Recent Advances in the Rehab of ACL Ligament Injuries

- Non-contact injuries 67%
  Greater during competition 82.3%
- Last 15 min 35%
- Strong evidence for increased hip adduction moment
- Females 5-9 times greater incidence of ACL tears
- Wider pelvis
- Increased Q angle

Mechanism of Injury

- Typically non-contact deceleration situation with hyperextension or rotational component
- ***Rotational Component***

Mechanics of ACL Tears

- Hyperextension
ACL common in the Female Soccer Player

Factors in Females for increased risk
- Posture of the knee in landing – valgus / hyper-extension
- Dominant leg over used
- Over powering Quad strength – Hamstring less effective in reducing anterior translations when knee is extended most protective 15-30 degrees flex

Perturbation training improves knee kinematics and reduces muscle co-contraction after complete unilateral ACL rupture

- Perturbation training reduced quadriceps femoris-hamstring muscle and quad gastroc muscle co-contraction
- Prior to training potential copers stiffened their knees with higher co-contraction and slightly lower peak flexion angles
- Increased compressive forces from strong co-contraction can contribute to degeneration of articular cartilage
- The use of joint stiffening strategy = unopposed quad contraction that can cause anterior tibial translation = increased shearing forces with overpowering Quad
- Normal knee kinematics = knee flexion angles increased in copers

Single Leg Hop
- Single Leg Hop on Unstable surface
- Straight leg position does not bring in hamstring protection
- 20-30 Degree Angle is necessary for hamstring activation
  - Poor angle
Forces to ACL NWBE vs WBE

- ACL loading occurs primarily between 0 – 50E knee flexion. 50-100E knee flexion reduces ACL strain.
- Higher ACL loads between 0 and 30E peak 150N in NWBE compared to 50N WBE.
- Squatting and Lunge techniques can alter ACL strain:
  - Forward trunk tilt recruits the hamstrings = reduced anterior tibial translations compared to a erect trunk.
  - Anterior knee movement beyond the toes 8cm = increase ACL loading during squat and lunge.

ACL Reconstruction

- The primary goal of the reconstruction is to restore stability to the knee and restore function allowing the patient to return to normal activities, including sports and prevent OA.
- Dynamic function of all of the complex neuromuscular control mechanisms, including neuroproprioceptive output characteristics from the limb as well as central and cerebellar sequences of motor unit contractions, spinal vestibular reflex mechanisms, dynamic muscle strength, and endurance.
- Recent work has indicated that weakness of the quadriceps after reconstruction of the anterior cruciate ligament primarily reflects a deficit in neural activator drive from the central nervous system rather than a pure muscle weakness – Neuromuscular rehab.

ACL Post-op Results

Rehabilitation outcomes:

- 20-37% Professional football players never return to prior level of function.
- Review of 48 studies – more than 5700 patients 63% returned to pre-injury levels & 2/3’s were not back 12 months post-op.
- 44% returned to competitive sports.

24% re-injury rate of reconstructed knee.
24% injury rate of contralateral knee.
49% overall of re-injury of the ACL reconstruction or ACL rupture to the contralateral knee.
40-95% of patients exhibiting radiographic OA 7-12yrs following the surgery.

ACL Rehab Based on Healing Ligament

Week 1-2
- No aggressive passive movement – grade II mobilisation large amplitude
- Russian squats and isometric exercises
- Hip strengthening exercises – posterior-lateral
- Trunk endurance exercises
- Low Load Prolonged Stretch into extension
- Active Flexion exercises - bicycle

Week 1.2
- CKC exercises for strengthening – single leg squat - leg press, Dyn Edge, Lunges,
  Eccentric loading
- Perturbation exercises – balance training - vestibular
- Passive stretch – joint mobs into extension and flexion – Grade III end of range

Week 7-16
- Complex surfaces – perturbation and vestibular exercises
- Hopping one foot to next – 30 E flexion angle, Balance complex surfaces

Week 16
- OKC strengthening Quads
- Week 17-24
  - Plyometric exercises (jump training) – Aggressive weight training

Balance in the Athlete

- Four Systems
  - Strength of the Hip and Lower Leg
    - Eccentric loading
    - Dynamic and Static LE testing
  - Somatosensory
    - Star Excursion Balance Test
  - Vision
  - Vestibular

Early application of Negative Work via Eccentric Ergometry Following ACL

- Case study JOSPT May 2006 Gerber et al.
- Semi-tendinosus-graciliis autograft initially and then Patella-tendon after 2nd tear.
- 3 weeks post-op patient started an eccentric exercise program for 31 wks over 12 weeks after the repair and 33 sessions after the revision.
- Quad strength increased 28% while protecting the repair no anterior shear force
Eccentric Loading

Roi et al described an case of an elite soccer player returning to competition 77 days after ACL surgery by using eccentric resistance training program.

In 12 weeks quadriceps size and volume increased 28% in the surgically repaired knee.

15 weeks post-surgery the quadriceps strength was 50% greater than pre-operative measures.

Quadriceps atrophy and strength deficits are the greatest during the first 3 months following ACL repair.

Histological Changes with Eccentric Loading

Positive changes in tissue structure and mechanical properties as a result of eccentric training have been previously described by Shalabi.

Evaluated 25 patients with chronic Achilles tendinopathy before and after an eccentric program using the Alfredson protocol. 12 reps 12 sets over 12 weeks.

Subjects’ tendon volume and intra-tendinous signal were measured via MRI both were decreased with eccentric exercise.

Improved pain and reduction in fluid content within the tendon may suggest increased healthy collagen deposition.

Ohberg found a decrease in tendon thickness and normalized tendon structure measured by ultrasound.

Langberg found that Type I collagen synthesis increased after eccentric training in a group of twelve soccer players with unilateral Achilles tendinosis indication of tendon healing. (Initial collagen Type III)

Eccentric Loading to Hamstring Strains

Eccentric loading of the hamstrings is performed in the OKC Non wt bearing low velocity eccentric loading exercises
- Stiff leg dead lifts
- Nordic hamstring exercise
- Eccentric backward steps
- Eccentric forward pulls
- Eccentric Lunge drops - forward flexion with wt ball
- Eccentric loading more effective greater changes in neural activation and hypertrophy
The Role & Implication of Eccentric training in athletic rehab tendinopathy hamstring strains & ACL reconstruction

Lorenz D & Reiman M
Internat J Sports PT  March 2011

- Eccentric forward pulls
- Forward flexion with wt ball

Nordic hamstring exercise
Eccentric backward steps
Stiff leg dead lifts

Dynamic and Static Movement Testing

**Eccentric**
- Step-Down Test
- Jump Down Test
- Full Squat Test
- Single Leg Squat Test – Unstable knee
- Knee Flexion Angles - Hop Test unstable surface R-L – Activation of hamstrings

**Isometric**
- Single Leg bridge with Dorsi-flexed Ankle
- Side Plank Test

Step Down – Test

- Stool or step 8-inch (20.3 cm)
- Lower R/L leg, so heel touches the ground return to platform touch top of platform
- Continue sequence for 30 seconds

**Criteria to watch**
- Do not push off ground as lowering heel/touching
- Heel must make contact with slight hesitation both @ down phase & start phase
- Do not allow vaulting up with their touch leg
- Greater than 10% difference is significant
Jump Down Step down Tests Valgus Knee Hyper-extended Varus Knee Pronated Foot Position

Full & Single Leg Squat in Sports Lateral shift Single leg squat knee over foot Restricted mobility Full squat Full Range

Restoring Neuromuscular Control Balance in the Athlete

Somatosensory - Vestibular – Vision
The muscle must be set on a higher state of readiness to prevent injury by protecting joints from perturbation forces and be able to perform exceptionally skilled activities performed at high velocities. This higher state of readiness of the neural control of the musculoskeletal system can be achieved through neuromuscular training such as perturbation, plyometrics and vestibular exercises.
Neuromuscular Control

Defined: subconscious integration of sensory information that is processed by the CNS resulting in controlled, coordinated muscular activity.

Interpret Sensory input from the environment

- **Somatosensory – mechanoreceptors**
  - Joints (Ruffini receptors, golgi tendon organ)
  - Perturbation
- **Vestibular apparatus**
- **Vision – Eyes**

Somatosensory Testing

Star Excursion Balance Test
Reach Test to Predict LE Injures in Basketball Players

**Results:**
The reliability of the SEBT components ranged from 0.82 to 0.87 and was 0.99 for the measurement of limb length.

- Athletes with anterior right/left reach distance difference greater than 4 cm were 2.5 times more likely to sustain injury.
- Incorporated into pre-participation physical examinations to identify basketball players who are at increased risk for injury.
Reach Test

- Composite reach distance was the sum of the 3 reach directions divided by 3 times limb length, then multiplied by 100.
- Girls – (Basketball) with a composite reach distance less than 94.0% of their limb length were 6.5 times more likely to have a lower extremity injury (P.05).

Classic Test for Sensory Integration and Balance CTSIB
Somatosensory – Vestibular – Vision combined test

- **BESS test** – balance error scoring system = 9 or less
  Errors:
  - Opening eyes, lifting hands from hip, touchdown of non-stance foot, step, hop, or other movement on stance foot or feet
  - Lifting forefoot or heel, moving hip into more than 30E flexion or abduction, remaining out of position for longer than 5 seconds

  Comparison of Static and Dynamic Balance in Female Collegiate Soccer, Basketball & Gymnastics
  Bressel et al. J of Athletic Training 2007

Theory of neuro-muscular mechanisms in perturbation training: “Readiness”
Johansson and Sjolander

- Neuromuscular training results in more efficient processing of sensory input as well as faster selection of the correct motor program resulting in relatively fast but more appropriate movement

- Results in a higher state of readiness of muscles and joints to respond to perturbing forces applied to the joints.
Somatosensory System
Mechano-receptors

- Mechanoreceptors rapidly and slowly adapting receptors
  - Mechanoreceptors rapidly adapting sense sudden movement, acceleration or deceleration
  - Mechanoreceptors slowly adapting sense joint position
  - Training must be performed throughout the ROM: Proprioceptors are activated selectively at specific angles

- Protective mechanism through reflexes between the ligament and the muscles (e.g., ACL/Ham)
- Signals the end-range of joint motion facilitating protective reflexes
- Muscle fatigue and injury alters Mechanoreceptor input

Training the Somatosensory System
Perturbation Training

- Johansson suggested by stimulation of mechanoreceptors increases gamma motor activity increasing muscle spindles sensitivity.
- Caratta et al. Knee Surg Sports Trauma Arth 2006
  - 96 athletes (300 trained traditional, 300 perturbation training)
  - 70 ACL tears trad. and 10 ACL tears balance group

- 5 levels of difficulty:
  1. Flexion angles
  2. Single leg stance

Perturbation Strategies

- Progressively more challenging perturbing forces
- Phase one:
  - Perturbation in all directions
  - Flexion angles
  - Single leg stance
- Phase two:
  - Add light sports specific activity during perturbation
  - Throwing ball into plyoback
  - SL stance – kicking - reaching
- Phase three:
  - Increase difficulty of perturbation by jumping on to unstable surface
  - Hopping from one foot to the other
Advance Training Jumping On to Unstable surface

Neuromuscular Training Muscle Spindle Plyometrics Prerequisites
- Strength base – Power Squat 60 % body wt.
- One leg half squat – balance & quad strength
- Stork balance test Eyes open / closed
- Good Quad strength MMT
- No patella femoral pain / poor alignment
- Good landing surface/shoes
- No acute injuries to the foot or ankle

Plyometrics Training
- Stretch Reflex or Myotactic– Intrafusal fibers / muscle spindle responds to the rate at which the muscle is stretched
- Stronger muscle contraction to reduce the stretch
- Stretch shortening cycle – rapid deceleration followed by an immediate rapid acceleration
Types of Plyometrics

- **Natural Plyometrics** – hopping jumping
- **Depth Jumping**
  - Only for specific athletes 220lbs no higher than 18 inches
- **Low Intensity**
  - Skipping drills, 8 inch cone hops
  - Lateral bounding
- **Shuttle 2000 MVP Vertamax**

Plyometric Training in Female Athletes

- *Decreased impact forces and increased hamstring torque* *ASM 1996*
- Hewett, Stroupe, Nance, Noyes

Teaching neuromuscular control of the LE during landing and to increase vertical jump

**Results**
- After training peak landing forces dec. 22% and knee add & abd moments dec. 50%
- Hamstring power inc. 44% Peak torque ratio hams/quad inc. 13%

Plyometric Training

- 48-72 hours recovery
- 2x per week
- 60-90 seconds per exercise
- 50-100 seconds rest
Plyometrics

Plyometric Drills Sports Specific

Balance in the Athlete
The Missing Link

- Vestibular (inner ear) CNS
- Vision = Three visual oculomotor systems
  - Saccades – smooth pursuit- optokinetic
  - VOR perception of linear and angular accelerations
**Vestibular System**

Head – Eye coordination mediated by vestibular receptors in the inner ear cells

- Position of head in reference
- Speed – Direction
- Acceleration

**Vestibular Receptors**

- Provide an exquisitely accurate representation of head motion in 3 dimensions
- Perception of linear and angular acceleration

**Vestibulo-ocular Reflex**

- Maintains the stability of the visual field in response to acceleration of the head in a particular direction
- Running velocities head acceleration up to 6000 deg/sec

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**Neural Pathway of Vision**

- **Cones** provide color vision and are responsible for acuity (detailed vision)
- **Rods** provide night vision, peripheral vision, and detect motion

**Peripheral Retina**

- Visual neural impulses propagate through the optic nerves to the brain centers

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**Visual Workspace and Motor Performance**

- The spatial environment within which objects and locations exist
- Gaze is the ability to bring the critical information required to perform well onto the part of the eye, the fovea:
  - that sees with clear acuity
  - for prolonged durations even as they move dynamically in cluttered and difficult environments
Visual Perception

- Visual perception = capture the light with our eyes.
- Complex NMC of the extra ocular muscles is required for foveal visual perception (cones) A useful analogy is to recall that camera person must first point and focus the camera in order to get a nice detailed color picture.

**Smooth pursuit** system allows fixation of gaze onto a moving object with a frequency of less than 1.2 Hz. = rods

Optokinetic eye movement of equal velocity & opposite direction of head movements

**Saccades** are used to catch the foveal vision up to faster moving targets or move between targets. While slower to initiate they move the eye at much higher speeds than smooth pursuits.

Visual Angle

- Small area on the fovea where we are able to see clearly is $2^\circ$ - $3^\circ$ of visual angle

- Estimate the size of this area by holding your thumb in front of you at arms length. The width of your thumb is about $2^\circ$ of visual angle projected into space.

- The athlete must move their gaze purposely to see the different aspects of a scene with full acuity

**Quiet Eye**: Is the final fixation or tracking gaze that is located on a specific location or object in the visuomotor workspace within $3^\circ$ of visual angle for a minimum of 100ms. (1000ms in one second) Dr. Vickers
Quiet Eye – Final Gaze

- Since the Quiet Eye has been shown in elite athletes to be earlier and longer than that of athletes with lower skill levels.
- It is trainable large increases in performance.
- The quiet eye is an objective measure of optimal perceptual-motor coordination.

![Graph showing the quiet eye comparison between professional and amateur golfers.](image)

Professionals: Longer 500 msec
Amateurs: 250-300 msec

Final Gaze – Quiet Eye - DVA

Are we helping are athletes see better?

- Seeing the Target
- What is wrong with Andy’s eyes
- Where is the ball?

Roger Federer Vision System

- Watch the ball from the back of the racket
- Watch for the contact instead of trying to impossibly watch the ball all the way in.
- Keep the head still to the follow through.
- Keeps the head and eyes still longer before contact and makes it easier for you to prevent the head from jerking forward during the swing.
Balance in the Athlete

- Walking on the balance beam is affected by loss of vestibular function – Compromise of the athlete's ability to use somatosensory information to control posture – Requires hip or step strategy for center of mass control.

Vergence/Teaming

- Ability to point both eyes simultaneously on target
- Only automatic in about 30% of population
- If one eye off target then not true binocular vision and inaccurate depth perception

Testing the Three Visual Oculomotor Systems

- Vestibular Ocular Reflex
  - Saccades
  - Smooth Pursuit
  - Optokinetic
Head Thrust Test for Identifying Vestibular Hypofunction

- Normal Head Thrust A-B
  - Initial starting position eyes are focused on a target cervical flexion B- Turning to the left upon stopping the head turn eyes are still on target.

- Abnormal Head Thrust C-E
  - Initial starting position D- turned to right eyes are not on target.
  - E- eyes make a corrective saccade bring eyes back to target.

Dynamic Visual Acuity

- Head moves
- Eyes on target
- 1Hz combo VOR & COR
- 3 Hz purely VOR
- Can quantify with eye chart
- Up to 2 line changes (i.e. 20/20 → 20/50) is WNL
- Herdman et al 1998

Smooth Pursuit Exercise & Test for CNS Dysfunction

- Head still
- Eyes follow target through 20-40 deg/sec through narrow arc
- Unable to maintain image on retina over 150° sec = 15mph
- Test look for overshoot and/or nystagmus of the eyes when following a target
- Deteriorates with age
- Detects spins of an object, acceleration or decreases in speed
Saccades Exercise and Test for CNS Dysfunction

- Head Still
- Ballistic eye movements reach speeds excess of 900–1000°/sec = 90 mph (145 kph)

Important for high velocity objects such as in baseball, hockey puck, tennis ball, lacrosse, handball etc.

- Test look for over shoot and/or nystagmus of the eyes when moving from targets

Vestibular Testing

Peripheral

1. Classic Test for sensory integration and balance CTSIB
   - Eyes open / eyes closed / firm surface / soft foam – R – L single leg

2. Romberg – patient stands feet together arms crossed with the eyes closed to test if the patient can maintain balance. 60 sec
   - It tests vestibular (primary – otolith organs) and proprioceptive balance pathways. The vestibulospinal pathway can be isolated by having the patient stand on a foam surface

3. Sharpened Advanced Romberg – Feet – Tandem extend head – close eyes – then to single leg
   - 45 sec hold times except single leg (30sec)

4. Ehlers Test – March Test the patient steps in place with the eyes closed for 60 sec
   - The patient may turn towards the side of the lesion. It is important to note that the patient may drift to the left somewhat with this test.

5. Fast businessmen – the patient is asked to point at a target as fast as possible.

Vestibular Dysfunction = Physical Limitations in the Athlete

- Unable to focus with quick head movements
- Poor hand-eye coordination
- Poor balance compensations hip and step strategies
  - Make compensations that reduce the athletes agility, speed, and performance
  - May cause injury
- Maintenance of GAZE and Posture interaction of inputs from;
  - Vestibular
  - Visual
  - Somatosensory
**Patient Case - Dancer**

- Post-op ACL reconstruction
- 4 weeks post-op
- Weakness of the Quads and Hamstrings
- Poor balance – history of inner ear infections and minor concussions
- Weak posterior hip muscles

**Hip Strengthening External Rotation**

**Perturbation Training Shuttle Balance**
Balance Positions

Balance & Vestibular Training
- Dynamic Edge – Quad strengthening and endurance training & balance training

Advanced Perturbation Training
Place kicker football Torn Rectus
See Fred Impact

Using Binocular vision perceives the exact distance the ball is to the club.

Quiet Eye maintains object on the fovea directly after ball contact saccades & visual pursuit allows him to follow the ball.
Theoretical VOR in Swing

- Take Away
- Address
- Follow Through

**See Fred After Impact**
- Uses Saccade to locate rapidly moving ball

**See Fred Follow Through**
- Smooth Visual Pursuit tracks ball to ground
- Provides visual feedback on shot
- Helps preview next lie
- Prevents anxiety in amateurs

Provides visual feedback on shot.
Vision and Putting for the Elite Golfer

1. Fixation of the hole longer and uses slow saccades of about 500 ms between the hole & ball.
2. Directed 2-3 fixations to the hole & ball or club, with saccades linking the fixations.
3. During the stroke maintained quiet eye on the top or back of the ball thru the back swing and forward swing.
4. At contact the quiet eye remained on the putting surface for 250ms.

Location of Gaze - Top or Behind the ball

Quiet Eye Drills

- Tack & Detect Drill write #1-20 on the volleyball receiver calls out the # before passing it – progress to letters – combination of both.
- Volleyball Track and detect drill with barrier.
Tennis Quiet Eye Drills

- Track & Detect drill with a barrier – Net in tennis is covered with a sheet, ball is served from behind the covered barrier receiver tracks ball in flight calls out # or letter - Tennis
- Track & detect - full body turn 180 degrees after serving called out letters and numbers – Volleyball

Neuromuscular Training Summary

- Pre-season neuromuscular training (perturbation) & plyometrics can decrease knee injury rates in females
  - Silvers, Mandelbaum, Clin J Sport Med, 17, 2001
- Lower injury rates in elite players compared to less skilled players
- Pre-season conditioning and fitness can reduce overall injury rates

Sport Specific Rehab
Restoring Balance in the Athlete

- Strength training to reduce Muscle Imbalances
- Perturbation training
- Training the Vestibular system VOR
- Plyometrics – Explosive power
  - Agility training combination of all the above