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Current Concepts for PT Management of The Knee

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Objectives

At the conclusion of this lecture, attendees will be able to:

- Accurately identify the necessary tissue protection approaches after surgery for injury to the anterior cruciate ligament, posterior cruciate ligament, medial and lateral corners of the knee, and the meniscus.
- Design a rehabilitation program that restores motor control to the knee with a focus on rectifying standard impairments and common complications after knee joint injury or surgery.
- Design a rehabilitation program for the late phase of rehabilitation to optimize function for return to work and return to sport.
- Implement aspects of secondary injury prevention after surgery for the knee joint beginning in the motor control phase and progressing through the functional optimization phase.

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Course Outline

Session	Time	Lecture	Lab
1	8 to 10	Anatomy Review with a focus on Tissue Protection for Pre-op and Post-op Treatment; Biomechanics of Knee Joint Motion and the relation to Treatment for Stiffness;	Advanced Knee Joint Mobilizations Selective Stretching for the QT, PT, Proximal vs. Distal Hamstrings Muscle Activation Exercises for NWB Tx
2	10 to 12	Gait Review Role of Quads in Outcome Hamstrings in Athletic Function Relevant Biomechanics for Muscle Strengthening	Gait Interventions Squat Interventions Lower Extremity Loading to Preference Quads Hamstrings as knee flexors vs. hip extensors
Lunch	Noon – 1 p.m.		
3	1 to 2:30	Motor Control Screening and Intervention for the Lower Extremity	Motor Control Lab
4	2:30 to 5	Terminal Activity Progression Concepts	Terminal Activity Progression Training and Testing

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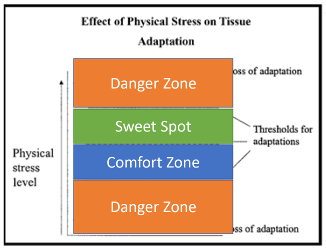
From: Tissue Adaptation to Physical Stress: A Proposed "Physical Stress Theory" to Guide Physical Therapist Practice, Education, and Research
. 2002;82(4):383-403. doi:10.1093/ptj/82.4.383



Experts recommend exercise for treatment.

However, a common complaint is that exercise increases symptoms, which makes exercise difficult & uncomfortable.

Individuals are not likely to exercise into the painful ranges (nor should they be).

We need to figure out how to shift into the "increased tolerance" range without causing injury or increasing pain.

Figure Legend:

Effect of physical stress on tissue adaptation. Biological tissues exhibit 5 adaptive responses to physical stress. Each response is predicted to occur within a defined range along a continuum of stress levels. Specific thresholds define the upper and lower stress levels for each characteristic tissue response. The relative relationship between these thresholds is fairly consistent between people, whereas the absolute values for thresholds vary greatly.

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Defining Dosage

	Aerobic	Resistance	Flexibility
Mode	Walk, cycle, row, etc.	NWB versus WB, dumbbells vs. cuff weights, etc.	Passive stretch, hold-relax, etc.
Intensity	Target heart rate	Percentage of 1- or 10-repetition maximum	How strong should the stretch be?
Duration	For how long?	How many sets/reps?	How long to hold the stretch? How many?
Frequency	How many days per week?	How many days per week?	How often?

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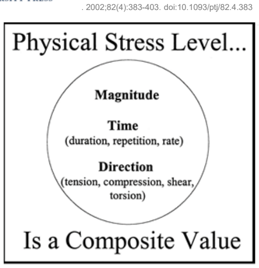

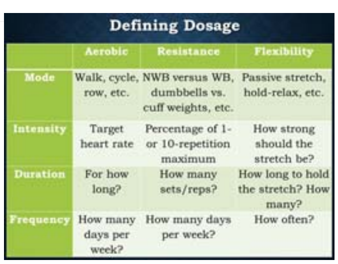

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Physical Stress Level and Dosing are SYNONYMOUS!

Physical stress level is a composite value. Stress magnitude refers to the amount of stress (force per unit area) on a tissue. Time factors include the duration, number of repetitions, and the rate at which stress is applied to tissues of the body. Stress will have a different effect depending on whether it is applied in tension, compression, shear, or torsion.

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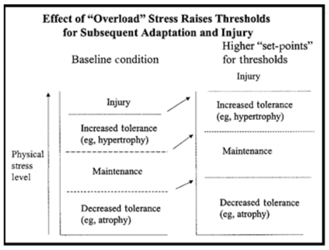
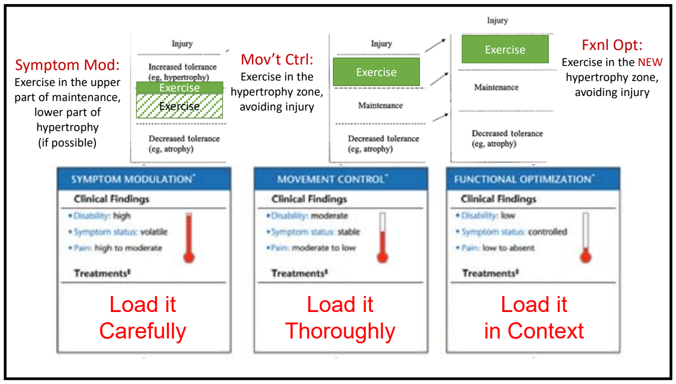


Ongoing exercise (in the hypertrophy zone) shifts all levels up the physical stress continuum.

"Increased Tolerance" zone remains small, maintenance zone expands.

We must educate individuals how to stay in the "increased tolerance" zone to prevent regression!

Effect of "overload" stress raises thresholds for subsequent adaptation and injury. Prolonged physical stress levels that are higher than the maintenance range result in increased tolerance of tissues to subsequent stresses (eg, hypertrophy). Although relative thresholds remain the same, the absolute magnitude of physical stress is higher for each threshold. Injury (and all other adaptations) occurs at a higher level of physical stress than required previously.



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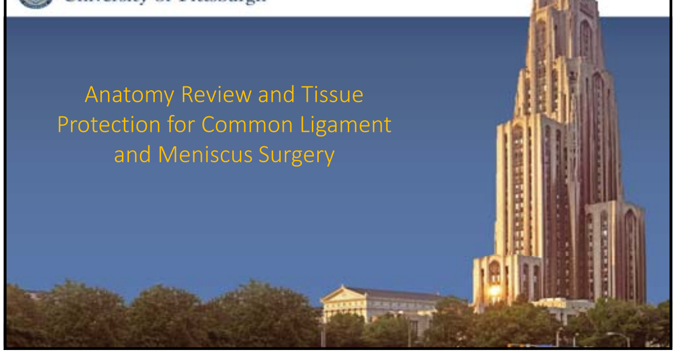
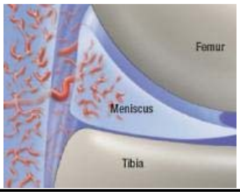
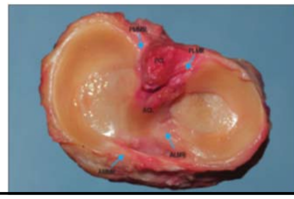


Meniscus

- Surface of the tibia is covered by fibrocartilaginous menisci
  - Wedge-shaped, concave superiorly
    - Enhance the joint stability by deepening the contact surface
    - Multidirectional stabilization, limiting excess motion





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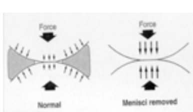
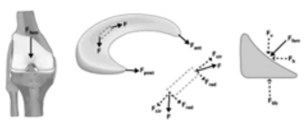
Meniscus

- Shock absorption - transmits ½ of weight bearing load in full extension and some in flexion\
  - In high load situations, 70% of the load is absorbed by the menisci, especially the lateral meniscus
  - Reduces the load per unit area on the tibio-femoral contact sites.
  - Contact area in the joint is reduced 50% when the menisci are absent
  - 20% increase in friction following meniscal removal





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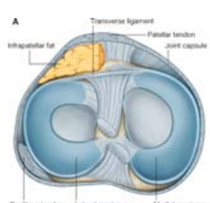
Meniscus

- Medial Meniscus
  - Larger
  - Reflects the shape of medial tibial condyle
  - A + P horns – attached to medial collateral ligament and basically immobile
- Lateral Meniscus
  - Smaller, tighter,
  - Almost a complete circle A+ P horns
  - NOT attached to LCL



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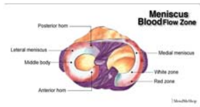
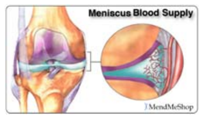
Meniscal Blood Supply

- Blood supply by age
  - Infancy: 100% meniscus
  - Weight-bearing to age 50: diminishes to outer 25-33%
  - Age 50+: only the periphery
- Peripherally – capillaries from capsule
- Centrally – diffusion from synovium
  - Aided by cyclic loading
  - Immobilization/NWB is problematic





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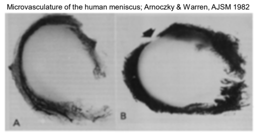
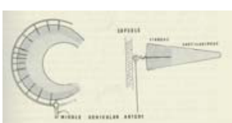
Meniscal Repair

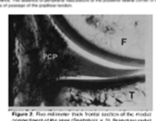
- Considered when lesion is in area of good vascularization
  - if tear is w/in 3 mm of the periphery, it is considered vascular
  - area 3-5 mm from periphery is grey zone, & > 5 mm from periphery is considered avascular

A – Medial B - Lateral

Microvasculature of the human meniscus; Arnoczky & Warren, AJSM 1982







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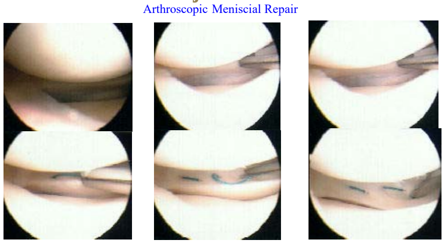
The Knee – Meniscial Injuries

Arthroscopic Meniscial Repair



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The Knee – Meniscial Injuries

- Meniscal Repair of Avascular, Central Region
  - Becoming more common, due to importance of preserving meniscus when possible
  - Modifications of surgical techniques to enhance healing in this area are used:
    - Fibrin Clot
    - Rasping of synovial fringe
    - Creating vascular access channels

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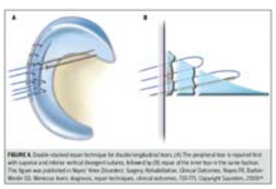
Noyes FR. Barber-Westin SD. Arthroscopic repair of meniscus tears extending into the avascular zone with or without ACL-R in patients 40 years of age+. Arthroscopy. 16(8):822-9, 2000 Nov.

- 30 repairs in patients 40 years or older
- 26 patients were asymptomatic and had not required further surgery after a mean of 34 months post-operatively



- Rehab Program Consisted of:
  - Immediate Knee Motion
  - Early PWB for 4 weeks
  - More Complex Tears Restricted
    - radial or mult. longitudinal were restricted 2 add. weeks
  - ROM - 0-90
    - Increased to 120 by 3-4
    - Increased to 135 by 5-6
  - No Squatting past 125 for 4 months
  - Run, Jump, Cut, Twist restricted for 6 months

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- Hoop Stress!!
  - Disrupting the root can cause meniscal extrusion in WB
  - After repair, WB can significantly stress the repair!
- Hamstrings attach to medial meniscus
  - Contraction will cause posterior glide

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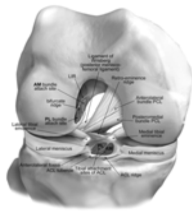
Anterior Cruciate Ligament

- Attached to the anterior intercondylar area of the tibia and passes posteriorly, superiorly, and laterally to be attached to the posterior part of medial surface of the lateral femoral condyle.
- Fibers run in three directions – anteromedial, intermediate and posterolateral directions
- Intracapsular, extrasynovial
- Has anterior attachment with anterior horn of medial meniscus



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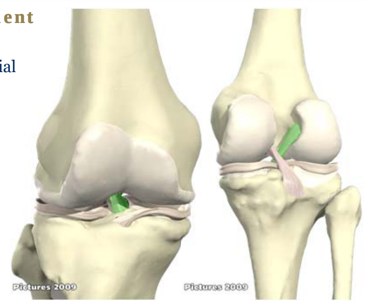
Anterior Cruciate Ligament

- Primary stabilizer for anterior tibial translation/posterior femoral translation
- Secondary stabilizer for
  - Varus and valgus forces
  - Medial tibial rotation
  - Lateral femoral rotation



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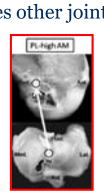
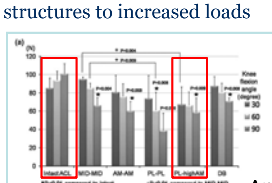
Risk of Graft Re-Rupture

- **Non-Anatomic ACL Reconstruction:**
  - Non-anatomic ACL-R results in graft forces lower than normal
  - Exposes other joint structures to increased loads





Araujo et al JBJS 2015
Kato et al KSSTA 2010

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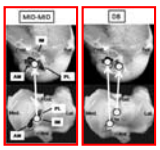
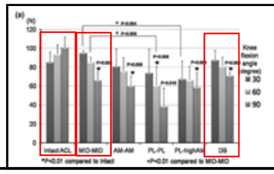
Risk of Graft Re-Rupture

- **Anatomic ACL Reconstruction:**
  - Anatomic ACL-R results in forces that are closer to normal ACL
  - Exposes anatomically placed graft to increased risk of injury
  - **May Require Slower Rehabilitation to Protect Graft Healing**





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Graft Healing

- Phases:
  - Synovial envelopment of graft & avascular necrosis
  - Revascularization, cellular proliferation & collagen formation
  - Normal vascular pattern, remodeling & maturation of graft
- Graft strength decreases during the period of necrosis and then it increases as it remodels and matures, but it does not reach the original strength of the native ACL

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Ligament Graft Healing

- Initially the graft is avascular
  - 6-8 weeks: the graft shows signs of avascular necrosis
  - 8-10 weeks: revascularization begins; mesenchymal cells invade the graft
  - 16 weeks: vascularization is “complete”; mesenchymal cells and proliferate and form collagen
    - Collagen changes from fragments of fibers to dense longitudinally oriented fibers

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Graft Healing

Time Frame Not Well Known & Likely Variable Between Individuals

Claes et al, AJSM 2011

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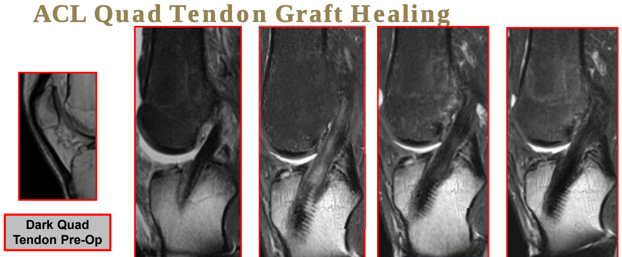
ACL Quad Tendon Graft Healing



Dark Quad Tendon Pre-Op

Time zero | 3 months | 6 months | 1 year

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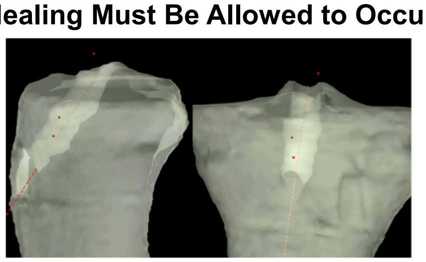
Healing Must Be Allowed to Occur



In vivo kinematics of a hamstring graft 6 weeks after surgery during walking

Tashman S, Harner CD, et al, ongoing study

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Autografts vs. Allografts

Autografts
- Faster incorporation and healing
- Better outcomes in young & active
- Donor-site morbidity
  - Which is most problematic?
- Risk of fracture
  - Preventable?

Allografts
- Higher cost
- Predictable graft size
- Availability
- Better for revisions
- Re-injury Rate?
- They don't hurt enough

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Bone-Patellar Tendon-Bone Autograft (BPTB)

- Gold standard
- Rigid bone to bone fixation allows accelerated rehab to attain full ROM & strength
  - Boney plugs heal in approximately 6-8 weeks
  - Up to 30% of patients complain of donor-site morbidity
- Central 1/3 of tendon is 186% as strong as native ACL
- Patellar fracture
  - No aggressive strengthening for 6-8 weeks**
  - Avoid high eccentric loading for 12 to 16 weeks**
- Patellar Tendon Rupture
  - Persistent extensor lag with SLR at 4 weeks post-op
  - Inability to perform a SLR 1-2 weeks post-operatively

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Hamstring Tendon Autograft

- Usually Semitendinosis/Gracilis graft
  - Semitendinosis – 70% strong as native ACL
  - Gracilis – 49% strong as native ACL
- Fixation not as strong as BPTB
- Potentially less quad atrophy
- Less donor-site morbidity
  - Able to kneel
  - But now you've disrupted the hamstrings – implications in injury prevention
- Soft tissue-to-bone heals in approximately 8-12 weeks

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Quadriceps Tendon-Bone Autograft v. Quadriceps Tendon Soft Tissue Autograft

- Shown to have similar stability vs. a BPTB graft but with less kneeling pain
  - Quad strength for rehab?
  - Few long term studies available
- Research out there says that quad strength catches up over time
  - Questionable

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Allografts

- Usually bone-patellar tendon-bone, Achilles, tibialis anterior,
- Mixed results for:
  - Failure rates
  - Laxity
  - ROM outcomes
  - Can allow for faster rehab because of decreased pain

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Post-Op ACL Rehabilitation

Controversies:

- NWB TE causes anterior shear forces in the knee, creating excessive anterior laxity
- NWB TE may cause patellar fracture after bone-block harvest.

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Post-Op ACL Rehabilitation

- Generally, CKC exercises cause less strain than OKC exercises. But some OKC exercises are safe for the healing ACL
- 44 subjects were randomized into a CKC exercise only vs. a CKC and OKC exercise group following ACL Reconstruction with BPTB graft
  - OKC exercises were initiated 6-weeks post-op and in the range of 90-40° and progressed to 90-10° by 12-weeks post-op
    - Mikkelsen C, Werner S, Eriksson E. Closed kinetic chain alone compared to combined open and closed chain exercises for quadriceps strengthening after anterior cruciate ligament reconstruction with respect to return to sports: a prospective matched follow-up study. *Knee Surg, Sports Tramatol, Arthrosc.* 2000; 8: 337-342.

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Post-Op ACL Rehabilitation Mikkelsen et al. KSSTA. 2000

- Results:
  - No significant difference in anterior knee laxity at 6 months
  - Significant increase in quadriceps torque in the CKC/OKC group
  - Significant higher number of patients returned to pre-injury sports level in the CKC/OKC group and did so 2 months earlier than the CKC group
- Conclusion:
  - Incorporate OKC exercises with CKC exercises in the protected ranges following ACL Reconstruction

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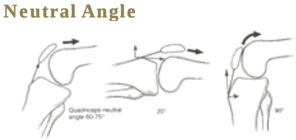
Quadriceps Neutral Angle



- Knee flexion range at which tension in the quadriceps does not create anterior or posterior shear force
- Less than 60° produces anterior shear
- Greater than 75° produces posterior shear

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ACL STRAIN AND TENSILE FORCES FOR WEIGHT BEARING AND NON—WEIGHT-BEARING EXERCISES AFTER ACL RECONSTRUCTION: A GUIDE TO EXERCISE SELECTION

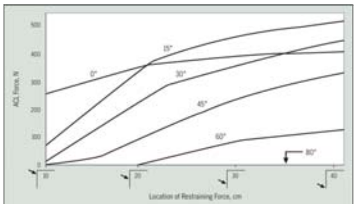

FIGURE. Changes in ACL loading during the seated knee extension exercise with proximal or distal resistance applied on the lower leg. The location of the restraining force is given relative to the distance from the knee joint. Given a constant external knee torque applied to the leg, moving the restraining force closer to the knee joint axis decreases ACL force. Abbreviation: ACL, anterior cruciate ligament. Adapted from Pandy and Shelburne.43 Reproduced with permission.

To **safely** load the quadriceps after ACL reconstruction:

- Apply loads proximally on the tibia OR
- Apply loads at less than 60° of knee flexion

Clinical Commentary
ACL Strain and Tensile Forces for Weight Bearing and Non—Weight-Bearing Exercises After ACL Reconstruction: A Guide to Exercise Selection
| VOLUME 42 | ISSUE 3 | March 2012 | © 2012 JOURNAL OF ORTHOPAEDIC & SPORTS PHYSICAL THERAPY®
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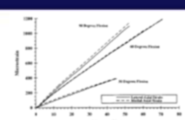
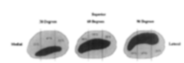
Quad Strengthening & Patellar Fracture

- There is greater axial strain on the patella in greater degrees of knee flexion
- What are the implications for post-op ACL rehabilitation with BPTB autografts or QT with bone block?





Sharkey et al., *Arch Phys Med Rehabil*. 1997

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Quad Strengthening & Patellar Fracture

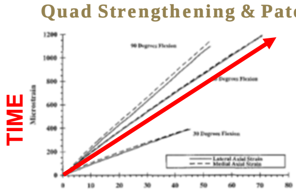
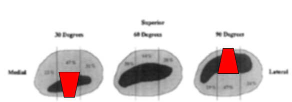


Fig 2. Line plots of mean axial surface strain for intact patella versus knee extension moment. Increasing the extension moment about the knee by simulated quadriceps contraction produced corresponding increases in axial strain. The rate of strain increase, as defined by the slope of the strain versus moment plots, increased significantly with increasing knee flexion ($p < .0001$; $n = 13$). Strains recorded at the medial and lateral gauge sites were not significantly different.

Sharkey et al., *Arch Phys Med Rehabil*. 1997



The quads have poor force generating capacity early after surgery, so even "maximal" contractions will not produce moments to fracture a patella.

However, beginning isometric contractions of the quadriceps in "vulnerable" positions early after surgery will begin to load the patella and encourage remodeling of the bone.

- As the quad improves, the load becomes greater.
- This is progressive loading of the iatrogenic "fracture"!!

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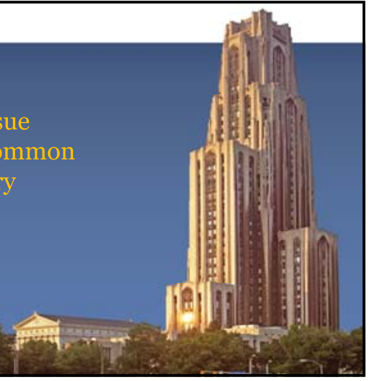
Anatomy and Tissue Protection for Less Common Ligament Surgery



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Tissue Specific Protections

ACL Reconstruction

- WBAT with/without brace and crutches
- Unrestricted ROM
  - Seek (hyper)extension
  - Follow w/AROM flexion
- Immediate WB and NWB quad/LE therex
  - NWB 90° to 60°
  - WB 45° to 0°
  - HS graft: NWB HS strength after (8-12 wk)

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Posterior Cruciate Ligament

- Attaches to the posterior intercondylar area of the tibia and passes superiorly, anteriorly, and medially to be attached to the anterior part of the lateral surface of the medial femoral condyle.
- Fibers run in two directions:
  - Anterior-lateral bundle most taut in flexion
  - Posterior-medial bundle most taut in extension
- Prevents posterior displacement of tibia
  - Secondary role in limiting:
    - Femoral external rotation
    - Tibial internal rotation

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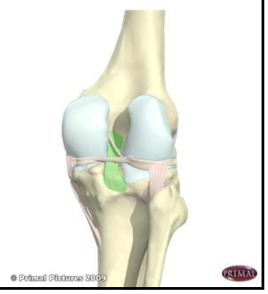
Posterior Cruciate Ligament



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PCL Mechanism of Injury

- Hyperflexion
- Fall on a flexed knee with foot in plantarflexion
- Hyperextension mechanisms
  - Step in a pot hole
- Blow to anterior tibia (Dashboard)

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Healing Potential of the PCL

- PCL healing is possible 1 year after injury with protection
  - 67% to 75% demonstrated continuity on MRI at 1 year [1, 10, 16]
  - Tended to have a firm end-point with residual laxity
  - Greater initial laxity/combined injuries led to less healing
- Adequate protection of posterior translation during rehabilitation is important to optimize healing
  - Not well tested at this time

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Tissue Specific Protections: PCL

ACL Reconstruction

- WBAT ± brace & AD
- Unrestricted ROM
- Immediate WB and NWB quad/LE therex
  - NWB 90° to 60°
  - WB 45° to 0°
  - HS 8-12 wk

PCL Injury, Reconstruction or Repair

- WBAT with brace and crutches
- Restricted ROM
  - Goal: anatomic 0 (neutral) early, maintain for 4-8 wk
  - Goal: 90° without excessive posterior tibial subluxation
  - Avoid posterior tibial glides for flexion
- Therapeutic Exercise – Care for Hamstring TEs:
  - Avoid NWB, non-resisted exercise for 8 weeks
  - Add resistance at 12 weeks

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Tissue Specific Protections: PCL

Modifications

Self-Supported Knee Flexion

PCL Injury, Reconstruction or Repair

- WBAT with brace and crutches
- Restricted ROM
  - Goal: anatomic 0 (neutral) early, maintain for 4-8 wk
  - Goal: 90° without excessive posterior tibial subluxation
  - Avoid posterior tibial glides for flexion
- Therapeutic Exercise – Care for Hamstring TEs:
  - Avoid NWB, non-resisted exercise for 8 weeks
  - Add resistance at 12 weeks

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Tissue Specific Protections: PCL

Modifications

Acceptable Glute Strengthening

PCL Injury, Reconstruction or Repair

- WBAT with brace and crutches
- Restricted ROM
  - Goal: anatomic 0 (neutral) early, maintain for 4-8 wk
  - Goal: 90° without excessive posterior tibial subluxation
  - Avoid posterior tibial glides for flexion
- Therapeutic Exercise – Care for Hamstring TEs:
  - Avoid NWB, non-resisted exercise for 8 weeks
  - Add resistance at 12 weeks

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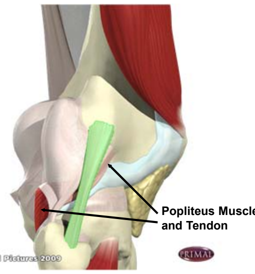
Lateral Collateral Ligament

- Attached above the lateral condyle of femur and below the head of the fibula
  - Not attached to capsule or meniscus
    - Separated from meniscus by popliteus tendon
- Resists medial/varus displacement
  - Also resists:
    - Lateral tibial rotation
    - Medial femoral rotation



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LCL During Knee Motion

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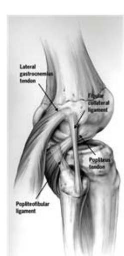
Posterolateral Corner (PLC)

- Static structures:
  - LCL, posterior horn of lateral meniscus, PL capsule
    - Oblique Popliteal
      - Derived from semimembranosus on posterior aspect of the capsule
      - Runs from that tendon to medial aspect of the lateral femoral condyle (posteriorly)
    - Arcuate popliteal
      - Head of fibula
      - Runs over the popliteus muscle to attach into posterior joint capsule
- Dynamic structures:
  - ITB, Popliteus, Biceps Femoris



Lunden et al., JOSPT, 2010

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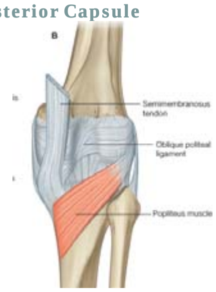
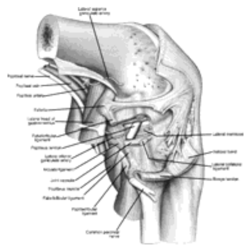
Posterior Capsule





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Posterolateral Corner Injuries

- Posterolateral-directed force to the anteromedial tibia
- Knee hyperextension
- Severe tibial external rotation with knee in low flexion angles
- Varus forces to a flexed knee
- Atraumatic may present as chronic laxity without a PCL component
  - ER of the lateral tibial plateau occurs around the still intact PCL

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Tissue Specific Protections: Lateral Corner

ACL Reconstruction

- WBAT ± brace & AD
- Unrestricted ROM
- Immediate WB and NWB quad/LE therex
  - NWB 90° to 60°
  - WB 45° to 0°
  - HS 8-12 wk

PLC Injury, Reconstruction, Repair

- WBAT with brace and crutches
- Restricted ROM
  - Goal: anatomic 0 (neutral) early, avoid hyperextension
  - Goal: 90° without excessive posterior tibial subluxation
  - No varus force, tibial rotation and posterior tibial glides

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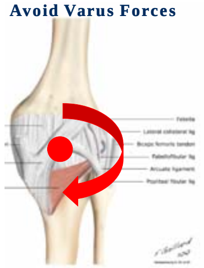
Tissue Specific Protections: Lateral Corner

Avoid Varus Forces



PLC Injury, Reconstruction, Repair

- WBAT with brace and crutches
- Restricted ROM
  - Goal: anatomic 0 (neutral) early, avoid hyperextension
  - Goal: 90° without excessive posterior tibial subluxation
  - No varus force, tibial rotation and posterior tibial glides

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Tissue Specific Protections: Lateral Corner

Avoid Varus Forces

Avoid Side-Lying Abduction

PLC Injury, Reconstruction, Repair

- WBAT with brace and crutches
- Restricted ROM
  - Goal: anatomic 0 (neutral) early, avoid hyperextension
  - Goal: 90° without excessive posterior tibial subluxation
  - No varus force, tibial rotation and posterior tibial glides

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Tissue Specific Protections: Lateral Corner

If Hamstring Involved: Avoid Hamstring Ex

PLC Injury, Reconstruction, Repair

- WBAT with brace and crutches
- Restricted ROM
  - Goal: anatomic 0 (neutral) early, avoid hyperextension
  - Goal: 90° without excessive posterior tibial subluxation
  - No varus force, tibial rotation and posterior tibial glides
- Therapeutic Exercise – Care for Hamstring TEs:
  - Avoid NWB exercise for 8 weeks
  - Add resistance at 12 weeks

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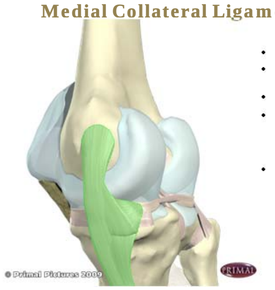
Medial Collateral Ligament



- Flat band
- Attached above medial condyle of the femur and below to the medial surface of the shaft of the tibia
- Resists lateral/ valgus displacement
- Also resists:
  - Lateral tibial rotation
  - Medial femoral rotation
- 3 layers
  - Superficial
    - more vascularized and first to be injured
  - Intermediate
  - Deep
    - fibers that blend with medial meniscus

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MCL During Knee Motion

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Healing Potential of the MCL

- Combined with ACL Injury[20]
  - Injury to superficial femoral MCL responded well to bracing
  - Injury to superficial & deep MCL often required surgery
- Tibial Sided Injury thought to not heal as well
- Functional rehabilitation important; avoiding valgus stress

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Tissue Specific Protections: Medial Corner

ACL Reconstruction

- WBAT ± brace & AD
- Unrestricted ROM
- Immediate WB and NWB quad/LE therex
  - NWB 90° to 60°
  - WB 45° to 0°
  - HS 8-12 wk

Medial Corner Injury, Reconstruction, Repair

- WBAT with brace and crutches
- Restricted ROM
  - Goal: anatomic 0 (neutral) early, may avoid hyperextension completely (capsule involvement)
  - Goal: 90° without excessive valgus forces/tibial ER
- Therapeutic Exercise
  - Care for Hamstring TEs if capsule involved

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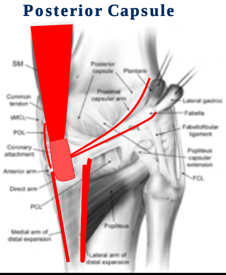
Tissue Specific Protections: Medial Corner

Posterior Capsule



Medial Corner Injury, Reconstruction, Repair

- WBAT with brace and crutches
- Restricted ROM
  - Goal: anatomic 0 (neutral) early, may avoid hyperextension completely (capsule involvement)
  - Goal: 90° without excessive valgus forces/tibial ER
- Therapeutic Exercise
  - Care for Hamstring TEs if capsule involved

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Tissue Specific Protections: Medial Corner

Avoid Valgus Forces

Medial Corner Injury, Reconstruction, Repair

- WBAT with brace and crutches
- Restricted ROM
  - Goal: anatomic 0 (neutral) early, may avoid hyperextension completely (capsule involvement)
  - Goal: 90° without excessive valgus forces/tibial ER
- Therapeutic Exercise
  - Care for Hamstring TEs if capsule involved
  - Avoid Valgus Forces

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Tissue Specific Protections: Hamstrings Considerations

Active Posterior Drawer

- If contraction of the hamstrings causes a visible posterior dislocation or subluxation of the tibia, there is insufficient healing of the PCL or PLC
  - Warrants referral back to the surgeon
- If this causes significant pain after a hamstring repair, may indicate incomplete healing

Non-Resisted Hamstrings Ex

8 weeks post-surgery

- Heel Slides
- Prone HS Curls
- Standing HS Curls
- Prone Glute Press

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Assessment and Intervention for Stiff Knee Joint ROM

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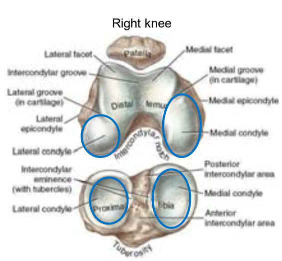
Tibiofemoral Osteology

- Medial side is longer
- Plateaus don't match condyles
  - Rotation occurs in ~50 of TKE
  - Screw home mechanism
    - IR of femur on tibia
    - Popliteus unlocks from full extension



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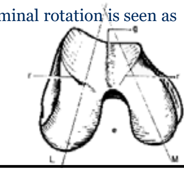
Terminal Rotation
Screw Home or Locking Home

- Knee moves towards full extension, the tibia external rotates about 20-30 degrees on the fixed femur – Explain relationship of condyles
- Purely mechanical event
  - Occurs with passive or active knee extension, can not be produced voluntarily
- In weight bearing, such as rising from sitting, terminal rotation is seen as internal rotation of the femur on fixed tibia



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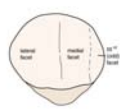
Patellofemoral Osteology

- Medial and lateral facets engage early
- Odd facet engages around 135°
- Patellofemoral tracking and engagement are very important!!



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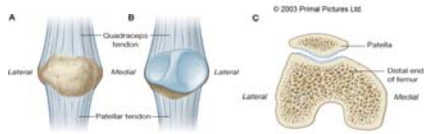

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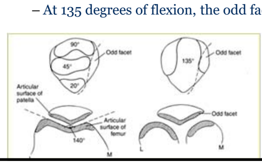
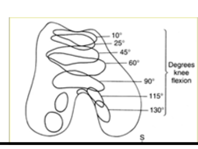
Patellofemoral joint

- From full flexion to extension, the patella slides 7 to 8 cm
- Contact area
  - During the beginning of flexion, the contact on the distal end
  - As flexion approaches 90 degrees, the articulating surface moves towards the base to cover the proximal one half of the patella
  - At 135 degrees of flexion, the odd facet comes into contact





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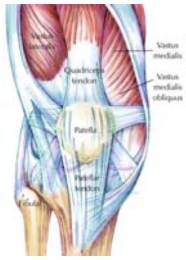
Patella

- Stabilization:
  - Quads stabilize on all sides and guide motion between patella and femur
  - Distally, anchored by the patellar tendon
  - Retinaculum anchors on medial and lateral sides
  - VMO contributes on medial side
  - IT band and VL assist laterally



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Joint Mobilization to Improve Knee Flexion

Patellofemoral Joint

- As the knee flexes,
  - Patella glides inferiorly
  - Lateral facet and odd facet contact the femur
    - My experience – greater compression laterally, especially with joint effusion
- Intervention:
  - Medial & Inferior glides in Flexion
  - Medial tilt mobilizations in resting

Tibiofemoral Joint

- Tibia glides posteriorly
  - Minimal tibial rotation
  - May get some posterior "pinching" or impingement
- Intervention
  - Joint distraction in sitting
  - Posterior glides in flexion
    - Get the patient to relax!!
  - If you have posterior impingement, you may need to do an anterior or rotational glide!!

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Anterior and Posterior Tibial Mobilizations

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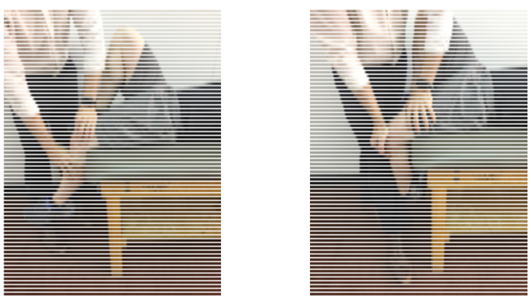

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Joint Mobilization to Improve Knee Extension

Patellofemoral Joint

- As the knee extends,
  - Patella glides superiorly
  - In full extension, there is minimal contact with the walls of the trochlea
    - My experience – greater compression laterally, most often from a tilt of the patella
- Intervention:
  - Medial & Superior glides in Flexion
  - Medial tilt mobilizations in resting

Tibiofemoral Joint

- Tibia glides anteriorly
  - Tibia must externally rotate to engage screw home mechanism
- Intervention
  - Joint distraction in supine
  - Anterior glides in extension
    - Get the patient to relax!!
  - If you are missing terminal extension, may need to bias tibial external rotation.

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Knee Extension Measurements

Resting Knee Extension
- Prop the heel on a bolster
- Relax the leg

Knee Extension with a Quad Set
- Keep the heel on the bolster
- Contract the quadriceps

Knee Extension During Straight Leg Raise
- Perform a Quad Set, then lift about 6"
- Visually estimate ROM
- Measure if knee flexes

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Knee Extension ROM Considerations

Resting Knee Extension
- Resting position or Loose Pack Position is about 20° to 30° of flexion
- Can the individual rest with their limb on the table and no posterior support?
- Can the individual rest their limb with the heel supported and nothing under the knee?
- Where is discomfort felt?
  - Posterior (capsule v. hamstring tendons v. gastroc)
  - Anterior ("pinching")

Knee Extension with Quad Set
- Does the quad visibly contract?
- Does contraction produce a superior patellar glide?
  - Visually? Palpation?
  - Lateral deviation?
- Does the gluteus maximus co-contract?
  - Typically see an apparent "reduction" in extension when you ask the person to contract.
  - Knee stays in the same place, greater trochanter rises due to glute contraction.
- Does this cause pain?
  - Anterior (patellar tendon v. quad tendon v. quad muscle)
  - Retropatellar
  - Posterior

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Quadriceps Lag

- A **Lag Sign** is a clinical finding that indicates a muscle is not capable of holding an end range position.
  - The ability of the muscle to maintain the position **lags** behind the total ROM
  - Typically no external resistance is used (i.e. body weight only)
- A **Quadriceps Lag** indicates that the quadriceps is not able to maintain full knee joint extension when there is no support to the tibia.
  - Maximum Extension – Extension during SLR

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Quadriceps Lag

- If a quadriceps lag is present, there is considerable muscle weakness
  - Individual likely not strong enough to achieve ACTIVE terminal knee extension in gait
    - Hyperextension thrust vs. Flexed Knee Gait
  - Restore muscle activation toward end range
    - Superior patellar mobilizations
    - Quadriceps sets
    - Short Arc Quadriceps Exercises
    - Terminal Knee Extension (Prone vs. Standing vs. Dorsiflexed)

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Restoring Quadriceps Function

- Pain and effusion adversely affect quad function (“quad inhibition”)
- Quadriceps activation failure is a problem when extensor mechanism is disrupted
  - Quad Tendon or Patellar Tendon Autografts
- Poor quad function can lead to patellofemoral arthrofibrosis
- Good quad function requires adequate patellar mobility
- Restoration of quad function correlates with ADL function in early stages of recovery
- **Quantity and Quality** of exercise key to maintaining & improving quad function
  - 3 sets of 10 quad sets 3x/day?
  - **50 quad sets every hour you are awake!**

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NMES Parameters

- 2500 hz,
  - 75 bursts/sec
- 10 contractions
- 10” on/50” off

Fitzgerald et al., *JOSPT*, 2003

- Stimulus produces full, sustained quad contraction with evidence of superior patellar glide

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Fitzgerald et al. JOSPT 2003 Results

- Patients receiving modified high-intensity NMES had:
- Better quadriceps index at 12 weeks
- Higher KOS-ADLS scores at 12 & 16 weeks
- Greater proportion met criteria for progression to agility exercises at 16 weeks (62% vs. 30%)

TABLE 2. Twelve- and 16-week maximum isometric torque quadriceps (quad) indices, Activities of Daily Living Scale (ADLS) scores, and knee pain ratings. All values are mean ± SD.

	NMES* Group	Comparison Group
12-wk quad index†	75.9 ± 16.8	67.0 ± 19.9
16-wk quad index	83.1 ± 15.6	75.0 ± 17.8
12-wk ADLS†	89.2 ± 8.9	82.2 ± 10.4
16-wk ADLS†	91.5 ± 7.3	86.4 ± 8.2
12-wk knee pain rating	1.5 ± 1.9	1.2 ± 1.4
16-wk knee pain rating	0.9 ± 1.1	1.1 ± 1.2

* Neuromuscular electrical stimulation.
† Significant difference between groups, $P<.05$.

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Therapeutic Exercise in Tissue Protection & Symptom Modulation Phase

Strength Training

- Non-Weight Bearing Quad Strengthening
  - See following slides
- Weight Bearing Quad Strengthening
  - TKE (standing v. prone v. dorsiflexed)
  - Step Up/Down
  - Squats
  - Leg Press
- Neuromuscular Electrical Stimulation (NMES)
- Hip/Core/Hamstring?

Functional Training

- Gait Training
  - Sequencing with AD
  - 3-way Weight Shifting
  - Step and Holds
- Cycling for ROM
  - Arc of motion to stretch
  - 100 to 110 for full revolutions

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Isometric Exercise: Muscle Setting Exercises

- Low to moderate-intensity isometric exercises performed against little or no resistance
  - Can think of it as practicing muscle activation
- Will not appreciably increase strength, but may retard atrophy
  - Can increase recruitment of muscle
- Additional Uses:
  - relaxation, circulation, reduce pain/spasm

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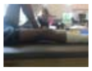
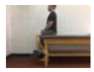
Quadriceps Isometric Matrix

		Hip Position		
		0°	45°	90°
Knee Position	0°			
	45°			
	90°			

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Acceptable OKC Quad Strengthening

- Isometrics at 90° and 60°
- Long arc quadriceps exercises
  - Weeks 0-12 - 90-60°
  - Weeks 12-16 – 90-45°
  - Weeks 16+ - 90-0°
- Short arc quadriceps exercises
  - 0-10° does not put excess strain on ACL
  - 0-30° may not be appropriate after ACLR

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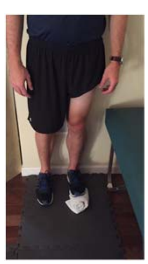
Additional Interventions for Terminal Knee Extension



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Weight Bearing Strengthening

- More “functional”, BUT doesn’t isolate the quad!
- Generally thought to be safer for early rehabilitation
  - Reduce anterior shear force (after ACL)
  - Increase tibiofemoral compression
  - Increase co-contraction of the hamstrings
- Incorporates the entire kinetic chain
- Element of proprioception

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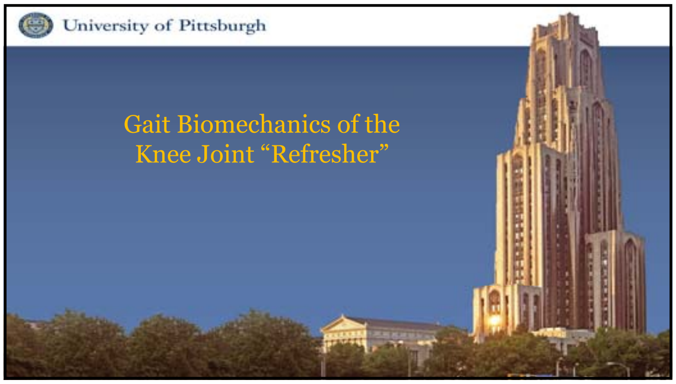
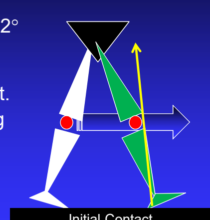
Gait Biomechanics of the Knee Joint “Refresher”



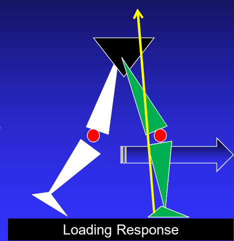
Gait Analysis: Knee: Initial Contact

- Knee is mostly extended (2° hyperext to 5° flex)
- GRF is ant to knee and creates extension moment.
- Some quad and hamstring cocontraction for stability



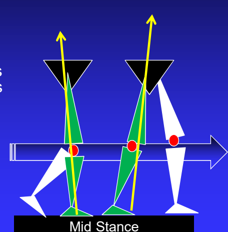
Gait Analysis: Knee: Initial Contact Through Loading Response

- Knee flexes about 15°
- GRF now behind knee resulting in a flexion moment.
- Quads have to control the flexion moment.
- Shock absorption



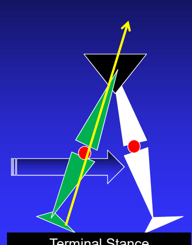
Gait Analysis: Knee: Loading Response to Mid Stance

- Knee extends to near full extension.
- First done by quadriceps
- Later, momentum of body moves femur forward over tibia with less quadriceps required
- GRF moves more anterior requiring less quadriceps



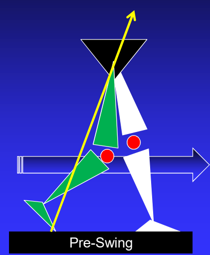
Gait Analysis: Knee: Terminal Stance

- Knee completes maximum extension
- Toward end of terminal stance, slight flexion occurs in preparation for swing.



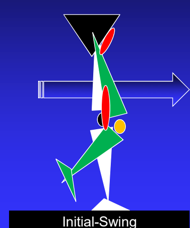
Gait Analysis: Knee: Pre-Swing

- Approximately 40° of knee flexion occurs passively
- PF of ankle by gastroc-soleus indirectly causes passive knee flexion



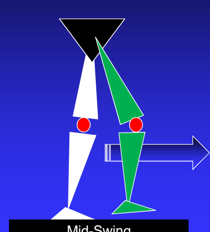
Gait Analysis: Knee: Initial Swing

- Knee flexes to 60° for foot clearance.
- Caused by momentum of thigh and by contraction of hamstrings



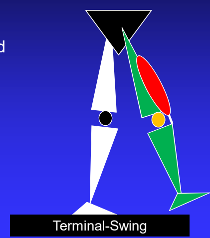
Gait Analysis: Knee: Mid-Swing

- Knee begins to passively extend
- Gravity acting on the tibia and the forward momentum of the thigh provide the forces for extending the knee.



Gait Analysis: Knee: Terminal Swing

- Active extension occurs.
- Quads needed to get knee into enough extension for contact and to assist in making the knee stable on contact.
- Hamstrings are active to decelerate the knee at this time and also help make knee stable for initial contact



Gait Analysis: Knee: Adduction Moment

- Greatest during loading response, but present throughout stance phase

Gait Analysis: Knee: Rotation

- Medial rotation (~ 8°) occurs as result of tibial rotation in first part of stance
- Lateral rotation occurs as result of tibial lateral rotation in later part of stance

Expected Deviations in the Acutely Injured Knee

- Noticeable Limp
  - Avoiding weight bearing on the injured limb
  - Short stance time injured limb; Short step length for the uninjured limb
- Flexed Knee Gait
  - Avoids terminal knee extension at initial contact and mid-stance
  - Avoids eccentric knee flexion through loading response
  - Theory
    - Quadriceps avoidance gait vs. Optimal length-tension for the quads
    - Co-contraction of the quadriceps and hamstrings to limit motion

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Motor Learning in Gait Retraining

- The capability of learning a skill may be influenced by the stage of motor learning.
  - Motor learning: a complex set of internal processes that involves the acquisition and relatively permanent retention of a skilled movement or task through practice (Kisner & Colby)
- Expectations, practice methods and feedback can vary depending on the stage of motor learning.

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3 Types of Motor Tasks

- Discrete
  - Beginning and end
- Serial
  - Sequence of discrete tasks
- Continuous
  - No beginning/end

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Environment for Motor Learning

- Open
  - Balance board
  - Busy clinic or in community
  - Patient must adjust/interact
- Closed
  - Less complex

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Stages of Motor Learning

Verbal-Cognitive Stage

- Learning the goals and appropriate responses
- Requires higher attention demands on part of learner
- Responses are uncertain, uncoordinated
- Gradually develops ability to self-correct

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Stages of Motor Learning

Motor (Associative) Stage

- Focus on more effective ways of responding
- Attention demands diminish
- Developing motor programs for more effective responses
- Exploring variations and modifications of task under changing conditions
- Developing internal feed-back mechanisms and self correction of errors

Stages of Motor Learning

Autonomous Stage
- Very little instruction needed
- Motor programs are in place
- Responses are automatic and executed on subconscious level
- Easily adapts to variations in task demands and environmental conditions
- Refinement of responses for high level function

What Type of Practice Method Should Be Used?

- Physical
  - Overall superior
- Mental
  - Reinforces cognitive component of motor learning

What Type of Practice Method Should Be Used?

Part Practice
- Break task into segments. When each segment is mastered then practice the whole task
  - Best for serial skills

Whole Practice
- Practice the entire task without breaking into segments
  - Best for continuous skills

What Type of Practice Method Should Be Used?

Blocked
- Segments of task or whole task, repeated
- Static conditions.
- Early stages of learning
- Permanent behavior change?

Random
- Slight variations of task in random order
- Either different segments or different conditions of the whole task.
- Later stages of learning
- Permanent behavior change?

What Type of Practice Method Should Be Used?

- Random-Blocked Practice
  - Variations of same task are performed in random order but each variation is performed at least twice.
- Variable Practice
  - Practicing different parameters of the task (speed, force levels, terrain, timing)

What Type of Feedback Method Should Be Used?

Continuous Feedback
- Give learner continuous knowledge of performance or results as they are doing the task
- Ok in very beginning (cognitive stage) but may interfere with long-term learning
- Does not allow for self detection and correction of errors

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What Type of Feedback Method Should Be Used?

- Summary Feedback
  - Allow patient to practice task for a while then give them a summary of how they did.
  - Pick out a few key points for changes
  - Allows them to develop self detection and correction of errors
  - Better for more permanent changes in behavior or learning
  - Use in Motor (Associative) stage of learning

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What Type of Feedback Method Should Be Used?

- KP vs KR
  - Knowledge of Performance: either intrinsic feedback sensed during the task, or immediate post-task feedback re: QUALITY of performance
  - Knowledge of Results: immediate post-task feedback re: RESULTS of performance

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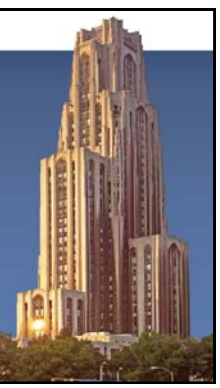
Assessment and Intervention of Muscle Performance in the Motor Control Phase



Manual Muscle Tests

- Are of greatly limited use in the main muscles of the knee joint – quadriceps and hamstrings!
  - Large, strong muscle groups
  - Difficulty stabilizing
  - Can likely overcome the strength of the tester
    - Must ensure proper body mechanics and stabilization
  - Difficulty determining relative side-to-side differences in strength

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Electromechanical Dynamometry

- Gold standard for measuring quadriceps strength in clinical studies[1]
  - Highly reliable[2]
  - Requires extensive equipment
  - Expensive

1. Martin 2006 J Gerontology
2. Kean 2010 Archives of PM&R
3. Verdijk 2009 J Sport Sci

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1 Repetition Max (1-RM)

Testing Procedure:

- Alternating limbs
  - Fully extend knee
  - Hold extension for 2 seconds
  - Return under control
- Failure determined by 3 unsuccessful attempts at a single weight
- Maximum weight lifted was recorded for each limb

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Leg Press – 1-RM

Standard Leg Press Machine

- Knee at 90°, Hip ~ 90°
- Compensation avoided
  - Gastroc-Soleus minimized
  - Opposite limb suspended

Results:

- Over-estimated quadriceps strength compared to Biodex

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Leg Extension – 1-RM

Standard Leg Extension Machine

- Knee at 90°, Hip ~ 90°
- 2 ranges tested
  - 90° – 0° (LegExt90)
  - 90° – 45° (LegExt45)

Results:

- No difference between LegExt90 & LegExt45
- Correlated well with Biodex, but cutoffs slightly different

TABLE 4 Cut Points for KX45 Alternative Measure to Identify Clinical Threshold QI Symmetry*

	Clearance for Return to Running (80% QI)			Clearance for Return to Play (90% QI)		
	Cut Point	Observed Specificity	Observed Sensitivity	Cut Point	Observed Specificity	Observed Sensitivity
Minimum specificity						
80%				96.4	81.3	29.2
85%	83.1	89.5	64.9	100.9	87.5	16.7
90%	83.1	89.5	64.9	104.6	90.6	12.5
Area under the curve†		86.7 (74.3, 99.1)			70.5 (56.6, 84.4)	

Abbreviations: KX45, knee extension from 90° to 45°; QI, quadriceps index.
*Values are percent.
†Values in parentheses are 95% confidence interval.

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Handheld Dynamometry - Quadriceps

Without Fixation

With Fixation

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Handheld Dynamometry - Hamstrings

Without Fixation

With Fixation

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Functional Strength Testing

- Sit to Stand Test/Chair Rise Test
- Forward Step Down Test
- Lateral Step Down Test
- Single Leg Squat Test

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30 second Chair Rise

- Can also record time to 5 reps
  - "5x Sit to Stand Test"
- Can attempt single leg for side to side comparisons
  - 30 seconds vs. 5x

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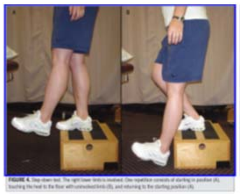
Forward Step Down

- Platform 8 inches (20.32 cm) high.
- Patients step forward and down toward the floor.
  - Down limb only brushes the floor with the heel and then returns to full knee extension (one repetition).
  - Each repetition must be completed such that the step limb (down limb) is not used to accelerate back onto the step.
  - The number of repetitions the subject performs in 30 seconds is recorded.



Loudon JK, Wiesner D, Goist-Foley HL, Asjes C, Loudon KL. Intrarater reliability of functional performance tests for subjects with patellofemoral pain syndrome. *J Athl Train*. 2002;37:256-261.

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Also must consider…

Muscles that control the femur
- Gluteus maximus
- Gluteus medius
- Other lateral rotators
- Iliopsoas
- Sartorius??

Muscles that control the tibia
- Gastrocnemius/Soleus
- Peroneals
- Posterior tibialis
- Anterior tibialis

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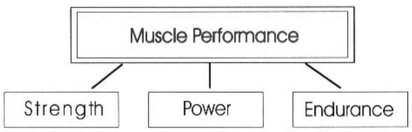
Strengthening of the Quadriceps During the Motor Control Phase

Muscle Performance

- “The capacity of a muscle or group of muscles to generate forces”: APTA Guide to Physical Therapy Practice, Phys Ther. 2001;81:S72.



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Muscle Performance

- Strength - The muscle force exerted to overcome a resistance under a specific set of circumstances.
- Power - The work produced per unit time or the product of strength and speed.
- Endurance - The ability to sustain forces repeatedly, or to generate forces over a period of time.
    - APTA Guide to Physical Therapy Practice, Phys Ther. 2001;81:S72.

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General Progression

- Isometric exercises used during early stages of recovery when limb is immobilized or motion is contra-indicated
    - Useful to modulate symptoms, especially muscle/tendon pain
- Eccentric exercises used when motion is permitted, but tension developing capacity of muscle is poor
- As recovery progresses a combination of concentric and eccentric exercises should be utilized since most functional activities require both forms of contractions

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Types of Resistance Exercises: Isometric Exercise

- Muscle contracts to produce tension without change in overall muscle-tendon length
  – No joint movement is produced.
  – Muscle portion contracts, tendon portion lengthens
- Good in early stages of a strengthening program when muscle is weaker or if pain is a concern
- Easier to teach the concept of pain-free contractions with isometrics for some patients.

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Types of Resistance Exercises: Isometric Exercise

- May be tolerated better by patients with conditions where shear forces may exacerbate the problem
  – arthritis, articular cartilage lesions
- Some recommend performance at multiple angles for better carry-over throughout the range.
- Some carry-over can be achieved in other ranges.
  – Book is not correct in saying there is little to no carry-over.
  – Evidence shows some carry-over at other angles (Bandy WD, Phys Ther, 1993)

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Isometric exercise induces analgesia and reduces inhibition in patellar tendinopathy

Ebonie Rio,[1] Dawson Kidgell,[2] Craig Purdam,[3] Jamie Gaida,[1,4] G Lorimer Moseley,[5] Alan J Pearce,[6] Jill Cook[1]

Rio E, et al. Br J Sports Med 2015;49:1277–1283. doi:10.1136/bjsports-2014-094386

Table 2 Loading protocols in the study

	Apparatus	Prescription	Recovery (min)	Loading bolus
Isometric	Biodex Pro	5×45 s at 60°	2	70% MVC
Isotonic	Leg extension machine	4×8 repetitions 4 s eccentric phase 3 s concentric phase	2	100% 8RM

MVC, maximal voluntary contraction; RM, repetition maximum.

Compared isometric vs. isotonic:
- n=6 (very small)
- Time under load was matched
- Considered pain on a single leg decline squat
- **Pain Reduction and Strength Increases were greater with isometric exercise than with isotonic exercise**
  - Immediate and 45min later

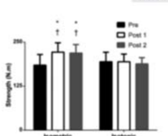

Figure 4 Maximal voluntary isometric strength: mean (±SD) maximal voluntary isometric contraction torque preisometric and postisometric and preisotonic and postisotonic strength training. Immediately following an acute bout of isometric strength training, isometric strength increased by 19% and was sustained at 45 min post compared with no change following a single bout of isotonic strength training. * Denotes difference to preintervention (p<0.05); † denotes difference to the same time point for the isotonic intervention (p<0.05).

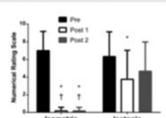

Figure 2 Single-leg decline squat (SLDS; tendon pain) preintervention and postintervention: mean (±SD) changes in SLDS preisometric and postisometric and preisotonic and postisotonic strength training. Immediately following an acute bout of isometric strength training, SLDS numerical pain rating scale improved by 87% and was sustained at 45 min post compared with isotonic. Immediately following an acute bout of isotonic strength training, SLDS numerical pain rating scale improved by 42%, however by 45 min post the intervention, it was not significantly different to baseline. * Denotes difference to preintervention (p<0.05); † denotes difference to same time point for the isotonic intervention (p<0.05).

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Isometric Contractions Are More Analgesic Than Isotonic Contractions for Patellar Tendon Pain: An In-Season Randomized Clinical Trial

Ebonie Rio, BASc, BA Phys (Hons), PhD, MSp(Phys),*†¶ Mathijs van Ark, PhD, MSc,† Sean Docking, PhD, BHSc(Hons),*†¶ G. Lorimer Moseley, BASc (Phty)(Hons), PhD, FACP,‡ Dawson Kidgell, PhD,¶ Jamie E. Gaida, PhD,*|| Inge van den Akker-Scheek, PhD,‡ Johannes Zwerver, MD, PhD,† and Jill Cook, PhD*†¶

Clin J Sport Med • Volume 27, Number 3, May 2017

- Same 2 Training Protocols
  - 20 subjects, 10 in each group
  - **Greater analgesia with isometric exercise than isotonic**
  - No difference in overall function per the VISA-P

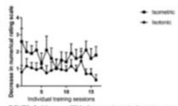
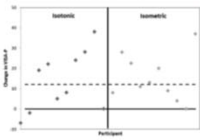


FIGURE 1. Mean ± SEM decrease in pain between pre-measures and postmeasures for the isotonic group (circles) and isometric group (squares) for each training session.



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2009 ACSM Recommendations for Resistance Training

- Strength Training
- Muscle Hypertrophy
- Muscle Power
- Local Muscle Endurance
- Motor Performance
- Older Adults

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ACSM Recommendations: Strength Training

- Novice and Intermediate; 60-70% of 1 RM, 8-12 repetitions, 1-3 sets
- Advanced; cycle loads of 80-100% of 1 RM
- Intermediate and advanced should use multiple sets (varying load and volume)
- Unilateral and bilateral, and single and multi-joint ex encouraged with an emphasis on multi-joint exercise.

ACSM Recommendations: Strength Training

- Free weights and machines for novice and intermediate
- Advanced should emphasize free weights with supplementation by machines
- Recommended Sequencing:
  - Large groups before small groups
  - Multiple joint exercise before single joint exercise
  - High intensity before low intensity

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ACSM Recommendations: Strength Training

- Exercise Speed:
  - Slow and moderate velocities for untrained
  - Moderate velocities for intermediate
  - Combo of slow, moderate and fast for advanced depending on load amount
- Frequency:
  - 2-3 days/week for novice
  - 3-4 days/ week for intermediate
  - 4-6 days/week for advance
- Rest: 2-3 min rest between sets for primary ex, 1-2 min for secondary ex

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ACSM Recommendations: Muscle Hypertrophy

- Novice and intermediate: 70-85% 1 RM, 8-12 reps, 1-3 sets
- Advanced: 70-100% of 1 RM, 1-12 reps, 3-6 sets
- Rest:
  - Novice and intermediate is 1-2 min between sets.
  - Advanced is 2-3 minutes for heavier load and 1-2 minutes for moderate load ex
- Sequencing, velocity, and frequency is same as strength training

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ACSM Recommendations: Muscle Power

- Recommended as concurrent with strength program.
- 1-3 sets of exercise, using light to moderate loads for 3-6 reps but not to failure.
  - Upper body load 30-60% 1 RM
  - Lower body load 0-60% of 1 RM.
- Performed at explosive speed for fast force production.
- May perform 6 sets, with 1-3 min rest between sets depending on load
- Frequency/wk:
  - 2-3d for novice, 3-4d for intermediate, 4-5d for advanced

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ACSM Recommendations: Local Muscle Endurance

- Novice and intermediate use relatively light loads, 10-15 reps with moderate to high volume.
- Advance should vary loading with multiple sets (10-25 reps or more)
- 1-2 min rest for sets of 15-20 reps or more.
- Less than 1 minute rest for 10-15 reps.
- Frequency same as strengthening and power training

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ACSM Recommendations: Motor Performance

- For jumping, sprinting, etc.
- Multiple joint exercise with combination of light, moderate, and heavy loads using fast repetition velocity with moderate to high volume.
- Use of plyometrics in combination with resistance training is recommended
- Heavy resistance combined with ballistic resistance ex with sprint and plyometrics should be included to improve sprinting ability

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ACSM Recommendations: Older Adults

- Both multiple joint and single joint exercises
- Free weights and/or machines
- 60-80% 1 RM, 8-12 reps, 1-3 sets, with 1-3 min rest between sets.
- Can also incorporate power programs of 30-60% 1 RM, 6-10 reps, 1-3 sets at higher repetition velocity.
- Endurance training similar to others, using lighter loads with higher reps (10-15 or more)

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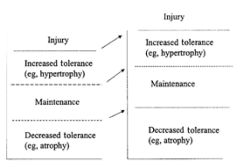
Progressive Resistive Exercise

Introduced by Delorme in 1945 for post-surgical rehab

- "a condition wherein a muscle must work to full capacity against ever increasing resistance"
- Key is to progress exercise intensity to increase strength
- Avoid under-dosing!



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How do I progress the resistance of my PREs?

- Weekly assessment of 10 RM
  - Delorme (1945)
- Weekly progression of 10 lbs
  - Donoho (1966); Kline (1956)
- Daily progression of 1lb per day
  - Zinehieff (1951)
- 10 RM Assessment is time consuming!
  - Worthwhile at the beginning of treatment
  - Great measure of strength for follow-up
  - Not a good use of time every week
- Other programs don't allow for individual progression!

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Alternative to Repetition Maximum for Dosing

- Borg Perceived Exertion Scale
  - Begin in hard to very hard range
    - 6 to 20 Scale: 15-17
    - 0 to 10 Scale: 5-7
  - When rating at a given load drops below "hard to very hard", increase load until perceived exertion is back in "hard to very hard" range

Borg Perceived Exertion Scale			
	Least Effort		
6			0
7	very, very light		
8			
9	very light		1
10			
11	fairly light	Endurance Training Zone	2
12			3
13	somewhat hard		4
14			
15	hard	Strength Training Zone	5
16			6
17	very hard		7
18			8
19	very,very hard		9
20			10
	Maximum Effort		

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[RESEARCH REPORT]

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JAMES J. IRRGANG, PT, PhD, ATC, FAPTA • G. KELLEY FITZGERALD, PT, PhD, FAPTA

Test-Retest Reliability of Rating of Perceived Exertion and Agreement With 1-Repetition Maximum in Adults

Generally, **agreement was poor within the ranges that would typically be used for training (50% 1RM for muscle endurance, 70% 1RM and greater for muscle strength)**. Within the training zone, participants tended to underestimate the amount of weight they were lifting.

TABLE 2 — Agreement Between 1RM and RPE at Each Resistance Interval

1RM, %	Agreement, %	Overestimates, %	Underestimates, %	Overestimates/ Underestimates, n	Median (Range) RPE
10	96	4	0	1/0	1 (1-3)
20	92	8	0	2/0	1 (1-6)
30	68	4	28	1/7	2 (1-5)
40	68	0	32	0/8	3 (1-5)
50	28	12	60	3/15	3 (1-9)
60	32	16	52	4/13	4 (1-10)
70	40	16	44	4/11	6 (1-10)
80	52	12	36	3/9	8 (2-10)
90	60	0	40	0/10	9 (2-10)
100	60	0	40	0/10	10 (2-10)

Abbreviations: 1RM, 1-repetition maximum; RPE, rating of perceived exertion.

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Daily Adjustable Progressive Resistive Exercise Technique (DAPRE)

- Knight AJSM 1979
  - Establish a target training weight
    - Educated Guess
  - Complete 2 warm-up sets
    - 50% of training weight x10
    - 75% of training weight x6
  - Complete 2 training sets
    - Maximum # of Reps
    - As many reps as possible – (AMRAP)
    - Adjust if <6 or >10

TABLE 1
DAPRE technique

Set	Weight	Repetitions
1	One-half working weight	10
2	Three-quarters working weight	6
3	Full working weight	Maximum[a]
4	Adjusted working weight[a]	Maximum[b]

[a] The number of repetitions performed during the third set is used to determine the adjusted working weight for the fourth set according to the guidelines in Table 2.
[b] The number of repetitions performed during the fourth set is used to determine the working weight for the next session according to the guidelines in Table 2.

TABLE 2
General guidelines for adjustment of working weight

No. of repetitions performed during set	Adjusted working weight	
	Fourth set[a]	Next session[b]
0–2	Decrease 5–10 lb	Decrease 5–10 lb
3–4	Decrease 0–5 lb	Keep the same
5–6	Keep the same	Increase 5–10 lb
7–10	Increase 5–10 lb	Increase 5–15 lb
11 to . . .	Increase 10–15 lb	Increase 10–20 lb

[a] The number of repetitions performed during the third set is used to determine the adjusted working weight for the fourth set (Table 1).
[b] The number of repetitions performed during the fourth set is used to determine the working weight for the next session (usually the next day) (Table 1).

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ACSM Guidelines for Resistance Training

	% of 1 Repetition Maximum for Common Quadriceps Exercises							
	60%	70%	75%	80%	85%	90%	95%	100%
Strength (Novice)	1 to 3 sets; 8 to 12 reps							
Strength (Advanced)				2 to 6 sets; 8 to 12 reps				
Muscular Endurance	<70% 1 RM 2 to 4 sets; 10 to 25 reps							
Muscular Power	0 to 60% 1-RM 1 to 3 sets; 3 to 6 reps							

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Daily Adjustable Progressive Resistance Exercise

TABLE 1
DAPRE technique

Set	Weight	Repetitions
1	One-half working weight	10
2	Three-quarters working weight	6
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	% of Training Weight	Strength Reps
Target Training Weight	% 1RM that corresponds to goal of training	
Warm-up 1	50%	Upper End of Rep Range
Warm-up 2	75%	Lower End of Rep Range
Training 1	100%	Maximum Achievable Reps
Training 2	See Chart	Maximum Achievable Reps

Reps During Set	4th Set	Next Session
< Lower End of Rep Range	Decrease by 5-10 %	No change
Within the Rep Range	No change	No change
> Upper End of Rep Range	Increase by 5-10 %	Increase by 5-10 %

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Daily Adjustable Progressive Resistance Exercise

	% of Training Weight	Strength Reps
Target Training Weight	% of 1RM that corresponds to goal of training	
Warm-up 1	50%	Upper End of Rep Range
Warm-up 2	75%	Lower End of Rep Range
Training 1	100%	Maximum Achievable Reps
Training 2	See Chart	Maximum Achievable Reps

Reps During Set	4th Set	Next Session
< Lower End of Rep Range	Decrease by 5-10 %	No change
Within the Rep Range	No change	No change
> Upper End of Rep Range	Increase by 5-10 %	Increase by 5-10 %

Strength:
8 to 12 reps
1 to 3 sets
60-85% of 1RM

Endurance:
12 to 25 reps
2 to 4 sets
<70% of 1RM

Power:
3 to 6 reps
1 to 3 sets
0-60% of 1RM

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How do I determine my initial target weight?

- 1RM Testing
- 5RM Testing
- 10RM Testing
- Educated guess?
- Leg Extension Exercise Estimated 1 RM (Bove et al, 2016, JOSPT):
  - Women – 50% Body Weight
  - Men – 70% Body Weight
  - Both tend to underestimate by about 15%, but it gets you in the ball park!

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DAPRE: 1RM is 125 lbs. Goal: Muscular Strength Training

	% of Training Weight	Strength Reps	Strength Weight
Target Training Weight	(80%)	--	
Warm-up 1	50% (40%)		
Warm-up 2	75% (60%)		
Training 1	100% (80%)		
Training 2			

Reps During Set	4th Set	Next Session
< Lower End of Rep Range (8 reps)	Decrease by 1-10%	No change
Within Rep Range (8 – 12 reps)	No change	No change
> Upper End of Rep Range (12 reps)	Increase by 1-10%	Increase by 1-10%

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DAPRE: 1RM is Unknown. (Likely to Under Dose) Goal: Muscular Endurance Training (12 to 15 reps)

	% of Training Weight	Strength Reps	Endurance Weight
Target Training Weight		--	
Warm-up 1	50%		
Warm-up 2	75%		
Training 1	100%		
Training 2			
Next Session			

Reps During Set	4th Set	Next Session
< Lower End of Rep Range (12 reps)	Decrease by 1-10%	No change
Within Rep Range (12 – 15 reps)	No change	No change
> Upper End of Rep Range (15 reps)	Increase by 1-10%	Increase by 5-10%

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Comments on Progression of Intensity

- When patient can perform 1-2 reps over the target reps for 2 consecutive sessions, training load should be increased by 2 to 10%.
  - "+2" Principle
  - Eitzen, 2011
- I would recommend re-establishing the 1 RM every 2 weeks to re-adjust training loads appropriately.
  - Unless progressing with DAPRE

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Therapeutic Exercise in the Motor Control Phase

Strengthening
- Squat, Leg Press
  - Preferential Squats, Single Leg Squats
  - Wall Sits
- Lunges, Split Squats
- Step Ups/Downs
- Hamstring Progression
  - Bridges ±hamstring curls on physioball
  - Seated to prone HS Curl machine
- Gluteus Medius Progression
  - Clamshells, ABD SLR, Lateral Stepping, etc.

Functional Training
- Balance/Proprioception
  - SLS
    - Eyes open/closed
    - Stable/unstable surfaces
    - Star Excursion?
  - Perturbation Training
- Fast treadmill walking
- Cycling with resistance/interval training
- Elliptical

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Sit to Stand

Anterior View
- Trunk should move vertically
  - No sway
- Pelvis plane should stay level
- Knee should be stable in frontal plane
  - Slight hip abduction encouraged
- Foot should not over-pronate

Lateral View
- Lumbar spine should not flex
- Pelvis and hips should move the trunk into flexion
- Motion should come from knee
- CoP should not shift into the ball of the foot

Sit to Stand

30º Squat

60º Squat

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Sit to Stand

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Sit to Stand – Preferential Loading

Anterior View

- Trunk should move vertically
  - No sway
- Pelvis plane should stay level
  - Slight deviation due to foot position
- Knee should be stable in frontal plane
  - Slight hip abduction encouraged
- Foot should not over-pronate

Lateral View

- Lumbar spine should not flex
- Pelvis and hips should move the trunk into flexion
- Targeted limb should have foot closer to support surface
  - Motion should come from knee
- CoP should not shift into the ball of the foot

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Sit to Stand – Preferential Loading


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Step Ups


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Goblet Squat vs. Romanian Dead Lift


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Split Squat vs. Uni RDL

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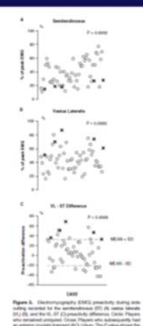
THE ROLE OF THE HAMSTRINGS AND CORE IN SECONDARY INJURY

University of Pittsburgh — Department of Physical Therapy

Identification of Athletes at Future Risk of Anterior Cruciate Ligament Ruptures by Neuromuscular Screening

Mette K. Zebis,*[†] PhD, Lars L. Andersen,[†] PhD, Jesper Bencke,[‡] PhD, Michael Kjær,[§] MD, DMsci, and Per Aagaard,[‖] PhD
From the [†]National Research Centre for the Working Environment, Copenhagen, Denmark, [‡]Gait Analysis Laboratory, Hvidovre University Hospital, Copenhagen, Denmark, [§]Institute of Sports Medicine Copenhagen, Bispebjerg Hospital, Copenhagen, Denmark, and [‖]Institute of Sports Sciences and Clinical Biomechanics, University of Southern Denmark, Odense, Denmark

- 55 elite female athletes
- Screened during a side-cutting task
  - EMG on quads and hams
- 5 ACL injuries in next 2 seasons
  - Lower pre-activity of Semi-T
  - Higher pre-activity of Vastus Lateralis
  - VL – ST EMG pre-activity was 47% in injured athletes; 2% in non-injured



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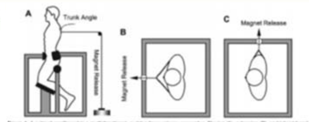
Deficits in Neuromuscular Control of the Trunk Predict Knee Injury Risk

A Prospective Biomechanical-Epidemiologic Study

Bohdanna T. Zazulak, DPT, MS, OCS, Timothy E. Hewett, PhD, FACSM, N. Peter Reeves, MSc, Barry Goldberg, MD, and Jacek Cholewicki, PhD



- 277 college athletes at baseline
  - Followed for 3y for knee injury, ligament injury, ACL injury
  - Tested trunk motion after release of force in flexion, extension, lateral bending
  - 25 knee injuries: 11 ligament, 6 ACL
- Subject held an isometric contraction
  - Magnet suddenly released
  - How much motion occurs?

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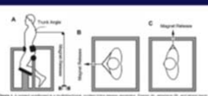

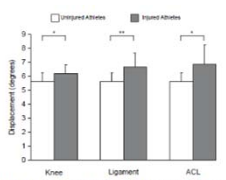

Figure 2. Displacement at 150 milliseconds in athletes (female and male combined) who subsequently sustained or did not sustain knee, ligament, or anterior cruciate ligament (ACL) injury. *P ≤ .05, **P ≤ .01. Error bars designate standard error of the mean.

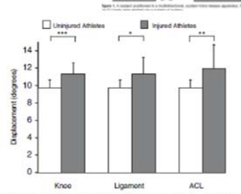

Figure 3. Maximum displacement in athletes (female and male combined) who subsequently sustained or did not sustain knee, ligament, or anterior cruciate ligament (ACL) injury. *P ≤ .05, **P ≤ .01, ***P ≤ .001. Error bars designate standard error of the mean.

Displacement at 150 milliseconds and history of LBP predicted injury with 83% sensitivity and 63% specificity

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The Effects of Core Proprioception on Knee Injury

A Prospective Biomechanical-Epidemiological Study

Bohdanna T. Zazulak, DPT, MS, OCS, Timothy E. Hewett, PhD, FACSM, N. Peter Reeves, MSc, Barry Goldberg, MD, and Jacek Cholewicki, PhD

- Investigating proprioception in rotation
- Injured females demonstrated poor trunk proprioception

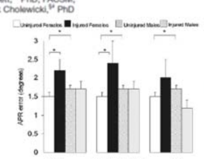

Figure 2. Average absolute error in active proprioceptive repositioning in female and male athletes who sustained or did not sustain knee, ligament/meniscal, or anterior cruciate ligament injury during the follow-up period (*P < .05). Error bars designate standard error of the mean.

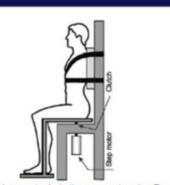

Figure 1. An apparatus for testing core proprioception. The stepper motor drive can be disengaged for active repositioning or engaged for passive repositioning.

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Utilization of ACL Injury Biomechanical and Neuromuscular Risk Profile Analysis to Determine the Effectiveness of Neuromuscular Training

Timothy E. Hewett,[*†] PhD, Kevin R. Ford,[‡] PhD, Yingying Y. Xu,[§] MS, Jane Khoury,[§] PhD, and Gregory D. Myer,[§] PhD
Investigation performed at Mayo Clinic, Rochester, Minnesota, High Point University, High Point, North Carolina, and Cincinnati Children's Hospital Medical Center, Cincinnati, Ohio, USA

- 624 female athletes completed testing
- Looked at 6 biomechanical variables:
  - ground-reaction force during the DVJ
  - hip abduction moment during the SCD
  - hip adduction moment maximum during the
  - hip adduction moment minimum during the
  - hip adduction moment minimum during the
  - peak frontal plane pelvis angle during the SCD

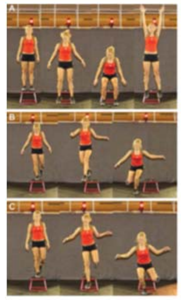

Figure 1. The 3 testing maneuvers: (A) drop vertical jump, (B) crossover single-leg drop, and (C) single-leg drop.

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Investigation performed at Mayo Clinic, Rochester, Minnesota, High Point University, High Point, North Carolina, and Cincinnati Children's Hospital Medical Center, Cincinnati, Ohio, USA

- 3 profiles identified:
  - Low, Moderate, High Risk
    - Knee Abduction Moment increased across profiles
  - GRF during DVJ increased across profiles
  - Hip adduction max during SCD increased across
  - Pelvis angle was greatest in max during SCD

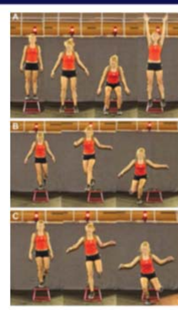

Figure 1. The 3 testing maneuvers: (A) drop vertical jump, (B) crossover single-leg drop, and (C) single-leg drop.

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Likelihood of ACL graft rupture: not meeting six clinical discharge criteria before return to sport is associated with a four times greater risk of rupture

Polyvios Kyritsis,[1] Roald Bahr,[1,2] Philippe Landreau,[1] Riadh Miladi,[1] Erik Witvrouw[1,3]

Risk of Graft Re-Rupture

- 158 professional male athletes
  - 26 ACL Re-Rupture

Table 1 Discharge tests and criteria used during the study period

Six-part return to sport tests	Discharge permitted when each of these criteria was met
Isokinetic test at 60, 180 and 300°/s	Quadriceps deficit <10% at 60°/s
Single hop	Limb symmetry index >90%
Triple hop	Limb symmetry index >90%
Triple crossover hop	Limb symmetry index >90%
On-field sports-specific rehabilitation	Fully completed
Running t test	<11 s

Criteria were set according to the literature at the start of the study.

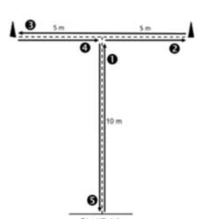

Figure 2 Agility running t test.

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Likelihood of ACL graft rupture: not meeting six clinical discharge criteria before return to sport is associated with a four times greater risk of rupture

Polyvios Kyritsis,[1] Roald Bahr,[1,2] Philippe Landreau,[1] Riadh Miladi,[1] Erik Witvrouw[1,3]

Risk of Graft Re-Rupture

- 17 of 26 re-injured within first 6m of RTS
- Fail RTS Criteria – 4x more likely to fail
  - 75% fully discharged; 10% re-injury rate
  - 25% not fully discharged; 33% re-injury rate
- H:Q Ratio:
  - each 10% decrease increased hazard x 10

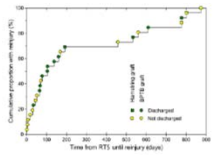

Figure 3 Cumulative prevalence of ACL re-injuries (n=26). Grey symbols denote players who were fully discharged, black symbols those not fully discharged. BPTB, bone–patellar tendon–bone; RTS, return to sport.

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Simple decision rules can reduce reinjury risk by 84% after ACL reconstruction: the Delaware-Oslo ACL cohort study

Risk of Graft Re-Rupture

- 106 athletes after ACL reconstruction
  - 28 subsequent knee injuries in 24 patients
    - 10 ACL (2 contralateral), 11 meniscus (1 contralateral), 4 cartilage, 2 MCL, 1 patella subluxation
    - Range 3 to 22m post-op; median 13 months
    - 45.5% of injuries within 2 months of RTS
  - RTS Criteria:
    - Quadriceps Index, Hop Limb Symmetry Indexes >90%
    - KOS-ADLS, Global Rating Scale > 90%

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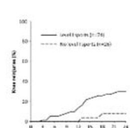
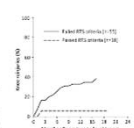
Simple decision rules can reduce reinjury risk by 84% after ACL reconstruction: the Delaware-Oslo ACL cohort study

Risk of Graft Re-Rupture

- Delay return by 1m, 50% drop in injury risk (to 9m)
- Return to Level 1 = 4.32 LR of failure vs. L2
- Pass RTS Criteria = HR of 0.16 (p=.075)
  - Fail RTS – 38% re-injury rate
  - Pass RTS – 6% re-injury rate
- RTS with < 90% QI = 3x risk of failure
- Each 1% increase in QI reduced risk x 3%





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NAJSPT

INVITED CLINICAL COMMENTARY

UNDERSTANDING AND PREVENTING ACL INJURIES: CURRENT BIOMECHANICAL AND EPIDEMIOLOGIC CONSIDERATIONS - UPDATE 2010

Timothy E. Hewett, PhD
Kevin R. Ford, PhD
Barbara J. Hoogenboom, EdD, PT, SCS, ATC
Gregory D. Myer, PhD, CSCS

Figure 2. *Squat jump sequence. Note, in a tuck jump the knees are flexed toward the trunk while in the air. See Appendix 1 for more detail on the tuck jump.*

Table 1. *Relationship between Mechanism, Neuromuscular Imbalance, and Neuromuscular Intervention for ACL Injury Prevention in Female Athletes.*

Injury Mechanism Component	Underlying Neuromuscular Imbalance	Targeted Neuromuscular Intervention Component
Knee adduction during landing	Ligament dominance	Train for proper technique
Low flexion angle in landing	Quadriceps dominance	Strengthen posterior chain
Asymmetrical landings	Leg dominance	Train side/side symmetry
Inability to control center of mass	Trunk dominance ("Core Dysfunction")	Core stability & perturb training

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		e stability & turb training

Figure 3. *"Russian" hamstring exercise with elastic resistance around the trunk to emphasize concentric and eccentric hamstring*

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Exercises to prevent lower limb injuries in youth sports: cluster randomised controlled trial

Odd-Egil Olsen, Grethe Myklebust, Lars Engebretsen, Ingar Holme, Roald Bahr

Oslo Sports Trauma Research Center

Box 2: Programme of warm-up exercises used to prevent injuries

Warm-up exercises
(30 seconds and one repetition each)
Jogging end to end
Backward running with sidesteps
Forward running with knee lifts and heel kicks
Sideways running with crossovers ("carioca")
Sideways running with arms lifted ("parade")
Forward running with trunk rotations
Forward running with intermittent stops
Speed run

Technique
(One exercise during each training session; 4 minutes and 3×30 seconds each)
Planting and cutting movements
Jump shot landings

Balance
(On a balance mat or wobble board, one exercise during each training session; 4 minutes and 2×90 seconds each)
Passing the ball (two leg stance)
Squats (one or two leg stance)
Passing the ball (one leg stance)
Bouncing the ball with eyes closed
Pushing each other off balance

Strength and power
(2 minutes and 3×10 repetitions each)
One quadriceps exercise:
Squats to 80° of knee flexion
Bounding strides (Sprunglauf)
Forward jumps
Jump shot—two legged landing
"Nordic hamstring lowers" (2 minutes and 3×10 repetitions each)

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Exercises to prevent lower limb injuries in youth sports: cluster randomised controlled trial

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Table 3 Intention to treat analysis. Values are numbers (percentages) of injured players

	Intervention group (n=958)	Control group (n=879)	Intracluster correlation coefficient	Inflation factor	Number needed to treat	Relative risk (95% CI)*	P value (Wald's test)
All injuries	95 (9.9)	167 (19.0)	0.043	1.6	11	0.49 (0.36 to 0.68)	<0.0001
Lower limb injuries	66 (6.9)	115 (13.1)	0.050	1.7	16	0.51 (0.36 to 0.73)	<0.001
Acute knee or ankle injuries:	46 (4.8)	76 (8.6)	0.057	1.8	26	0.53 (0.35 to 0.81)	0.004
Acute knee injuries	19 (2.0)	38 (4.3)	0.071	2.0	43	0.45 (0.25 to 0.81)	0.007
Acute ankle injuries	28 (2.9)	40 (4.6)	0.071	2.0	59	0.63 (0.36 to 1.09)	0.097
Upper limb injuries	17 (1.8)	39 (4.4)	0.071	2.0	38	0.37 (0.20 to 0.69)	0.002

*Cox model calculated according to method of Lin and Wei,[17] which takes cluster randomisation into account.

- NNT for All injuries – 11
- NNT for Lower Limb Injuries – 16

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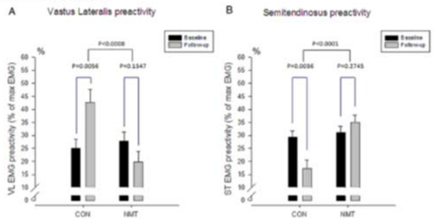
Effects of evidence-based prevention training on neuromuscular and biomechanical risk factors for ACL injury in adolescent female athletes: a randomised controlled trial

Mette K Zebis,[1,2] Lars L Andersen,[3,4] Mikkel Brandt,[3] Grethe Myklebust,[5] Jesper Bencke,[2] Hanne Bloch Lauridsen,[2] Thomas Bandholm,[6,7] Kristian Thorborg,[8] Per Hölmich,[8] Per Aagaard[9]



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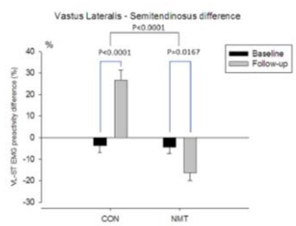

Figure 2 Neuromuscular VL-ST preactivity difference during side cutting at baseline and follow-up in the CON and NMT groups. CON, control; EMG, electromyography; NMT, neuromuscular training; ST, semitendinosus; VL, vastus lateralis.

Kinematic and kinetic data at baseline are presented in table 3. No changes within groups were observed for maximal valgus moment, valgus angle, and knee and hip flexion angle at IC.

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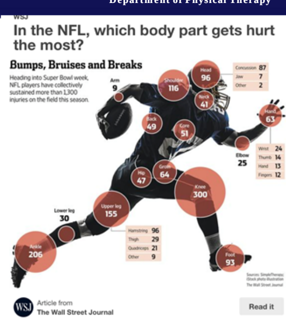
HS Injury Rates

- #1 time loss injury in major/minor league baseball
  - (Ahmad, 2014)
- 1 in 3 HS strains will recur in first 2 wks following return
  - (Orchard, 2002)
- NFL 10 year study, average time loss of 8-25 days
  - (Feely, 2008)

*Once injured always at risk regardless of time/rehab/prevention

You need to wait 8/w for a <5% reoccurrence!

(Orchard 2005)



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Hamstring Function

- **Forward propulsion** (Thelen et al 2015)
- **Decelerate shank during terminal swing** (Chumanov et al 2007)
- **Produce large force @ high speed** (Wiemann et al 1995)
- **Co-contraction during cutting** (Houck et al 2003)
- **Control tibial rotation** (Mohammed et al 2002)
- **Facilitate pelvic stability** (Windergergen et al 2004)
- **PLC / PMC stability** (Beltran et al 2003)

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Mechanism of Injury

- High Speed Running
- Most commonly BFemoris LH - distal MTJ
  Terminal swing phase - active lengthening, peak stretch
  - Ground contact mechanism
- Pain/function initially improve rapidly, but easily fooled as can't absorb energy + force
- Excessive Lengthening
- Collision mechanism, rapid stretch, high kick
  - Usually involved proximal free tendon particularly semimembranous
- Mild initial symptoms but….prolonged rehab

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PROGNOSTICS

Exam Findings	Prognosis
Injury proximity to ischial tuberosity (Askling, 2006)	More proximal the injury = greater time to return
Mechanism of injury (Askling, 2007)	Stretch injuries take longer than high speed running injuries
Location of injury within HS muscle complex (Askling, 2007)	Proximal free tendon takes longer than MTJ injury
Time to walk (Warren, 2010)	> 1 day to walk pain-free following injury; likely to require > 3 weeks of rehabilitation prior to RTS

Active knee extension deficit >10° (Moen et al 2014, Reurink et al 2015)

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Be Sure to Examine

- Adverse Neural Tension
  - More common with repeat HS injuries
    - Turl, 1998
  - Slump testing
  - Neural gliding
  - Faster recovery in grade I injuries
    - Kornberg, 1989

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Where are we testing strength?

- PRONE
  - @ 90, 60 and 30 Degrees…
- SUPINE
  - Imperative to test strength at max end-range!

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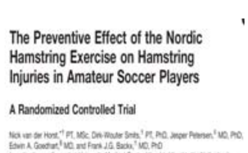
Research

- Inability to produce sufficient force in a lengthened position increases the muscle's susceptibility to injury
- 287 amateur soccer players
- 13 week/25 session Nordic curl program
  - Control group= soccer only
  - Nordic curl group (31% injuries)
  - Control group (69% injuries)



The Preventive Effect of the Nordic Hamstring Exercise on Hamstring Injuries in Amateur Soccer Players

A Randomized Controlled Trial

Nick van der Horst,[*†] PT, MSc, Dirk-Wouter Smits,[†] PT, PhD, Jesper Petersen,[‡] MD, PhD, Edwin A. Goedhart,[§] MD, and Frank J.G. Backx,[†] MD, PhD
Investigation performed at University Medical Center Utrecht, Utrecht, the Netherlands

Table 2 Percentage of H RMS EMG of the MVIC for Each of the Resistance Training Exercises Evaluated (Analysis of All Subjects; N = 34)

	Russian Curl (RC)	Seated Leg Curl (SLC)	Stiff Leg Dead Lift (SLDL)	Single Leg Stiff Leg Dead Lift (SGLDL)	Good Morning (GM)	Squat (S)
RMS normalized as % RMS MVIC	98.0 ± 39.0[a]	81.0 ± 28.0[a]	49.0 ± 27.0[b]	48.0 ± 39.0[c]	43.0 ± 16.0[d]	27.0 ± 20.0[a]

Values are mean ± SD.
[a]Significantly different than all other exercises ($P < .001$)
[b]Significantly different than RC, SLC, and S ($P < .05$)
[c]Significantly different than RC, SLC, GM, and S ($P < .05$)
[d]Significantly different than RC, SLC, SGLDL, S ($P < .05$)

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Eccentric Literature Continued

- Sole, 2001:
  - Decreased strength and EMG activation in a lengthened hamstrings range for the athletes with prior HS injury suggested a change in NM control
- Askling 2013:
  - Lengthened vs Conventional protocol
  - Lengthened protocol returned to sport mean days of 28 vs 51 in conventional group
- Following injury → shift in peak knee flexion torque development to a shorter musculotendon length (greater flexion angle)
- Injury recurrence has been linked to this shift in the torque-angle relationship, as force development in elongated positions is compromised

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When is it safe to start eccentrics?

- Testing isometric strength!
- ~75% of uninvolved at 30°, 60° and 90°
- No greater than 3-4 pain level on VAS with any eccentric exercise

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What to do now?

- Early eccentrics a must…
  - As early as day 5/6 - pain VAS less than ISOMETRIC (Hickey et al 2016)
  - @3 weeks 20% change in MFL due to neuroplascity (Opar et al 2013)
  - Lose architectural changes in 10 days if no eccentric stimulus (Bourne et al 2015)
  - 6s otherwise can increase fibrosis with faster eccentrics → increased scar
    - (Fyfe et al 2014)
  - A longer eccentric phase duration (ie 4s+) can increase hypertrophy / strength
    - (Periera et al 2016)

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What to do now?

- Early eccentrics a must…
  - Eccentric exercise positively effects voluntary muscle activation
    - (Pensini et al, 2002)
  - Training at longer lengths → greater architectural adaptation + strength + angle of peak torque
    - (Sole et al, 2011, Guex et al 2016)

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ROMAN CHAIR

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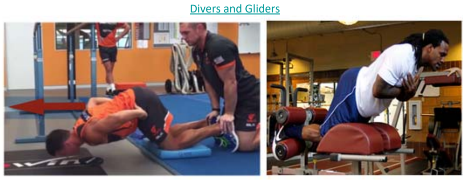
Divers and Gliders



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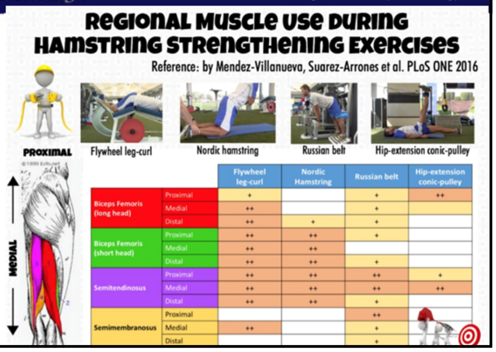
Not Just Nordics



		Flywheel leg-curl	Nordic Hamstring	Russian belt	Hip-extension conic-pulley
Biceps Femoris (long head)	Proximal	+		+	++
	Medial	++		+	
	Distal	++	+	+	
Biceps Femoris (short head)	Proximal	++	++	+	
	Medial	++	++		
	Distal	++	++	+	
Semitendinosus	Proximal	++	++	++	+
	Medial	++	++	++	++
	Distal	++	++	+	
Semimembranosus	Proximal			++	
	Medial	++		+	
	Distal			+	

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Dosing Eccentrics

- Minimum effective dose = 2 x 4   2x/week
  – (Presland et al 2016 – in press)
- Post practice before recovery day
- Mondays after games when Tuesdays are off (NFL)
- Performing NHE prior to sprinting decreases eccentric hamstring peak torque (-18.9%)
  – (Lovell et al, 2016)

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What to do now?

- Early eccentrics a must…

NORDIC HAMSTRING CURL RECOMMENDED PROGRESSION			
Week	Session/Week	Sets	Reps
1	1	2	5
2	2	2	6
3	3	3	6-8
4	3	3	8-10
5	3	3	12, 10, 8
11+	1-2	3	12, 10, 8

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Safe to Sprint?

- Peak force significantly increases from 80%-max speed (Chumanov et al 2007)
- Knee extension 10° via popliteal angle
- Full strength without pain (in lengthened state)
- 4 consecutive reps max effort MMT in prone knee flexion position (90° & 15°)
- Less than 5% deficit in eccentric testing on NordBoard or 95% of baseline
- Replication of sport specific movements near maximal speed without pain
  - 14 mph Treadmill Running intervals for WRs/RBs
  - 12 mph Treadmill Running for other positions

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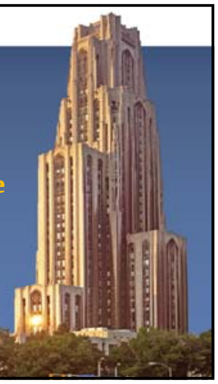

Screening for Neuromuscular Control of the Lower Extremity During the Motor Control Phase

Andrew D. Lynch, PT, PhD
Assistant Professor

University of Pittsburgh — Department of Physical Therapy

Lateral Step Down Test: Quality of Movement

- Subject stands in single limb support with the hands on the waist, the knee straight and the foot positioned close to the edge of a 20 cm high step.
- The contralateral leg is positioned over the floor adjacent to the step and was maintained with the knee in extension.
- The subject then bends the tested knee until the contralateral leg gently contacted the floor and then re-extends the knee to the start position.
- Repeated for 5 repetitions.

Reliability of measures of impairments associated with patellofemoral pain syndrome
Sara R Piva[1*], Kelley Fitzgerald[1], James J Irrgang[1], Scott Jones[2], Benjamin R Hando[3], David A Browder[4] and John D Childs[5]
BMC MSK Disorders 2006

Lateral Step Down Test: Quality of Movement

- Arm strategy.
  - If subject used an arm strategy in an attempt to recover balance, +1 point
- Trunk movement.
  - If the trunk leaned to any side, +1 point
- Pelvis plane.
  - If pelvis rotated or elevated one side compared with the other, +1 point
- Knee position.
  - If the knee deviated medially and the tibial tuberosity crossed an imaginary vertical line over the 2nd toe, +1 point
  - If the knee deviated medially and the tibial tuberosity crossed an imaginary vertical line over the medial border of the foot, +2 points
- Maintain steady unilateral stance.
  - If the subject stepped down on the non-tested side, or if the subject tested limb became unsteady (i.e. wavered from side to side on the tested side), +1 point.

Scoring:

- 0 or 1 was classified as good quality of movement,
- 2 or 3 was classified as medium quality
- 4 or above was classified as poor quality of movement.

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Lateral Step Down

Posterior View

Lateral View

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Lateral Stepdown

Anterior View

Posterior View

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Lateral Stepdown - Shod

Anterior View

Posterior View

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Biomechanical Measures of Neuromuscular Control and Valgus Loading of the Knee Predict Anterior Cruciate Ligament Injury Risk in Female Athletes

A Prospective Study

Timothy E. Hewett, PhD, Gregory D. Myer, MS, Kevin R. Ford, MS, Robert S. Heidt, Jr, MD, Angelo J. Colosimo, MD, Scott G. McLean, PhD, Antonie J. van den Bogert, PhD, Mark V. Paterno, MS, PT, and Paul Succop, PhD

- 205 adolescent female athletes
  - Pre-season screen in gait lab
  - 9 ACL injuries

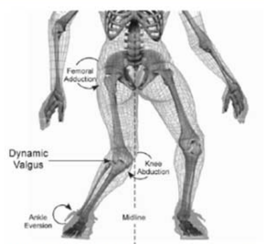

Figure 4. Dynamic valgus was defined as the position or motion, measured in 3 dimensions, of the distal femur toward and distal tibia away from the midline of the body. Dynamic valgus may have included the indicated motions and moments.

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Biomechanical Measures of Neuromuscular Control and Valgus Loading of the Knee Predict Anterior Cruciate Ligament Injury Risk in Female Athletes

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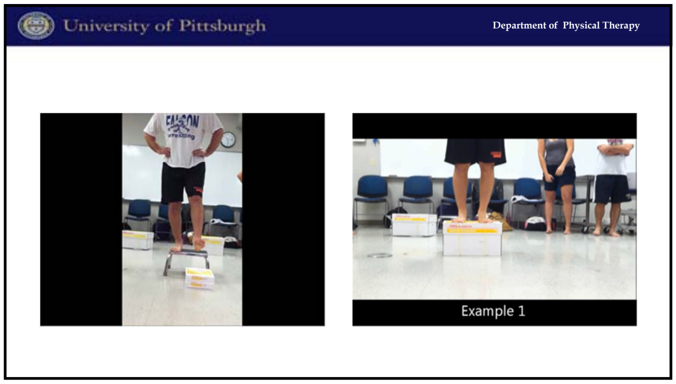
Figure 5. Biomechanical model depicting mean knee joint kinematics during the drop vertical jump at initial contact and maximal displacement in the ACL-injured and uninjured groups (n = 9 knees and n = 390 knees, respectively). Left, coronal plane view of knee abduction angle at initial contact in the ACL-injured and uninjured groups. Center, coronal plane view of maximum knee abduction angle in the ACL-injured and uninjured groups. Right, sagittal plane view of maximum knee flexion angle in the ACL-injured and uninjured groups.

- Greater knee abduction:
  - IC: 8.4° > in injured
  - Peak: 7.6° > in injured
  - Both predictive of future injury
- Peak knee flexion 10° < in injured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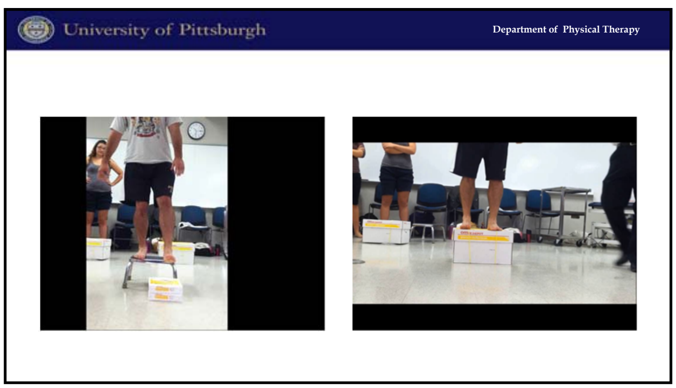
Example 1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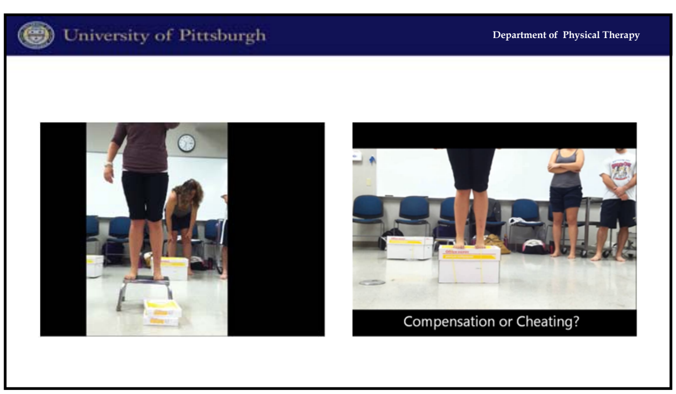
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Compensation or Cheating?

[RESEARCH REPORT]

ALON RABIN, DPT, MS • ZVI KOZOL, PT, PhD

Measures of Range of Motion and Strength Among Healthy Women With Differing Quality of Lower Extremity Movement During the Lateral Step-Down Test

DECEMBER 2010 | VOLUME 40 | NUMBER 12 | JOURNAL OF ORTHOPAEDIC & SPORTS PHYSICAL THERAPY


FIGURE 3. Hip external rotator muscle strength testing.


FIGURE 4. Weight-bearing ankle dorsiflexion.


FIGURE 5. Ankle dorsiflexion with the knee bent.

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Ankle Joint Contribution to Lower Extremity Dynamics

*A total score of **0 to 1** was classified as **good** quality of movement while a score of **greater than 2** was classified as **moderate**.*


FIGURE 1. A subject with a "good" performance on the lateral step-down test.


FIGURE 2. A subject with a "moderate" performance on the lateral step-down test.

TABLE 1 Scoring Criteria for the Lateral Step-Down Test

Criterion	Interpretation	Score
Arm strategy	• Removal of a hand off the waist	1
Trunk alignment	• Leaning in any direction	1
Pelvis plane	• Loss of horizontal plane	1
Knee position	• Tibial tuberosity medial to second toe	1
	• Tibial tuberosity medial to medial border of foot	2
Steady stance	• Subject stepped down on nontested limb, or foot wavered from side-to-side	1

Most frequent deviations

Rabin et al., JOSPT, 2010

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Ankle Joint Contribution to Lower Extremity Dynamics

Healthy women with a **moderate** quality of movement, as assessed visually during the lateral step-down test, exhibit **decreased** ankle **dorsiflexion** compared to women with a **good** quality of movement.

TABLE 3 ROM and Strength Measures Among Subjects With a Good, and Subjects With a Moderate, Score on the Lateral Step-Down Test, as Rated by Examiner 1*

Measures	Good Score	Moderate Score
Ankle dorsiflexion, knee extension	[illegible]	[illegible]
Ankle dorsiflexion, knee flexion	27.3 ± 6.1	21.8 ± 3.8
Ankle dorsiflexion, weight bearing	55.8 ± 5.3	46.4 ± 4.8
Hip internal rotation ROM	48.4 ± 7.4	41.1 ± 7.9
Hip external rotation ROM	[illegible]	[illegible]
Hip abduction strength (kg/BM)	[illegible]	[illegible]
Hip external rotation strength (kg/BM)	[illegible]	[illegible]

TABLE 4 ROM and Strength Measures Among Subjects With a Good, and Subjects With a Moderate, Score on the Lateral Step-Down Test, as Rated by Examiner 2*

Measures	Good Score	Moderate Score
Ankle dorsiflexion, knee extension	[illegible]	[illegible]
Ankle dorsiflexion, knee flexion	28.1 ± 5.2	20.9 ± 4.6
Ankle dorsiflexion, weight bearing	54.6 ± 2.5	46.4 ± 6.0
Hip internal rotation ROM	45.7 ± 9.5	40.4 ± 7.7
Hip external rotation ROM	[illegible]	[illegible]
Hip abduction strength (kg/BM)	[illegible]	[illegible]
Hip external rotation strength (kg/BM)	[illegible]	[illegible]

Rabin et al., JOSPT, 2010

Univ... hysical Therapy

JENNIFER E. EARL, PhD, ATC[1] • SARIKA K. MONTEIRO, MS[2] • KELLI R. SNYDER, MS, ATC[1]

JOURNAL OF ORTHOPAEDIC & SPORTS PHYSICAL THERAPY | VOLUME 37 | NUMBER 5 | MAY 2007

Differences in Lower Extremity Kinematics Between a Bilateral Drop-Vertical Jump and A Single-Leg Step-down

The **bilateral drop-vertical jump** produced greater **knee abduction** & may be appropriate for evaluating **excessive knee abduction** as a risk factor for noncontact **ACL injury**.

DVJ is likely **too provocative for** individuals with **PFPS at initial evaluation**.

	Males		Females	
	Step-down	DVJ	Step-down	DVJ
Hip internal rotation (°)*	5.4 ± 3.5	5.2 ± 5.0	5.0 ± 5.2	1.6 ± 5.1
Hip adduction (°)†	13.2 ± 4.2	-1.9 ± 4.9	18.8 ± 3.7	1.9 ± 4.9
Knee internal rotation (°)‡	0.2 ± 5.2	3.6 ± 6.9	0.3 ± 4.1	0.3 ± 3.2
Knee abduction (°)‡	-1.2 ± 2.6	1.0 ± 3.2	1.8 ± 2.4	6.0 ± 4.7
Knee flexion (°)‡	87.1 ± 6.5	96.3 ± 14.1	82.7 ± 5.8	94.4 ± 11.7
Rearfoot eversion (°)‡	10.8 ± 3.2	8.0 ± 4.6	12.2 ± 5.3	7.5 ± 6.2

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Single Leg Squat


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Step and Hold


Y-Balance Test

Anterior Reach | Posterior Medial Reach | Posterior Lateral Reach

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Y-Balance Test

Performance & Summary

- Warm-up of at least 6 reaches in each direction.
  - No weight transfer to reaching limb
- Perform 4 "real" trials
  - Record best performance
- Reach distance compared to limb length
  - ASIS to lateral malleolus in supine

Interpretation

- Overall summary
  - $\frac{Ant + PM + PL}{Limb\ Length * 3}$
  - Can compare bilaterally
- Individual reaches can be compared side to side
  - 4cm difference in anterior reach may be predictive of future injury

The International Journal of Sports Physical Therapy | Volume 11, Number 2 | April 2016 | Page 201

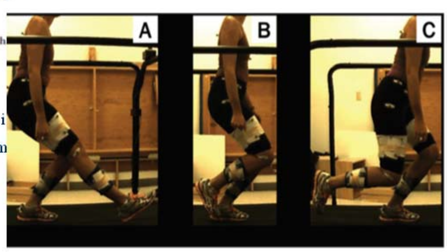
IJSPT

ORIGINAL RESEARCH

NOT ALL SINGLE LEG SQUATS ARE EQUAL: A BIOMECHANICAL COMPARISON OF THREE VARIATIONS

Anne Khuu[1]
Eric Foch, PhD[2]
Cara L. Lewis, PT, Ph

- 16 women
  - 23y.o. (SD=2)
- Squat as low as possi
- Smooth controlled m



Three single leg squat (SLS) tasks: (A) SLS-Front, (B) SLS-Middle, and (C) SLS-Back

The International Journal of Sports Physical Therapy | Volume 11, Number 2 | April 2016 | Page 201

Department of Physical Therapy

IJSPT

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NOT ALL SINGLE LEG SQUATS ARE EQUAL: A BIOMECHANICAL COMPARISON OF THREE VARIATIONS

Anne Khuu[1]
Eric Foch, PhD[2]
Cara L. Lewis, PT, PhD[1]

"Middle" SLS as a Reference

SLS Front

- Shifts weight anteriorly
  - Loads the **plantarflexors**
- Greatest knee flexion (°) at PKF
- Greatest **medial** knee joint loading (compression)
- Less hip ROM needed!
  - Loads the **hip extensors**!
  - Less hip ER moment, more hip IR ROM

SLS Back

- Shifts weight posteriorly
  - Minimizes PF compensations?
- Greatest KE moments at 60° and PKF
  - Loads the **quads**!
- Greatest **lateral** knee joint loading (compression)
- Greater hip flexion, ER, Add ROM

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Anne Khuu[1]
Eric Foch, PhD[2]
Cara L. Lewis, PT, PhD[1]

"Middle" SLS as a Reference

SLS Front

- Better exercise for **hip extensor strengthening**
- Could **unload lateral knee OA, lateral meniscus injury**
- Early in PFPS: beneficial because of **less quad activity** and **knee ROM**

SLS Back

- Better exercise for **quadriceps strengthening**
- Could **unload medial knee OA, medial meniscus injury**
- Early in PFPS: beneficial because of **less hip IR ROM** and **less hip ER strength needed**

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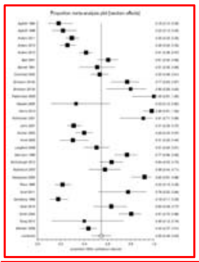
So How Are We Doing at Returning Athletes to Sport???

Return to Sports

Current Best Evidence:

- Systematic review of 7556 patients from 69 studies
- Return to sports:
  - Some form of sports – 81% (95% CI 74%-87%)
  - Pre-injury sports – 65% (95 CI 59%-72%)
  - Competitive sports – 55% (85% CI 46%-63%)

Ardern CL et al BJSM 2014



Return to Competitive Sports

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Return to Competitive Sports After ACL-R

- **Our Return to Sports Data:**
- Survey completed by 251 individuals
- 147 met definition for competitive athlete at time of injury:
  - Strenuous sports 4-7 times/week
- Definition of return to sports
  - Same type & frequency of sports participation
  - Same or better Marx Activity Score

Yabroudi et al.
Unpublished Data

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Return to Competitive Sports After ACL-R

Return to Sports By Age Group:

	Percent Return to Competitive Sports
High School Athletes (14 to 18 yrs. old)	71%
College Athletes (19 to 23 yrs. old)	52%
Beyond College (≥ 24 yrs. old)	19%
Overall	54%

Yabroudi et al.
Unpublished Data

Return to Competitive Sports After ACL-R

Reasons for Not Returning to Sports:

Fear of Re-Injury	62.5%
Ongoing Problems with Knee	43.8%
Lack of Confidence	37.5%
Work or Family Obligations	25.0%
No Longer Eligible for Competition	22.9%

Yabroudi et al.
Unpublished Data

Criterion-based Rehab

- Time after surgery for graft healing
- Should assess isolated strength, motor control and power development
- Differences in force development and force absorption persist after surgery and are independent of time after surgery
  - Myer GD., AJSM. 2012
- We must determine appropriate functional milestones to progress patients within physical therapy

Criterion-based Rehab

"When can I run?"

- When you are 12* weeks post-op AND you can demonstrate:

*NB – 12 weeks is an example and is not meant to reflect a universally agreed upon time for running after knee surgery

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Guidelines for Return to Sports

Testing Quadriceps Strength

- Hand-held Dynamometer and 1RM Knee Extension from 90° to 45° are comparable to electromechanical dynamometry
  - ICC > 0.65
- Leg Press is not
  - Over-estimated strength in ~25% of cases

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Guidelines for Return to Sports

- Criteria for Progression:
- Neuromuscular control:
  - Single leg squat/step-up test
  - Step & hold test
  - Jump landing test
- Quadriceps strength:
  - Isometric or isokinetic test
  - Repetition maximum test
- Functional testing & performance:
  - Hop tests
  - Running/agility tests
  - Successful performance of preliminary functional activities
- Absence of symptoms:
  - Pain
  - Swelling
  - Instability

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Progress to Straight Running

- MD clearance – usually indicated in a protocol
- Fast walking on TM for 15 minutes
- Quad strength >80% vs. uninvolved
  - Biodex
  - 1-RM Knee Extension - 90-45°
- 10 single leg squats to 45° in sagittal plane
- 30 step and holds
- >90% Composite Score on Y-Balance test

Progress to Low-Level Agility Training

- MD clearance
  - Quad strength ≥85%
  - 1-RM on knee extension/Biodex
- 10 single leg squats to 60° (with ≥75% external weight)
- Tolerate 1-2 miles of treadmill running
- 100% Composite Score on Y-Balance test

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Progress to Jumping

- MD clearance
- Quad strength ≥90%
  - 1-RM on knee extension/Biodex
- 10 single leg squats (with ≥85% external weight vs. uninvolved)
- No compensation patterns displayed with agility training at near 100% speed

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Progress to Hopping, Sprinting and Cutting

- MD clearance
- 10 single leg squats with ≥90% external weight vs. uninvolved
- No compensation patterns or medial collapse with jumps

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Functional Tests

- Single hop
- Triple hop
- Timed hop
- Triple cross-over hop

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Functional Testing

10-Yd Lower Extremity Function Test:

- Sprint/Back Pedal
- Side Shuffle
- Carioca
- Sprint

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Functional Testing - Pro Agility Test

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Returning to Sport

- MD clearance
- Tolerating sprinting, agility drills, jumping, and hopping at 100% effort without:
  - Compensation strategies
  - Episode of giving way
  - Increased pain
  - New s/s of inflammation
  - Increased effusion
- First return to practice and contact
- Then return to games