Current Concepts in the Treatment of ACL Injuries

Surgery & Rehabilitation

Kevin E. Wilk, PT, DPT

ACL Rehabilitation

Goals of Presentation:

- Discuss rehab protocol following ACL reconstruction utilizing various grafts
- Describe rehab program when concurrent injuries/surgeries are present
- Provide scientific evidence & clinical expertise for the rehab program
- Discuss “best treatment approach”

ACL INJURIES

Introduction

- ACL injuries common in sports & strenuous work
  - So frequent that the seriousness is often forgotten
- Totally disrupted more than any other knee ligament
- 200,000 ACL injuries annually
  - Fu, AJSM ‘99
- 100,000 ACL surgeries
  - Harner, Arthroscopy ‘04
- Rehab has changed in the past 10 yrs

Science to Rehabilitation

Knee Homeostasis
ACL INJURIES

Introduction

• 35 out of 100,000 people
  Walden et al: Knee Surg Spots Trauma Arthro ‘10
• Females are 4-6 times higher risk of ACL injury
  → ACL outcomes (IKDC scores) 61-67 of 100
  Biau et al: CORR ‘07
  → 40-90% of ACL patients exhibit radiographic knee OA 7-12 yrs following surgery
  Pinczewski et al: AJSM ‘07
  → Liden et al: Arthroscopy ‘08
  → 10x greater rate OA in ACL injured knee
  Fleming et al: JOSPT ‘03

• Over 200,000 ACL injuries annually
  → 62-66% sports related, usually non-contact – 70%
  → Over 60% in males
  → 67% occurs in individuals 15-29 yrs of age
  → 26% occurs in 30-44 yrs
  → 7% occurs in individuals above 45 yrs of age

ACL Injuries

Introduction

• ACL injuries common in sports & strenuous work
  → So frequent that the seriousness is often forgotten
• Totally disrupted more than any other knee ligament
• 200,000 ACL injuries
• Approximately one injury per 3,000 people per year
• 100,000 ACL surgeries annually

Brophy, Gill, Lyman, et al: AJSM ‘09

• Effect of ACL Reconstruction &/or Meniscectomy on length of career in NFL
• 54 athletes with meniscectomy alone
• 29 ACL reconstruction
• 11 both ACL recon & partial meniscectomy
• History of an isolated meniscectomy not isolated ACL reconstruction shortens career
• Combination (ACL & Meniscus) was most detrimental (~2yrs)

Carey et al: AJSM ‘06

• Effects of ACL injury on running backs & wide receivers in the NFL players (N=33)
  → 80% returned to NFL play
  → Performance of those returning – performance was reduced by 1/3

Shah, Andrews, Fleisig, Lemak: AJSM ‘10

• 49 NFL players underwent ACL/PTG
  → 63% returned to NFL play (31/49)
  → Average length of time to return 10.8 mos
• Age, position & number of procedures not a factor in return rate
• Players who had more than 4 yrs of experience higher rate of return
• Players drafted in first 4 rounds – higher rate of return to play
Return to Sports

After ACL Reconstruction:
- Systematic review of 48 studies reporting return to sports of 5770 individuals after ACL reconstruction at mean follow-up of 41.5 months

<table>
<thead>
<tr>
<th>Return to Sports</th>
<th>82% (95% CI 73 to 90%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Return to Some Form of Sports</td>
<td>63% (95% CI 54 to 71%)</td>
</tr>
<tr>
<td>Return to Competitive Sports</td>
<td>44% (95% CI 34 to 56%)</td>
</tr>
</tbody>
</table>

Ardern et al: BJSM 2011

Reasons for reduced sports participation for those that did not return to prior level:
- Fear of re-injury (19%)
- Problems with structure/function of knee (13%)
- Family commitments or lifestyle changes (11%)

Ardern, BJSM: 2011

Return to Play after ACL Surgery

Overview
- Arden et al: AJSM ’11
  - at 12 months only 1/3 were back to pre-injury level
  - Meta-analysis of 48 studies & 5,770 patients
  - 63% returned to pre-injury level
  - 44% returned to competitive sports

Arden et al: AJSM ’11
- Re-injury rates range from 3 to 49%
- Systematic review of 12 studies
- Re-injury rates of the reconstructed ACL ranged from 0 to 24%
- Injury to the contra-lateral knee ranged from 2-15%

Barber-Westin, Noyes: Phys Sportsmed ’11

Re-Injury Rates
- Paterno, Rauh, et al: AOSSM ’13
  - ACL reinjury rate following ACLR
  - 78 subjects underwent ACLR – return to sports
  - 15x greater 2nd ACL in subjects with ACLR if they return to sports during the first year
  - 6x greater 2nd ACL injury in subjects returning to sports within 12-24 mos
  - Females ACLR 4x greater rate of injury 24 mos.
  - 2x more likely to tear opposite knee ACL
  - 30% athletes sustained 2nd ACL inj – 21% on contralateral side 9% opposite side

Frobell et al: NEJM ’10
- Randomized trial of treatment for acute ACL tears
- 121 young adults, acute ACL injury
- Randomized into 2 groups:
  - Structured rehab & early ACL reconstruction (n=62)
  - Structured rehab & with option of delayed rehab (59)
- Of the 59 in delayed surgery, 23 underwent surgery
- 36 Rx with rehabilitation
- Conclusion: “a strategy of rehab plus early reconstruction was not superior to delayed surgery”
Return to Play after ACL Surgery

**Overview**

*Arden et al: AJSM ’11*
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*Arden et al: Br J Sports Med ’11*
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**Mechanisms of ACL Injuries**

*Not an Isolated Injury!!*
ACL Injuries

• Not an isolated injury
  » Meniscus injury
    55-65% incidence
    Lohmander: AJSM ’07
    Noyes: JBJS ’83
    Tandogan: Knee Surg ’04

Brophy et al: AJSM ’12

• Association between previous meniscal surgery & incidence of chondral lesions at revision ACL reconstruction
• MARS Group
  • 725 revision surgeries
    ✓ Knees with previous partial meniscectomy were more likely to have chondrosis
    ✓ Knees with meniscus repair no association

ACL Injuries

• Not an isolated injury
  » Collateral ligament injury
    Noyes: JBJS ’80
    41% minor sprains
    21% major sprains
    MCL sprains more common

ACL Injuries

• Not an isolated injury
  » Bone bruises present 71-91% patients
    Spindler: AJSM ’93
    Rosen: Arthroscopy ’91
    Graf: AJSM ’93
    Johnson: AJSM ’98
    ✓ 65% exhibited marrow changes & cartilage thinning 6 yrs after ACL injury
    Faber: AJSM ’99
ACL Injuries

- Not an isolated injury
  - Injury affects both extremities
  - For at least 3.6 mos
    Wilk, et al: CSM ’03
  - Alters firing mechanism
    Wojtys, Huston: AJSM ’94

Potter, Jain, Ma, et al: AJSM ’12

- 42 knees in 40 patients (28 ACLR, 14 non-op)
- MRI at time of initial injury then annually for a maximum of 11 yrs
  All patients sustained initial chondral injury
  Risk of cartilage loss doubled from yr 1 for the lateral & medial compartment & 3x for patella
  By 7 to 11 yrs: LFC 20x, MFC 19x, & patella 30x
  Size of the bone bruise associated to degeneration from yr 1 to yr 3

ACL Injuries

- Not an isolated injury
  Injury affects mechanoreceptors
  - Within 24 hrs after injury
    Lephart, AOSSM ’97
  - Deficits may last 6 yrs or more
    Denti: Knee Surg Spots Trauma ’80
  - “Quadriceps avoidance gait”
    Andriacchi: CORR ’94
    Berchuck: JBJS ’90

ACL Injury Effects Muscle & NM Control

ACL Injuries

- Not an isolated injury
  - Injury affects both extremities
  - Quadriceps weakness & activation failure following ACL injury &/or reconstruction bilaterally
    Hart et al: J Athletic Trn ’10
    Chmielewski: J Orthop Res ’04
    Hurley: Muscle Nerve ’05
    Hurley: Clin Sci ’94
ACL Injuries in the Female Athlete

• Females appear to be more susceptible than males
  - Chandy (HS sports) 4.6 : 1
  - Arendt (coll. sports) 4 : 1
  - Malone (basketball) 8 : 1
  - Lindenfeld (soccer) 6 : 1
  - Ferratti (volleyball) 4 : 1
  - McFarland (USNA) 10 : 1
  - Viola (skiing) 1.4 : 1

ACL Injuries in Female Athletes

Risk Factors

What affects injury rates???

8 Specific Risk Factors:

- Increased Knee Abduction angles - valgus
- Decreased Knee flexion angles – “Q dominant”
- Increased generalized laxity
- Decreased H/Q ratios
- Smaller intercondylar notch
- Running, cutting & landing from jumps
- Lateral trunk displacement
- Hormonal changes

ACL Reconstruction Surgery
ACL Reconstruction

Overview

• Common procedure
• 100,000 ACL reconstructions annually
• 85% of all ACL reconstruction performed by Orthopaedists who perform less than 10/yr

ACL REHABILITATION

Rehab Program Changes Based on Surgery

✓ Graft
  » PTG, STG, QTG
✓ Meniscus
  » Repair, excised
✓ Articular Cartilage
  » Debride, procedure, bone bruise
✓ Other ligaments
  » MCL, PCL, PL, corner, LCL

ACL Reconstruction Surgery

Graft Options

✓ Autogenous
✓ Allograft
✓ Prosthetics/Synthetics
✓ Bio-prosthetics

Gortex Grafts

ACL Reconstruction

Allografts

✓ Tissue type
  ✓ BTB
  ✓ Achilles
  ✓ Tibialis anterior
  ✓ Tibialis posterior
  ✓ Fascia lata
ACL Reconstruction

Allografts

- Advantages – Disadvantages
  - Good Points: +
    - No donor site morbidity
    - Graft size
  - Negative Points: -
    - Disease transmission & infection
    - HIV transmission 1:8 million
    - Infection (’93) 26 in 1 million
    - Cost $$$
    - Graft incorporation slower
    - Jackson, Grood, et al: AJSM ’93
  - Preservation: cryopreserved, fresh-frozen & freeze dried

Pallis et al: AJSM 2012

- Survival comparison of allografts vs autografts in ACL reconstruction in the US Military Academy
- Members of classes 2007-2013
- 122 ACL reconstructions in 120 cadets (2 bilateral)
  - 61 ACL/PTG
  - 45 ACL/STG
  - 16 allografts
- 20 failures occurred
  - 7 ACL/PTG 11%
  - 7 Allografts 44%
  - 6 ACL/STG 13%
- Allografts 7.7x more likely to experience graft failure

ACL Reconstruction

Allografts

- Foster et al: AJSM 2010

Failed Achilles Allograft 364 days from implant
**ACL Reconstruction**

**Quad Tendon Graft**

<table>
<thead>
<tr>
<th>Ultimate Load to Failure &amp; Stiffness of ACL Grafts</th>
<th>Ultimate Strength to Failure</th>
<th>Stiffness</th>
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<tbody>
<tr>
<td>Native ACL</td>
<td>2160 N</td>
<td>242 N/mm</td>
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<tr>
<td>Noyes et al: JBJS '84</td>
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</tr>
<tr>
<td>Native PCL</td>
<td>2867 N</td>
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</tr>
<tr>
<td>Patellar Tendon Graft</td>
<td>2977 N</td>
<td>455 N/mm</td>
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<td>Cooper et al: AJSM '93</td>
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<tr>
<td>Quadrupled STG</td>
<td>4090 N</td>
<td>776 N/mm</td>
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<td>Hamner et al: JBJS '99</td>
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<tr>
<td>Quad Tendon Graft</td>
<td>2174 N</td>
<td>463 N/mm</td>
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<td>Staubli et al: AJSM '99</td>
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<tr>
<td>Achilles Tendon Graft</td>
<td>4617N</td>
<td>685 N/mm</td>
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<tr>
<td>Wren et al: Clin Biomech '01</td>
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</table>
**ACL Reconstruction**

**Double Bundle Reconstruction**

- Fu FH – AJSM ‘08
  - Purports more normal kinematics
  - More closely reproduces the normal ACL anatomy
  - Technically feasible
  - Long term study required

_Aglietti et al: AJSM ’09_

**ACL Reconstruction**

**Double Bundle vs. Single Bundle**

- 16 prospective clinical outcome studies comparing SB v DB
  - Aglietti et al: AJSM ’10
  - Jarvela et al: AJSM ‘08
  - Muneta et al: Arthroscopy ‘06
- 10 randomized clinical trials
  - Adachi et al: JBJS ’04
  - Aglietti et al: AJSM ’10
  - Siebold et al: Arthroscopy ’08
- What do the results indicate??

_Aglietti et al: AJSM 2010_

- Prospective comparison between single & double bundle ACL Reconstruction
- 70 patients with chronic ACL rupture
- 2 year follow-up
- Outcomes: stability failures: 1(DB) 3 (SB)
- KT 1000 results: DB 1.2mm v 2.1mm (sign diff)
- Pivot shift results: 14% DB, 26% SB

**Suomalainen, ...Kannus: AJSM’11**

- 153 patients prospectively randomized into 1 of 2 groups:
  - SB group: n=78
  - DB group: n=75
- 2 yr follow-up: (KT1000, IKDC, Lysholm, MRI, & clinical exam) 90%
  - F/U (n=138)
- Revision surgery: SB=7, DB=1
- MRI findings: failures &/or invisible grafts: SB=12, DB=3

**ACL Reconstruction**

**Graft Placement**

- Number 1 cause of revision surgery
- Meticulous attention to femoral placement
  - Posterior
    - 6 mm anterior to posterior cortex
    - Notch side wall
    - 1:30 / 10:30 position
ACL Reconstruction

Graft Fixation

• “The weakest link”
  » First 6-12 weeks

West & Harner. JAAOS '05

ACL Reconstruction

Graft Tensioning

• What is the knee position when the graft is tensioned:
  • Flexed position 30 deg ?
  • Flexed to 20 deg ?
  • Flexed to 90 deg ?
  • Full extension ?
  • How much tension ?

Does this matter ???

ACL Reconstruction

Graft Tensioning

• Tension the graft at 20 degrees
• Graft tension of 44 N is best
PRINCIPLES OF ACL REHAB

Healing Constraints

• Revascularization
  » BTB: 6-8 weeks
    Clancy et al: JBJS ’81
  » STG: 8-12 weeks
    Rodos et al: JBJS ’93
• Graft strength
• Graft maturation

Autograft ——— Allograft

Graft Incorporation: Ligamentization

Mauromo et al. AJSM 2005

» Biopsy study, 50 patients
» Similar biochemical / histology @ 12 mos

I. Inflammatory Response (first 1-2 months)
- Inflammatory response, cell death remaining collagenous tissue becomes a scaffold

II. Revascularization Phase (within 20 days till 6 mos)
- Graft maturation, graft strength decreases sign.

III. Graft Maturation (till 12-18 months)
- Maturation & remodeling
  Clancy et al: JBJS ’81  Jackson et al: CORR ’96

Graft Incorporation: Ligamentization

ACL REHABILITATION

Rehab Program Changes Based on Surgery

• Graft
  » PTG, STG, QTG
• Meniscus
  » Repair, excised
• Articular Cartilage
  » Debride, procedure, bone bruise
• Other ligaments
  » MCL, PCL, PL corner, LCL
ACL Reconstruction

Notchplasty

Drilling Tunnels

Passing PTG

PTG

Tibial Fixation

Femoral Fixation - Bioscrew
ACL Reconstruction

Skeletal Immature Patients

- Midsubstance ACL tears in skeletally immature athletes exist (10-65% knees with hemarthroses)
  - Stanitski: AJSM '98
- Controversy exists in management of these lesions
- Non-op results poor
  - Graf et al.: Arthroscopy '92
- Girls grow until 14+1 yrs
- Boys grow until 16+1 yrs
  - Anderson JBJS '64
- Physiologic development (Tanner Stage)
  - Tanner et al.: J Pediatr '85

ACL Reconstruction

Double Bundle - Video

- Physeal Sparing Tech
  - Brief: Arthroscopy '91
- Transepiphyseal Reconstruction
  - Anderson et al.: JBJS '03

ACL Reconstruction

Skeletal Immature Patients

- Partial Tranphyseal Technique
  - Andrews M. Noyes: AJSM '94
- Tranphyseal Tech
  - Aromowitz: AJSM '00
  - Shelbourne: AJSM '04
ACL Reconstruction

**Graft Options**
- Autogenous
- Allograft
- Prosthetics / Synthetics
- Bio-prosthetics

**ACL REHABILITATION**

**Surgical Variables**
- **Graft source:** STG
- **PTG:** accelerated — regular
- **STG:** soft tissue - bone healing
  - No accelerated rehab approach
  - No hamstring strengthening 4wks
  - Isometrics: week 5-6
  - Isotonics: week 6-8 (light)
  - No running for 3mos, no jumping till 12-14 wks, return to sports 6 mos

Rodeo, Arnoczky, Torzilli, et al: JBJS '93

**Accelerated Rehabilitation Applied to STG Graft**
- **Aglietti, et al:** AJSM '94
  - 60/63, follow-up 28 mos
  - PTG 47%, STG 60% (3.5mm+)
- **Aglietti, et al:** Knee Surg Sports Trauma '95
  - 50 patients, follow-up 14 months
  - 48-56% were 3.5mm or greater
- **Anderson et al:** AJSM '01
  - Prospective randomized design
  - PTG vs. STG
  - At 3 yrs: greater stability, IKDC scores

ACL REHABILITATION

**Rehab Program Changes Based on Surgery**
- **Graft**
  - PTG, STG, QTG
- **Meniscus**
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- **Articular Cartilage**
  - Debride, procedure, bone bruise
- **Other ligaments**
  - MCL, PCL, PL corner, LCL

ACL Reconstruction with Meniscus Repair &/or Meniscectomy
ACL REHABILITATION

Rehab Program Changes Based on Surgery

- *Meniscus Surgery:*
  - Repair vs. partial meniscectomy
- *Meniscus Repair:*
  - Immediate passive PROM
  - Weight bearing with crutches
  - No active knee flexion beyond 90
  - No hamstring strengthening 6-8 wks
  - No deep knee flexion squatting 3 mos

- *Graft*
  - PTG, STG, QTG
- *Meniscus*
  - Repair, excised
- *Articular Cartilage*
  - Debride, procedure, bone bruise
- *Other ligaments*
  - MCL, PCL, PL corner, LCL

ACL REHABILITATION

Rehab Program Changes Based on Surgery

- *Graft source (PTG, STG)*
- *Graft fixation*
- *Concomitant injuries/surgeries*
  - Meniscus repair
  - MCL repair
  - LCL repair
  - PCL repair or reconstruction
  - Articular cartilage lesion

Does these variables effect rehab

ACL REHABILITATION

Surgical Variables

- Concomitant injuries
- Timing of surgery
- Graft selection
- Concomitant surgeries
- Type of patient
  - Athlete
  - Non-Athlete
- Quality of rehabilitation
- Insurance plans

Play significant role in outcome

Concomitant Injuries & Surgeries

And their effect on rehab program
ACL REHABILITATION

Current Concepts in the Rehabilitation Following ACL Surgery

ACL REHABILITATION

Current Rehabilitation Approach

- Immediate motion, & early weight bearing
- Immediate muscle exercises
- Closed kinetic chain exercise
- Early functional activities
- Earlier return to sports

More aggressive rehabilitation

ACL REHABILITATION

Previous Rehabilitation Approach

- Immobilization 6 - 8 weeks
- Cast or brace
- Restricted motion
- Delayed weight bearing (8 - 12 weeks)
- Prolonged rehabilitation (9 - 12 months)
- No sports for 12 months

The Advances of today are tomorrow absurdities
Dramatic change in rehabilitation philosophy since 1990

“ACCELERATED” ACL REHAB
Shelbourne & Nitz: AJSM 1990

- 2-3 weeks: Stairmaster
- 5-6 wks: isokinetic test
  Light jogging, jumping rope, agility drills, weight room exercises
- 10 weeks: sport specific drills
- 4-6 months: return to full sports

How many people this today ?

Selection biased

ACL REHABILITATION
Accelerated Rehabilitation

- Who is an appropriate candidate?
  - All patients - selected patients
  - All patients - athletes
  - Isolated ACL only
  - Concomitant surgeries?
  - Is accelerated rehab safe?

When do you allow the athlete to begin running?
When do you allow the athlete to return to sports?

Successful outcome today

Asymptomatic Knee
5 – 10 years later!

Longevity of the Knee!!
**Beynnon, Johnson, Naud, et al: AJSM ’11**

- PRCT Accelerated (n=24) vs Nonaccelerated (n=18) ACL rehab
- Assessed at 3, 6, 12 & 24 mos post-op
  - Accelerated group – greater thigh strength
  - No difference in laxity between groups
    - Accel grp (3.2 mm) vs NonAccel (4.5 mm)
  - Majority of increase in laxity occurred during healing when exercises were advanced & activity level increased
ACL REHABILITATION
Pre-Operative Phase -

- Prepare the patient for surgery mentally and physically
- Normalize the knee prior to surgery
  - Re-establish ROM
  - Reduce swelling
  - Restore quadriceps activation
  - Control activity level

PRINCIPLES OF ACL REHABILITATION
Timing of Surgery

- Acute surgery: ASAP after diagnosis – knee is often swollen, decrease ROM, hemarthrosis, & painful quads inhibition
- Delayed surgery: waiting to perform surgery until knee is in “normal” state

Shelbourne: AJSM ‘91

- Retrospective study 169 acute ACL reconstructions
  - Young athletes (mean age 22 yrs)
  - Three groups:
    - Group I: 33 pts had surgery between 0-7 days
    - Group II: 65 pts surgery between 8-21 days
    - Group III: 71 pts surgery greater than 21 days
  - Patients with 5 degrees or more loss of extension
    - Group I: 17%  Group II: 11%  Group III: 0%
  - Pts in group II who followed accelerated rehab lower rate of arthrofibrosis 4%

Hunter: Arthroscopy ‘96

- Prospective study 185 acute ACL injuries in skiers
- Prospective assigned to one of 4 groups:
  - Surgery within 48 hrs
  - Surgery between 3-7 days
  - Surgery 1-3 weeks
  - Surgery greater than 3 weeks
- No significant difference in ROM between the 4 groups

Guerra, Joyce, Wilk et al: AOSSM ‘96

- Surgical timing on incidence of arthrofibrosis
  - ACL/PTG surgery with aggressive motion rehab program - supervised
  - 571 patients, retrospective analysis (90-94)
    - 158 acute (less than 2 weeks)
    - 187 subacute (2-6 weeks)
    - 306 chronic (greater than 6 weeks)
  - Approximately 4% incidence (3.8, 3.7 & 4.2%)- incidence rate the same
  "Timing of surgery should be individualized"

- Cellular mechanism of arthrofibrosis
- Tissue samples in 18 patients following knee trauma
- Localized immunohistological response
- Synovial hyperplasia, fibrotic enlargement, infiltration of inflammatory cells
- “Immune response as a cause of capsulitis leading to formation of diffuse scar tissue”

Unterhauser, Bosch, Zeichen: Arch Orthop Trauma Surg ‘04

- Compared 9 patients with arthrofibrosis compared to 5 control patients – primary ACL reconstruction
- Tissue samples taken from infrapatellar fat pad and intercondylar region
- Fibroblastic cells – myofibroblasts
- Actin isoform alpha-smooth muscle actin (ASMA)
- Arthrofibrosis group had a 10 fold higher amount of ASMA

ACL REHABILITATION
Immediate Post-Operative Phase (Day 1 - 7)

- Restore “full” passive knee extension
- Diminish swelling and pain
- Restore patellar mobility
- Gradually improve knee flexion
- Re-establish quadriceps control – “turn it on”
- Restore independent ambulation
**Specific Concepts in ACL Rehab**

**ACL Forces During Rehab**

- ACL strain during motion
- Passive ROM
- Active ROM
- Resisted movements
PRINCIPLES OF ACL REHAB

ACL Strain

- ACL strain during motion
- Passive ROM
- Active ROM
- Resisted movements

"ACL Strain"

- Strain: the ratio of deformation to the tissue’s resting length
- Change in length
- Change resting length
- Normal strain: change in length
- Abnormal strain: loads beyond yield point, permanent deformation

OKC vs CKC

OKC vs CKC
With Resistance
Increased Resistance during OKC & CKC Exercises & Its Effect on ACL Strain

CKC & OKC Exercises

- Squats with resistance (sportcord) & without resistance resulted in similar strain patterns (magnitude)
- Knee extension: increasing resistance resulted in an increase in ACL strain

Beynnon: AJSM ‘95

ACL In Vivo STRAIN DURING BICYCLING

Fleming, et al ORS 1996

- No significant difference for 6 riding conditions
- Relatively low compared to other rehab
- Greatest strain when knee has reached greatest extension

<table>
<thead>
<tr>
<th>RPMs</th>
<th>Power</th>
<th>Strain</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>75</td>
<td>2.6%</td>
</tr>
<tr>
<td>60</td>
<td>125</td>
<td>2.8%</td>
</tr>
<tr>
<td>60</td>
<td>175</td>
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<td>90</td>
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<td>90</td>
<td>125</td>
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<tr>
<td>90</td>
<td>175</td>
<td>1.6%</td>
</tr>
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</table>
ACL Strain During Stair Climbing


- Strain gauge implanted in anteromedial bundle of the ACL
- 5 subjects tested with normal ACL (intact)
- Stairmaster 4000PT performed at 80 & 120 steps per minute cadence
- Results: 
  - 80 steps cadence: 2.69%
  - 120 steps cadence: 2.76%
- No significant difference between 2 speeds

The Role of the Gastrocnemius Muscle on the ACL

Fleming, Renstrom, et al: J Orthop Res '01

- Strain gauge implanted within AM bundle of ACL
- 6 subjects tested with EMS applied to gastroc
- Tested at various knee flexion angles
- Results: 
  - 5 degrees of flexion: 2.8%
  - 15 degrees of flexion: 3.5%
  - 30 & 45 deg flexion: no strain on ACL
  - Co-contraction of Q & G: higher strain values
  - Co-contraction of H & G: higher than isolated H

ACL In Vivo STRAIN

Johnson, Beynnon, et al

- Isometric quads @ 15 deg. (30 Nm) 4.4%
- Squat w/ sportscord 4.1%
- AROM 45N boot 3.8%
- Lachman test (150N) 3.7%
- Squat w/o sportscord 3.4%
- AROM 2.8%
- Co-contraction Q/H at 15 deg. 2.8%

ACL In Vivo STRAIN

Johnson, Beynnon, et al

- Isometric quads @ 30 deg.30NM 2.7%
- Anterior drawer (150N) 1.8%
- Isometric hams @ 15 deg. 0.6%
- Co-contraction Q/H at 30 deg. 0.4%
- Passive ROM 0.1%
- Isom quads @ 60°, 90° (30 Nm) 0.8%
**ACL Strain References**

Beynnon, Johnson, Fleming, et al: AJSM ’01  
Fleming, Renstrom, Beynnon, et al: J Biomech ’01  
Fleming, Renstrom, Ohlen, et al: J Orthop R ’01  
Fleming, Beynnon, Renstrom: Arthroscopy ’99  
Beynnon, Howe, Pope, et al: Int Orthop ’92

**ACL REHABILITATION**

**Range of Motion**

- “Full” passive extension immediately
- Gradual restoration of flexion
  - Week 1: 90 degrees
  - Week 2: 105 - 110 degrees
  - Week 3: 115 - 125 degrees
  - Week 4: 125 degrees or >
  - Week 8-12: “heel to gluts”

**Shelbourne & Gray: AJSM ’09**

- ACL reconstruction PTG
- How the loss of motion compounds other factors related to development of OA
  - Loss of extension – even a loss of 3-5 degrees affected outcome
  - Especially with meniscectomy & art cart damage
  - Patients with loss of extension & flexion had worse results

**PACE Yourself First – Start SLOW then Progress Faster !!!**

It's all about milestones !!!

**Loss of Knee Motion**

**Loss of Extension**

Correlation between loss of knee motion and PF Pain  
Sachs, Daniel, et al: AJSM ’89

**Patellofemoral problems after anterior cruciate ligament reconstruction**

1 cm = 1
Loss of Knee Motion
Loss of Extension

Reliability of heel height measurements (.75-.78)

What About Restoring Hyperextension?

ACL Strains at ROM Extremes
Patellar Mobility
Patellar Mobilizations

Treatment of Post-Operative Knee Stiffness
Clinical Treatment Guidelines

- **Motion Milestones:**
- Easy & gradual motion the first week

  - **Progress Motion Too Quickly — Swelling**
  - Our goal is to establish motion milestones:
    - Day 1-3: 0-75 degrees (at least)
    - Week 1: 5-0-90 degrees
    - Week 2: 7-0-115 degrees
    - Week 4: 7-0-135 degrees
    - Progress to full knee flexion
    - Heels to Gluts
Arthrofibrosis

Treatment of Post-Operative Knee Stiffness

Loss of Motion

• Arthrofibrosis
• Does everyone with a loss of motion have arthrofibrosis??
• Defined as:
  » Inflamed “angry” knee
  » With loss of motion
  » Loss of knee flexion & extension
  » Often not swollen but HOT !!!
  May lead to progressive knee degeneration

Rehabilitation of Arthrofibrosis

Conservative ® Aggressive

✓ specific treatment program
✓ prevention is the key...but
✓ patellar mobility
✓ reduce inflammation (NSAID, Medrol Dose Pack, PT)
✓ LLLD extension
✓ knee flexion ROM
✓ Frequent bouts of moderate/light intensity stretching & ROM
✓ Cast, brace, night splint, ???

Treatment of Post-Operative Knee Stiffness

Loss of Motion

• Loss of flexion correlates:
  » Capsular contracture
  » Intraarticular fibrosis
  » Restriction of PF mechanism
  » Graft placement
• Extension loss of motion:
  » Anterior scar formation
  » Cyclops
  » Graft-notch mismatch
  » Graft tension position
PRINCIPLES OF ACL REHAB
Weight Bearing Guidelines

- Brace vs. Non-Braced
  - Locked
  - Unlocked/motion
- How long in a brace?
- How long on crutches?

ACL FORCE
Level Walking

- Stance phase
- Toe off phase
- Delayed loading
- ACL: 25 – 50% BW
- ACL force: ramp walking
  - Level walking: bi-phasic
  - Down ramp: braking peak
  - Up ramp: propulsive peak

Estimated Forces on the ACL

<table>
<thead>
<tr>
<th>Activity</th>
<th>ACL</th>
<th>PCL</th>
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</thead>
<tbody>
<tr>
<td>Level Walking</td>
<td>169</td>
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<tr>
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<td>641</td>
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<td>Descending Stairs</td>
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<td>262</td>
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<td>Ascending Ramp</td>
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<tr>
<td>Descending Ramp</td>
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<td>449</td>
</tr>
</tbody>
</table>

Morrison: J Biomech ‘70
Morrison: Biomech Eng ‘69 & ‘68

ACL REHABILITATION
Immediate Post-Operative Phase
(Day 1 - 7)
Immediate Post-Operative Phase - Goals

- Restore "full" passive knee extension
- Diminish swelling and pain
- Restore patellar mobility
- Gradually improve knee flexion
- Re-establish quadriceps control – "turn it on"
- Restore independent ambulation

Early Rehabilitation Phase

(Week 2 - 4)

- Full passive knee extension
- Gradual improvement in knee flexion
- Muscle training
- Restoration of proprioception
- Reduce joint swelling / pain
- Independent ambulation
Factors to Minimize Anterior Knee Pain in an ACL/PTG Knee

ACL DEFICIENCY & EMG PATTERNS
Quadriceps Avoidance

- Increased hamstring activity during walking, stairs (stance), decreased quadriceps activity - Andriacchi, CORR 1993
- “Quadriceps avoidance gait” Berchuck, JBJS 1990

Co-Activation to Enhance Dynamic Stability

Co-Activation to Enhance Dynamic Stability

Co-Activation to Enhance Dynamic Stability

Proprioception & Neuromuscular Control Drills for the ACL Patient
**Dynamic Stabilization**

*Stages of Motor Control*

**Cognitive Stage**
- Identify Objectives
- Self-talk/Questioning
- Errors/Variability
- Instruction/Feedback

**Associative Stage**
- Associate with environmental cues
- Refining/Consistent
- Errors/Variability
- Identify/Correct Errors

**Autonomous Stage**
- Subconscious/automatic
- Multiple tasks
- Errors/variability
- Identify/Correct
- Perfection

Beginner   Expert

---

**Dynamic Stabilization**

*Stages of Mastery*

- Unconsciously Incompetent
- Consciously Incompetent
- Consciously Competent
- Unconsciously Competent

---

**Bone Bruises**

Johnson D, et al AJSM '00

- 40 patients isolated ACL rupture with bone bruise
- MRI within 1 week of injury
- Compared with patients without bone bruise
- Patients w/ bone bruise had:
  - Larger effusions
  - Prolonged effusion (2 vs 4 wks)
  - Prolonged gait problem (2.8 vs 4 wks)
  - More pain (level 3 vs 6.1)
  - Slower thigh hypertrophy

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  - Slower thigh hypertrophy
Respect the Bone !!!

Potter, Jain, Ma, et al: AJSM ’12

- 42 knees in 40 patients (28 ACLR, 14 non-op)
- MRI at time of initial injury then annually for a maximum of 11 yrs
- All patients sustained initial chondral injury
  - Risk of cartilage loss doubled from yr 1 for the lateral & medial compartment & 3x for patella
  - By 7 to 11 yrs: LFC 50x, MFC 19x, & patella 30x
  - Size of the bone bruise associated to degeneration from yr 1 to yr 3

Treat The Osseous Lesion

- Rehabilitation Guidelines:
  - Control wt. bearing forces (crutches)
  - No early running & jumping
  - Cryotherapy & compression
  - Train & restore proprioception
  - Emphasize unloading programs
  - Pool exercises, bicycle, etc...
  - Muscle stimulation to quads
  - Motion, motion, motion ...

- Weight bearing and water exercises...
Unloading Devices

Progressive Loading Devices !!

ACL REHABILITATION
Intermediate Phase
(Week 4 - 10)

ACL REHABILITATION
Intermediate Phase - Goals
• Gradually restore “full” ROM
• Improve LE strength
• Enhance proprioception and NM control
• Improve muscle endurance
• Restore limb confidence & function

Stabilization From ABOVE & BELOW
ACL REHABILITATION

Rehab Concepts

- "Stabilization of the knee - occurs from above & below"
  - Hip & core stabilization
  - Foot & ankle control
Wilk et al: Ortho Clin No Am '03
Powers et al: JOSPT '03
Wilk et al: J Athl Trn '99

Co-Activation to Enhance Dynamic Stability
Co-Activation to Enhance Dynamic Stability
Train the hip – Eliminate the foot

Establish Hip Control

Dynamic Q-Angle

- Proximal factors
  - Femoral adduction
  - Femoral internal rotation

- Distal factors
  - Pronation
  - Tibial internal rotation

Lower limb alignment & lateral forces on the patella

Q-angle: 15°
Who Needs Core Stability??

- Trunk & hip control exercises & drills to prevent knee injuries

*Myers, Chu, et al: Clin Spts Med ’08*
Hamstring Muscle Training
ACL Rehabilitation
What You Need to Know

Hamstrings, Hamstrings & Hamstring Control

ACL REHABILITATION
Rehab Concepts

• “Muscles act as shock absorbers”
  » Quadriceps
  » Hips, gluteals, hamstrings

Quad Exercises
Which is best??

Wilk et al: AJSM ’94
Escamilla & Wilk: JOSPT ’08
Escamilla & Wilk: Clin Biomech ’08

ACL Rehabilitation
Advanced Strengthening Phase

Strengthening Ex Days

- Leg press (45-100)
- Wall Slides (0-75)

Figure 2. 90-60 deg knee flexion during exercise ascent

Normalized EMG (%MVIC)

EMG Activity of Quadriceps & Hamstring During the Leg Press

Wilk et al: AJSM ’94
TIBIOFEMORAL COMPRESSIVE LOADS

- Level walking 3.4 x BW  
  *Morrison J Biomech ’70*
- Up ramp 4.5 x BW
- Down ramp 4.5 x BW
- Up stairs 4.8 x BW
- Down stairs 4.5 x BW
- Rise from chair 3.2 x BW  
  *Dumbleton Biomech ’72*
- Knee bend 4.2 x BW  
  *Ellis J Biomech Eng ’84*

TIBIOFEMORAL COMPRESSIVE LOADS

- Running 8 – 10 x BW
- Jumping 12 – 15 x BW
- Walking 3 x BW

Aquatic Rehab - LE
ACL REHABILITATION

Rehab Concepts

• “Gradually increase the stress on the knee”
  » Soft tissue hypertrophy
  » Graft strength
  Soft tissue adapts to stress – “Envelope of Function” Dye

• “Restore neuromuscular control”
  » Neuromuscular activation
  » Neuromuscular control
  » Perturbation skills
  » Gradually increase difficulty of tasks

  Wilk et al: J Athl Trn ‘99
  Fitzgerald et a: Phys Ther ’
  Wilk et al: OCNA ‘03

Recondition the Knee Joint !!

Bone Bruises

Stabilization From ABOVE & BELOW

Train the Uninjured Extremity Too!!
Train Bilaterally
Perturbation Training to Enhance NM Control

Challenge the Neuromuscular System

Perturbation Training to Enhance NM Control

Challenge the Neuromuscular System
### ACL Rehabilitation

#### Intermediate Phase (Week 4-10)
- Continue strengthening program
- Neuromuscular training (perturbations)
- Plyo leg press --> plyometrics
- Running and agility training (athletes)

*Progression based on test results*

#### Advanced Activity Phase (Week 10-16)
- Normalize LE function
- Improve muscular strength, power and endurance
- Enhance NM control
- Initiate sport-specific drills

---

### Strengthening Ex Days

<table>
<thead>
<tr>
<th>Exercises</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warm-up drills/exercises</td>
</tr>
<tr>
<td>Stretch &amp; ROM exercises</td>
</tr>
<tr>
<td>Strengthening exercises</td>
</tr>
<tr>
<td>Specific to deficiencies</td>
</tr>
<tr>
<td>Hip &amp; Core</td>
</tr>
<tr>
<td>Balance drills</td>
</tr>
<tr>
<td>Neuromuscular drills</td>
</tr>
<tr>
<td>Perturbation training</td>
</tr>
<tr>
<td>Stretch &amp; ROM</td>
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</table>

### Agility Drill Days

<table>
<thead>
<tr>
<th>Drills</th>
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</thead>
<tbody>
<tr>
<td>Warm-up drills</td>
</tr>
<tr>
<td>Stretch &amp; ROM drills</td>
</tr>
<tr>
<td>Cones</td>
</tr>
<tr>
<td>Lateral lunges</td>
</tr>
<tr>
<td>Foam drills &amp; bosu ball</td>
</tr>
<tr>
<td>Star drill, NM control drills</td>
</tr>
<tr>
<td>Running &amp; Agility drills</td>
</tr>
<tr>
<td>Perturbation/Proprioception</td>
</tr>
<tr>
<td>Stretch &amp; ROM</td>
</tr>
</tbody>
</table>
PRINCIPLES OF ACL REHABILITATION

Functional Activities

- Pool drills  dry land
- Plyometrics  running
- Lateral drills  backward drill
- Backward running  forward run
- Forward running  cutting/agility
- Half speed  increase %

Gradual Progression
Assess Technique & Response

ACL Rehabilitation

Running & Functional Drills

- Running straight line first
- Running – deceleration – stop – go again
- Then progress to 45 deg. cutting
- Then progress to 90 deg. cutting
- Initiate drills at 50-60% then progress to 60-75% then to 75-90% then lastly 100%

Progression is based on signs & symptoms

ACL Rehabilitation

Initiation of the Running Program

- Reduced body weight running:
  - 50-60% BW depends on condition articular surfaces & associated pathologies
- Interval running
  - Gradually increase WB forces:
    - 60-75%
    - 75-90%
    - 100%

Running progression designed to advance without pain/set backs

ACL Rehabilitation

Agility Drills – Running Drills

- Backward Running
- Forward Run
- Side slides (low)
- Cariocas
- Start/stops
- Acceleration ladders
- Reaction drills
- Combinations
ACL Rehabilitation
Agility Drills – Run/Cutting Drills

- Forward running
- 45 deg zig zag
- Shuttle run
- 90 deg hard cuts
- Backward run turn & go (run)
- Sport specific drills

ACL Rehabilitation
Agility Drills – Ladder Drills

- Forward & Backward Drill
- Side to side Drills
- Quick Feet Drill

Agility Drills
**ACL Rehabilitation**

*Agility Drills – 4 Corner Drill*

- Side Shuffle
- Back Peddle
- Forward Run
- Cariocas
- Start/Finish

**Agility Drills**

**ACL Rehabilitation**

*Agility Drills – 4 Corner Reactive Drill*

- Start/Finish
- On Demand Reactions

**ACL REHABILITATION**

*Advanced Activity Phase (Week 12 - 18)*

- Progress isotonic strengthening
- Continue proprioception and NM control
- Sport-specific training
  - Side shuffles, cariocas
  - Backward running
- Progress endurance training
When can I begin to run?
Play sports??
Perturbation Training

- Fitzgerald et al: Phys Ther ‘00
- Fitzgerald et al: JOSPT ‘00
- Snyder-Mackler et al: JOSPT ‘01
- Wilk et al: J Athl Train ‘00
- Chmielewski et al: J Electro Kinesiol ‘05
- Eastlack et al: MSSE ‘99
- Rudolph et al: J Electro Kinesiol ‘04
- Eitsen et al: AJSM ‘10
- Wilk et al: JOSPT ‘12

ACL REHABILITATION
Return to Activity Phase
(Week 16 - 26)

Isokinetic Testing
Overview

- Biodex system (NY)
- Full ROM: 100° – 0°
- Distal pad placement
- Speeds: 180 & 300 °/sec
- Repetitions 10 & 15
- Standardized warm-up

Isokinetic Testing
Interpretation Data

- QPT / BW ratio:
  (180°/sec)
  Males: 60-65%
  Females: 50-55%
- H/Q ratio: (180°/sec)
  Males: 66-72%
  Females: 75%
- HPT / BW ratio:
  (180°/sec)
  Males: 40-43%
  Females: 37-40%

Isokinetic Testing
Interpretation of Data

- Bilateral comparison
  75-80% ???
- Endurance ratio (300°/sec)
  Extensors: 12% or less
  Flexors: 9% or less
- Acceleration rates
  (180°/sec)
  QPT at .2 sec
  80% or greater PT
- Acceleration rates (180°/sec)
  HPT at .2 sec (females)
The Relationship Between Subjective Knee Scores, Isokinetic Testing, and Functional Testing in the ACL-Reconstructed Knee

Wilk et al: JOSPT ‘94

ACL REHABILITATION

Contralateral Graft

- Donor leg treatment: cryotherapy and ROM
- Full ROM in three weeks
- Gradual quadriceps strengthening
- Quad strength returns to normal in 8-9 months (within 80% in 6 months)

Contralateral ACL

- Reconstructed limb:
  - Less pain & swelling
  - Usually faster ROM restoration
  - Quadriceps weakness still present
  - Treat similar to ipsilateral ACL

Wilk, et al JOSPT 1993
DeCarlo, et al JOSPT 1999

Shelbourne & Urch: AJSM ‘00

- Primary ACL/PTG reconstructions
- Contralateral grafts 434, ipsilateral grafts 228
- Contralateral grafts group: sign. better ROM flexion, improved quad strength up to 4 months, tighter KT results
- Return to sports: contralateral grafts 4.1 mos. ipsilateral grafts 5.5 mos.
- Preinjury level at 4 months: contralateral 49%, ipsilateral grafts 12%
  “able to return to sports faster & without compromise of stability”

Concepts in ACL Rehab

Contralateral Grafts’

<table>
<thead>
<tr>
<th>Insilateral PTG</th>
<th>Contralateral PTG</th>
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<tr>
<td>717 ACLs</td>
<td>1063 ACLs</td>
</tr>
<tr>
<td>28 retears</td>
<td>54 re-tears</td>
</tr>
<tr>
<td>3.9 %</td>
<td>5.1 %</td>
</tr>
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</table>

Shelbourne: Unpub ‘92–’00

Shelbourne et al: AOSSM ‘08

- ACL injuries to either knee within 5 yrs following ACL reconstruction
- 1820 patients – 5 yr f/u 1415 patients (78%)
- 75 pts (5.3%) injury to contralateral knee
- 61 pts (4.3%) injury to ipsilateral knee
- Females stat sign more ACL injuries to the contralateral knee (7.8%) than males (3.7%)- injuries ACL recon knee was ~4%
- Females 18 yrs or younger injury rate was 8.7% - injury rate >18yrs of age was 3.3%
- No diff in injury rates in patients returning to sports before 6 mos compared to after 6 mos.
TIBIOFEMORAL SHEAR FORCES

Anterior Shear

- Isometric knee exercise (30°): 0.4 x BW
- Isokinetic extension 180°/s (25°): 0.2 x BW
- Walking downstairs (15°): 0.8 x BW
- Example: 180 pound person (72, 36, 144)

Recent Advances in ACL Rehab

Key Points

- Rehab plays a vital role in the functional outcome
- "faster is not better"
  - Biology of rehabilitation - homeostasis
  - Speed limits in rehab
- Gradually increase stresses & challenges
- Progressive & sequential
- Enhance neuromuscular control
- "New" rehab techniques & drills
  Not how fast to get back – longevity

Thank You!