder, and even the flexor tendons of the hand implemented with traditional techniques for exploring vascularity (intravascular silicone or contrast medium) (10, 14-16). However, the microvascular supply cannot be explored with these techniques.

The immunohistochemistry with CD31 staining has been used before as a marker of angiogenesis in order to describe the neovascularisation of some neoplasms (17, 18). Jones et al reported an experimental study for assessing flexor tendon vascularity in a quantitative and qualitative manner using immunohistochemistry (19). Since CD31 was targeted with a specific monoclonal mouse-anti-human body they could see the total of vessel area per section. Additionally, they found an avascular zone between the A2 and A4 pulley (19). This study showed the CD31 staining as a useful technique for determining the vascular supply inside the tendon tissue.

Tendons such as the supraspinatus, biceps, Achilles, patella, and posterior tibials have known regions of reduced vascularity. These avascular zones are commonly associated with degeneration and rupture (12).

Although there is no direct evidence to suggest that hypovascularity is a primary cause of tendon rupture, considering the main importance of the vascular supply for the tissue vitality and healing process, this finding could have implications in the degeneration process and could affect the healing potential. Furthermore, any surgical technique involving dissection around the gluteus medius tendon should consider preservation of the central portion of the tendon since the healing potential is theoretically reduced (e.g. intramedullary nailing for hip or femur fractures, greater trochanter transfer, surgical dislocation of the hip, and hip replacements).

Some limitations have to be considered when interpreting the results. Immunohistochemistry with CD31 staining is a common marker used to explore the angiogenesis in some neoplasms, however this technique is novel to determine the vascular supply of tendinous structures. Furthermore, negative controls for non-specific CD31 binding were not included and no age comparison was performed.

Because of the limited availability of fresh cadavers we only included male patients. The age of all patients was very variable. These 2 factors (sex and age) could affect the analysis. However, we were very careful to include only patients with no known history of hip abnormalities.

Conclusion

The microvessel density is decreased in the length of the tendon (central portion) in comparison with the musculotendinous junction and the tendon-bone junction. This finding could have implications in the degeneration process and could affect the healing potential.

Disclosures

Financial support: None.
Conflict of interest: None.

References

The regional microvascular density of the gluteus medius tendon determined by immunohistochemistry with CD31 staining: a cadaveric study

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2 Baylor University Medical Center, Dallas, Texas - USA
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ABSTRACT

Background and Purpose: There are no studies to date about the vascularisation into the gluteus medius tendon. The purpose of this study was to define the microvessel density of the gluteus medius in 3 zones through a special staining with CD31 and to identify regional differences in microvascular density that may have implications for the healing.

Methods: We obtained 12 complete gluteus medius tendons from cadavers who had been an average age of 30.3 years old (range 18 to 55). All the donors were males with no known history of hip abnormalities. Following a rigorous protocol, each gluteus medius tendon was divided in 3 portions. Each gluteus medius tendon was divided in 3 portions: (I: musculotendinous, II: Tendon, III: Tendon-Bone junction).

Results: There were regional differences between all anatomic zones in both the transverse section (p<0.001) and the longitudinal section (p = 0.007). Furthermore, a significant difference was found between zones II and I (mean difference -23.45 IC95% -38.77 to -8.13, p<0.001) and between zones II and III (mean difference -26.08 IC95% -41.93 to -10.27, p<0.001) in transverse section. In longitudinal sections, this difference was found as well between zones II and III (mean difference -24.94 IC95% -51.54 to -7.43, p = 0.01), but not between zones II and III (mean difference -10.87 IC95% -32.93 to 11.18, p = 0.67).

Conclusions: The microvessel density was significantly lower in the length of the tendon (central portion) compared to the other 2 regions.

Keywords: Gluteus medius tendon, Microvascular density, CD31 staining

Introduction

The vascular supply of tendon is variable, the majority have 3 sources: 1) the musculotendinous junction; 2) the length of the tendon; and 3) the tendon-bone junction (1). Both the musculotendinous junction and the tendon-bone junction have vessels coming from muscular and periosteal arteries respectively. The main blood supply to the middle portion of the tendon is exclusively via the paratenon (2).

The ratio of blood supply from the intrinsic to extrinsic systems varies from tendon to tendon. For example, the central third of the rabbit Achilles tendon receives 35% of its blood supply from the extrinsic system (3). In the absence of a synovial sheath, the paratenon provides the extrinsic component of the vasculature. Vessels entering the paratenon course transversely, and branch repeatedly to form a complex vascular network (4).

Tendon vascularity is compromised at junctional zones and sites of torsion, friction or compression, a finding particularly notable in the tibialis posterior, supraspinatus, and achilles tendons demonstrated in cadaveric studies using intravascular injection of India ink-gelatin mixture (5, 6). In the Achilles tendon, angiographic injection techniques have demonstrated a zone of hypovascularity 2-7 cm proximal to the tendon insertion (7).

There is a characteristic vascular pattern with avascular zones identified in the rotator cuff tendons of the shoulder (6), and those conclusions could be analogically used...
for the gluteus medius tendon based on their similarities. Nevertheless, the anatomy, position, and biomechanics of the gluteus medius tendon is highly different (8) and no published studies to date have determined if there is a real hypovascular zone in the gluteus medius tendon.

On another hand, the studies about vascular supply of the tendons are mainly performed in the external vascular structures (e.g. angiography, etc.) (9, 10). But there are few studies to date about the vascularisation into the tendon through histological or immunohistochemical techniques.

The objective of this study was to determine the microvessel density into the gluteus medius tendon in 3 zones through a special staining with CD31 antibody in order to identify regional differences in microvascular density that may have implications for the healing.

Patients and Methods

In accordance with the ethical standards of the responsible committee on human experimentation and with the Helsinki Declaration, the Department of Pathology of the University of Antioquia in Medellin (Colombia) provided the specimens for this study. A pathologist supervised the selection and preparation of the cadavers.

A total of 12 complete gluteus medius tendons (including bone from the greater trochanter) from 12 fresh human cadavers with a mean age of 30.3 years old (range 18 to 55) were obtained through a postero-lateral approach (Fig. 1). All the donors were males with no known history of hip abnormalities. The samples were processed only if they came from cadavers without inflammatory or arthritic changes on gross inspection.

The entire gluteus medius tendon was dissected with its bone and muscle attachment, and all adipose tissue was carefully removed. Then, each sample was divided in 3 similar transverse portions as follows: the musculotendinous junction (zone I), the length of the tendon (zone II), and the tendon-bone junction (zone III). Then, from each transverse section a longitudinal portion from each zone was obtained as well (Fig. 2).

Each specimen was immersion-fixed in 10% formalin for 24 hours, and paraffin-embedded. 4 μm thick sections were stained with hematoxylin-eosin. The vessels were detected by immunohistochemistry (IHC) using a commercial antibody against the endothelial antigen CD31 (PECAM-1 Ab-6, clone 1A10, Thermo Fisher Scientific, Fremont, CA, USA; 1:100 dilution, 40-min incubation). The reason for choosing this immunohistochemistry technique was the aim to provide a real data about the vascular supply inside the tendon.

For IHC labelling, each section (4 μm) was deparaffinised in xylene during 30 minutes and rehydrated by using graded ethanol concentrations. Endogenous peroxidase activity was blocked with hydrogen peroxide. Antigen retrieval was carried out by the steam tris buffer EDTA (ethylene-diamine-tetra-acetic acid) treatment, pH 7.0 (30 minutes). The detection system used was polymer-based (UltraVision Quanto, Thermo Fisher Scientific, Fremont, CA, USA).

Specimens were examined at x400 and x200 with H&E staining (Fig. 3) and at x100 magnification (objective 10X) with CD31 standing, every powered field at x100 meaning an area of 2 mm². The capillaries per mm² were counted for each specimen (only including the tendon itself and sepal structures) (Fig. 4).

Microvessel was defined as any blood vessel that average less than 0.3 mm in diameter. The comparison of the microvessel density between zones I, II and III (transverse and longitudinal) was performed using an Analysis of Variance (ANOVA). Furthermore, a multiple comparison between groups was performed using a Bonferroni correction. For data analysis we used SPSS, version 21.0 with an alpha error of 5% was considered.

Results

In all specimens, a septal vascular tree supplied the gluteus medius tendon. All specimens were adequate for the analysis.

The vascular density was not uniform when comparing the 3 zones. There were regional differences between all anatomic zones both in the transverse section (p<0.001) and the longitudinal section (p = 0.007) (Tab. I). Furthermore, a significant
difference was found between zone II (length of the tendon) and I (mean difference -23.45 IC95% -38.77 to -8.13, p<0.001) as well as between zones II and III (mean difference -26.08 IC95% -41.39 to -10.76 p<0.001) in transverse section. In the longitudinal sections, this difference was also found between zone II and zone I (mean difference -29.48 IC95% -51.54 to -7.43, p = 0.01), but not between zone II and zone III (mean difference -10.87 IC95% -32.93 to 11.18, p = 0.67) (Tab. II).

**Discussion**

This study suggests that the vessel density of the gluteus medius tendon is significantly lower within the central portion of the tendon compared to the other 2 regions, and therefore becomes the first evidence to support the presence of a critical zone in this tendon.

During development, tendons are highly cellular and metabolically active, and are thus supplied with a rich capillary network (11). Mature tendons, in contrast, are poorly vas-
cularised (12). With vessels generally arranged longitudinally within the tendon, passing around the collagen fibre bundles within the endotenon (11, 13).

To date, there are no reported studies about the specific microvascular supply of the gluteus medius tendon. Most of the conclusions about this issue have been extrapolated from studies performed in the Achilles tendon, the rotator cuff of the shoulder, and even the flexor tendons of the hand implemented with traditional techniques for exploring vascularity (intravascular silicone or contrast medium) (10, 14-16). However, the microvascular supply cannot be explored with these techniques.

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Tendons such as the supraspinatus, biceps, Achilles, patella, and posterior tibials have known regions of reduced vascularity. These avascular zones are commonly associated with degeneration and rupture (12).

Although there is no direct evidence to suggest that hypovascularity is a primary cause of tendon rupture, considering the main importance of the vascular supply for the tissue vitality and healing process, this finding could have implications in the degeneration process and could affect the healing potential. Furthermore, any surgical technique involving dissection around the gluteus medius tendon should consider preservation of the central portion of the tendon since the healing potential is theoretically reduced (e.g. intramedullary nailing for hip or femur fractures, greater trochanter transfer, surgical dislocation of the hip, and hip replacements).

Some limitations have to be considered when interpreting the results. Immunohistochemistry with CD31 staining is a common marker used to explore the angiogenesis in some neoplasms, however this technique is novel to determine the vascular supply of tendinous structures. Furthermore, negative controls for non-specific CD31 binding were not included and no age comparison was performed.

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Conclusion

The microvessel density is decreased in the length of the tendon (central portion) in comparison with the musculotendinous junction and the tendon-bone junction. This finding could have implications in the degeneration process and could affect the healing potential.

Disclosures

Financial support: None.
Conflict of interest: None.

References

Validity of Dynamic Impingement Testing for Determining the Location of Femoroacetabular Impingement: A Cadaveric Study

Benjamin R Kivlan, Ryan McGovern, RobRoy L Martin and Hal D Martin

Abstract

Reason

The purpose of this study was to assess the validity of the Dynamic Internal Rotation Impingement and Dynamic External Rotation Impingement tests by describing the point of contact of the femoral neck on specific zones of the acetabular labrum with respect to hip flexion angle.

Methods

The labrum of 26 hip joints from 14 embalmed cadavers (7 male; 7 female) were skeletonized and marked into 5 zones: Zone 1 – anterior-inferior, Zone 2 – anterior-superior, Zone 3 – superior, Zone 4 – posterior-superior, Zone 5 – posterior-inferior. The angle of hip flexion when the femoral neck was in contact with each respective zone was recorded while performing dynamic impingement testing. The version and inclination angles were measured to describe the orientation of the acetabulum and proximal aspect of the femur. The mean, standard deviation, and range of hip flexion angles at the initial contact and end contact of each respective zone were computed.

Results

The Dynamic Internal Rotation Impingement test contacted zones 1, 2, and 3 of the labrum. Contact with the anterior-inferior labrum (Zone 1) occurred in less than 56° of hip flexion, while contact with the anterior-superior labrum (Zone 2) occurred between 56° – 101°. Zone 3 was contacted in end-range flexion (101°-106°). The Dynamic External Rotation Impingement test contacted zones 3, 4, and 5. Contact with the posterior-superior portion (Zone 4) of the labrum to the femoral neck occurred between an arc of motion of 106° to 15° flexion. The posterior-inferior portion (Zone 5) of the labrum contacted the femoral neck as the hip joint was moved towards midline through an arc of 15-47° flexion.

Conclusions

This current study demonstrated that the Dynamic Internal Rotation Impingement and Dynamic External Rotation Impingement tests were able to establish contact of the femoral neck along the entire labrum and that a specific zone of contact can be estimated based on the degree of hip flexion. The results of the study offer evidence of validity for the dynamic impingements tests and may set the groundwork for future studies that aide in the clinical development of an evidence-based evaluation of the hip joint.

Key Words: Femoroacetabular Impingement; Labral Tear; Clinical Examination; Special Test; Non-arthritic Hip Pain

List of Abbreviations: Femoroacetabular Impingement (FAI); Magnetic Resonance Arthrography (MRA); The Dynamic Internal Rotation Impingement (DIRI); The Dynamic External Rotation Impingement (DEXRI)

Introduction

Despite the increased frequency of diagnosis, the clinical assessment of femoroacetabular impingement (FAI) and acetabular labral tears has proven to be challenging [1,2]. While many clinical tests have been developed to assess for intra-articular pathology, there is limited evidence to support their usefulness [3,4]. Evidence to support the use of a clinical test that not only potentially identifies the presence of a labral tear but also the location of the tear could prove valuable.

Due to the limited accuracy of clinical examination, magnetic resonance arthrography (MRA) has become the most accepted method for identification and diagnosis of acetabular labral pathologies [4,5]. However, MRA is not as accurate in identifying potential pathology as compared to hip arthroscopy [6] and is an expensive procedure. Current clinical tests for identifying FAI and acetabular labral tears have been shown to have a good sensitivity but poor specificity [3]. Clinical tests evaluating the entire surface of the acetabular labrum need to be validated in order to improve the quality of clinical diagnosis.
Martin and Palmer [7], have introduced a standardized clinical evaluation protocol to evaluate patients with non-arthritic hip pain that includes dynamic impingement tests. The Dynamic Internal Rotation Impingement (DIRI) test was derived to assess the integrity of the anterior aspect of the acetabular labrum [7]. The Dynamic External Rotation Impingement (DEXRI) test was derived to assess the integrity of the superolateral and posterior aspect of the acetabular labrum [7]. While both of these tests have been described to evaluate for the presence of labral pathology along the entire acetabular rim, the specific location of femoral contact on the acetabulum labrum has not been assessed for validity.

The ability of physicians to accurately describe the location of intra-articular lesions is necessary for uniformity of treatment. To aide surgeons in consistently and accurately identifying the location of intra-articular pathology during hip arthroscopy, Ilizaliturri [8] divided the acetabulum into 6 specific zones: Zone 1 - the anterior-inferior; Zone 2 - the anterior-superior; Zone 3 - the central superior; Zone 4 - the posterior-superior; Zone 5 - the posterior-inferior; and Zone 6 - the acetabular fossa (Figure 1). The use of these acetabular zones in regards to clinical testing for assessment of labral pathology has yet to be evaluated. The purpose of this study was to assess the validity of the Dynamic Internal Rotation Impingement and Dynamic External Rotation Impingement tests by describing the point of contact of the femoral neck on specific zones of the acetabular labrum with respect to the position of the hip flexion angle during dynamic impingement tests.

**Methods**

**Cadaver Preparation**

Twenty-six hips from 14 embalmed cadavers (7 male; 7 female) with a lifespan ranging between 51-95 years were used for this study. There were two hips that were excluded from the study due to profound osteoarthritic changes that included full thickness articular lesions on the femoral head and acetabulum. The pelvic region of each cadaver was skeletonized and the labrum divided into 5 equal zones: Zone 1 – anterior-inferior, Zone 2 – anterior-superior, Zone 3 – the central superior, Zone 4 – posterior-superior, Zone 5 – posterior-inferior [8]. To standardize the zones on the cadavers, two vertical lines were projected from the anterior and posterior limits of the acetabular fossa [8]. A horizontal line was then projected at the superior limit of the acetabular fossa [8]. The acetabular labrum was demarcated with color to define the boundaries of each respective zone as shown in Figure 1. The femoral neck was then standardized in quadrants with a vertical and a horizontal line passing through the midpoint of the femoral neck. The quadrants were marked with colored nail polish and designated as the following: Quadrant 1- anterior-inferior, Quadrant 2- anterior-superior, Quadrant 3 – posterior-superior, Quadrant 4 –posterior-inferior. This study was approved by the ethics committee for anatomical studies of the Rangos School of Health Sciences at Duquesne University.

**Dynamic Impingement Testing**

Once the zones of the labrum and the quadrants of the femoral neck were determined, the dynamic impingement tests were performed. The DIRI test was initiated from the anatomical position with the cadaver secured to a plinth in a supine position. The femur was then moved through a wide arc of flexion, adduction, and internal rotation while maintaining contact of the femoral neck to the labrum until the hip joint reached maximum flexion (Figure 2). The DEXRI test began with the hip joint in maximal flexion and moved passively through an arc of extension, abduction, and external rotation while maintaining contact of the femoral neck to the labrum (Figure 3). The position of hip flexion when the femoral neck initiated contact with each respective zone is shown in Figure 4.
and ended contact with each respective zone of the acetabulum was then recorded using a standard 12-inch goniometer (Baseline® Goniometer, Fabrication Enterprises Inc. White Plains, NY) to describe the arc of motion in the sagittal plane in which the DIRI and DEXRI tests were in contact with each specific zone of the labrum.

**Version and Inclination Angles**

The version and inclination angles were measured using a standard 12-inch goniometer (Baseline’ Goniometer, Fabrication Enterprises Inc. White Plains, NY) to describe the orientation of the acetabulum and proximal aspect of the femur. Acetabular version was determined by the angle formed by the sagittal plane and a line formed by connecting the midpoint of the anterior and the posterior acetabular rim. Femoral version was determined as the angle formed by a line bisecting the femoral head/neck and a line parallel to the posterior aspect of the femoral condyles. Femoral inclination was determined as the angle between a line bisecting the femoral neck relative to a line bisecting the femoral shaft.

**Statistical Analysis**

All data was analyzed using a common statistical software system (SPSS Version 21, Chicago IL). The mean, standard deviation, and range of hip flexion angles at the initial contact and end contact of each respective zone were computed during the DIRI and DEXRI tests. The mean, standard deviation, and range were also determined for the angles of inclination and version for the femur and acetabulum.

**Results**

**Descriptive Measures of the Specimens**

A description of the femoral and acetabular version and inclination angles of each cadaver are reported in Table 1. The mean version angle of the acetabulum was 26° anteversion (SD:6°) and 10° anteversion(SD:7°) for the femur. The mean angle of inclination for the femur was 120°(SD:6°).

<table>
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</table>
Dynamic Impingement Testing

The DIRI test contacted zones 1, 2, and 3 of the labrum with the anterior-superior quadrant of the femoral neck. Contact with the anterior-inferior labrum (Zone 1) occurred in less than 56° of hip flexion, while contact with the anterior-superior labrum (Zone 2) occurred between 56° – 101°. Contact in Zone 3 occurred between near end range flexion (101°-106°). The DEXRI test contacted zones 3-4 with the posterior-superior quadrant of the femoral neck. Contact with the posterior-superior portion (Zone 4) of the labrum to the femoral neck occurred between an arc of motion of 106° to 15° flexion. The posterior-inferior portion (Zone 5) of the labrum contacted the posterior-inferior quadrant of the femoral neck as the hip joint was moved towards midline and back into flexion through an arc of 15°-47° flexion. Table 2 shows the mean, standard deviation, and the range of values for each respective zone.

Discussion

This current study demonstrated that the DIRI and DEXRI tests contacted the femoral neck along the entire circumference of the labrum and that a specific zone of contact can be estimated based on the degree of hip flexion (Figure 4). During the DIRI test, contact of the anterior-superior quadrant of the femoral neck was maintained along the entire anterior to central superior aspect of the labrum. The DIRI test contacted Zone 1 with less than 56° of hip flexion, while Zone 2 was contacted from 57° to 101°, and Zone 3 near end-range flexion (101°-106°). The DEXRI test contacted Zones 3, 4 and 5 at the central superior, posterior-superior, and posterior-inferior aspect of the labrum. The DEXRI test began with contact of the posterior-superior quadrant of the femoral neck to the superior aspect of the acetabulum (Zone 3) at end range of flexion. The posterior-superior quadrant continued contact with the labrum through Zone 4 with an arc of motion of 106° to 47° flexion, and Zone 5 as the hip joint was moved towards midline and back into flexion through an arc of 15°-47° flexion.

Figure 4: Contact of the Femoral Neck to the Acetabular Rim During Dynamic Impingement Tests.

![Figure 4](image)

Table 2: Mean, standard deviation, and the range of values for hip flexion angle during initial and end contact of each respective zone.

<table>
<thead>
<tr>
<th>Zone 1</th>
<th>Zone 2</th>
<th>Zone 3</th>
<th>Zone 4</th>
<th>Zone 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Contact</td>
<td>End Contact</td>
<td>Initial Contact</td>
<td>End Contact</td>
<td>Initial Contact</td>
</tr>
<tr>
<td>Mean</td>
<td>16°</td>
<td>56°</td>
<td>101°</td>
<td>106°</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>7°</td>
<td>10°</td>
<td>10°</td>
<td>7°</td>
</tr>
<tr>
<td>Range</td>
<td>5-30°</td>
<td>29-71°</td>
<td>78-117°</td>
<td>94-121°</td>
</tr>
</tbody>
</table>
flexion through an arc of 15-47° flexion. This study offers evidence of validity for the DIRI and DEXRI tests in the clinical examination of individuals with FAI and a suspected labral tear.

Ganz et al. [9] first introduced the concept of combined movements of hip flexion, adduction, and internal rotation to elicit contact with the labrum for individuals with suspected FAI. Several researchers since then have studied the combined movements of hip flexion and rotation to elicit symptoms of labral pathology [10-19]. McCarthy et al. [20] recommended dynamic component of the hip assessment by moving the hip joint through an arc of motion similar to specific activities that exacerbate symptoms. While there is limited evidence of validity for the current clinical exam tests of the hip, [4] the studies that have been performed are primarily compared to the results of diagnostic imaging or arthroscopy. This is the first study to use cadaveric specimens to describe the specific zones in which the femur contacts the acetabular labrum during dynamic impingement testing. The results validate use of these positions to produce contact within zones of the labrum that may be applied clinically to elicit symptoms associated with labral pathologies. Further, the results offer new information to clinicians that may help to identify the specific location of labral pathology by noting the position of hip flexion during the DIRI and DEXRI tests. With this knowledge and a thorough history of symptoms, the clinician can be more efficient in differentiating possible labral injuries with other intra-articular pathologies. This study sets the foundation of future clinical investigations that may determine if the DIRI and DEXRI tests can predict location of pathology. Future research is needed to compare the clinical results of the DIRI and DEXRI test with MRA and surgical findings.

While this study provides useful information that can help in the clinical discrimination of intra-articular labral pathologies, there are limitations to this study that need consideration. First, the clock face description is an alternative method to define the location of intra-articular pathology [21]. However, we felt the zone method was more appropriate for this study to describe a range in which the labrum was contacted by the femoral neck. The use of cadaveric models limits the generalizability of the results to living subjects. The removal of the surrounding soft tissue structures of the pelvis may have changed the native mechanics of the hip joint and altered the absolute values of hip flexion when contact occurred in each respective zone. The sample size for this project was also limited by the number of available specimens. Two of the hips had severe degeneration and were excluded from analysis. While the analysis of 26 hip joints may be considered small in a clinical study, anatomical studies regularly have rather small sample sizes. The smaller sample size limits the generalizability of a more diverse population. Further, we cannot be certain the contact that occurs between the femur and acetabulum induces symptoms. The use of cadaver specimens provides a reliable anatomical model, but cannot account for the perception of symptoms by a living human subject. The age of the specimens must also be considered. There may have been age-related changes of the hip joint structures that could have changed the contact patterns we observed. Two hip joints demonstrated advanced osteoarthritic changes of the articular surfaces and were excluded from the study. One must also take into consideration the morphology of the proximal hip structures. We noted a wide distribution of values for the version and inclination angles of the femur and acetabulum. This may explain the relatively large standard deviations computed for flexion angles respective to each zone. A trend was noted in our data that showed decreased femoral anteversion resulted in less flexion angles to contact the respective zones. Future studies may investigate the influence of femoral and acetabular version and inclination on the specific zones of contact during dynamic impingement testing. Other morphologic measures such as alpha angle, acetabular angle, femoral offset, Tonnis angle, and center edge angles could offer additional information about the position of the hip joint when the specific zones of the labrum are contacted. Although it was beyond the scope of our study, the use of three-dimensional assessment tools may account for individual variability in the morphology of individual specimens. Future studies may consider applying the results of the current study to three-dimensional assessment of human subjects in vivo to determine the position of the hip joint when the specific zones of labrum are contacted during dynamic impingement testing.

Conclusions

This current study demonstrated that the Dynamic Internal Rotation Impingement and Dynamic External Rotation Impingement tests contacted the femoral neck along the circumference of the labrum and that a specific zone of contact can be estimated based on the degree of hip flexion. The results of the study offer evidence of validity for the dynamic impingements tests and may set the groundwork for future studies that aide in the clinical development of an evidence-based evaluation of the hip joint.

Authors Contributions

BRK- conception and design, acquisition of data, analysis of data, interpretation of data, drafting and revising the manuscript, final approval of version to be published, and agree to be accountable for all aspect of work.

RPM- drafting and revising the manuscript, final approval of version to be published, and agree to be accountable for all aspect of work.

HDM-drafting and revising the manuscript, final approval of version to be published, and agree to be accountable for all aspect of work.

RLM- conception and design, acquisition of data, analysis of data, interpretation of data, drafting and revising the manuscript, final approval of version to be published, and agree to be accountable for all aspect of work.
References


