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.

Course Outline

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<td>8 to 10</td>
<td>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</td>
<td>Advanced Knee Joint Mobilizations</td>
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<td>Motor Control Screening and Intervention for the Lower Extremity</td>
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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.
Effect of “overload” stress raises thresholds for subsequent adaptations 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.

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!
Meniscus

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

- 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

- 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
Meniscal Blood Supply

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

Meniscal Repair

- Considered when lesion is in area of good vascularization
  - If tear is within 3 mm of the periphery, it is considered vascular
  - Area 3.5 mm from periphery is gray zone, > 5 mm from periphery is considered avascular

The Knee - Meniscal Injuries
The Knee – Meniscal 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

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 multi. longitudinal were restricted 2 add. weeks
  - ROM = 0-90
  - Increase 10° per wk
  - No squatting past 125° for 4 months
  - Run, Jump, Cut, Twist restricted for 6 months

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
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

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

Risk of Graft Re-Rupture

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

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 remolds and matures, but it does not reach the original strength of the native ACL

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 proliferate and form collagen
  - Collagen changes from fragments of fibers to dense longitudinally oriented fibers
Graft Healing

Time Frame Not Well Known & Likely Variable Between Individuals

Claes et al, AJSM 2011

ACL Quad Tendon Graft Healing

Dark Quad Tendon Pre-Op

Time zero 3 months 6 months 1 year

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
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

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 4-6 weeks post-operatively

Hamstring Tendon Autograft

- Usually Semitendinosus/Gracilis graft
  - Semitendinosus – 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
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

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

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.
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


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

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

To safely load the quadriceps after ACL reconstruction:
• Apply loads proximally on the tibia OR
• Apply loads at less than 60° of knee flexion

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?

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”!!
Anatomy and Tissue Protection for Less Common Ligament Surgery

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 0° to 60°
  - WB 45° to 0°
  - HS graft: NWB HS strength after (8-12 wk)

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
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)

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
**Tissue Specific Protections: PCL**

**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

**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

**Modifications 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

**Self-Supported Knee Flexion**

**Modifications Acceptable Glute Strengthening**

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

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 fovea to initial 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

LCL During Knee Motion
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.

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
Avoid Varus Forces

• 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

Avoid Side-Lying Abduction

If Hamstring Involved:

Avoid Hamstring Ex

• 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 TEa:
  – Avoid NWB exercise for 8 weeks
  – Add resistance at 12 weeks
Medial Collateral Ligament

- Flat band
- Attached above medial epicondyle 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

MCL During Knee Motion

Healing Potential of the MCL

- Combined with ACL Injury:
  - 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
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

**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

**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
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 Exercise**
8 weeks post-surgery
- Heel Slides
- Prone HS Curls
- Standing HS Curls
- Prone Glute Press

Assessment and Intervention for Stiff Knee Joint ROM

Tibiofemoral Osteology
- Medial side is longer
- Plateaus don’t match condyles
  - Rotation occurs in ~5° of TKR
  - Screw home mechanism
    - Ill of femur on tibia
    - Popliteus unlocks from full extension
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, cannot be produced voluntarily
- In weight bearing, such as rising from sitting, terminal rotation is seen as internal rotation of the femur on fixed tibia

Patellofemoral Osteology

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

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
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

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
- Got the patient to relax?
- If you have posterior impingement, you may need to do an anterior or rotational glide!!

Anterior and Posterior Tibial Mobilizations
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.
**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

**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. gastrocnemius)
    - Anterior (“clicking”)

- **Knee Extension with Quad Set**
  - Does the quad visibly contract?
  - Does contraction produce a superior patellar glide?
    - Visually palpated?
    - 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 gluteal contraction.
  - Does this cause pain?
    - Anterior (patellar tendon v. quad tendon v. quad muscle)
    - Retropatellar
    - Posterior

**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
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)

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 quadriceps function can lead to patellofemoral arthrofibrosis
- Good quadriceps function requires adequate patellar mobility
- Restoration of quadriceps 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!

NMES Parameters

- 2500 Hz,
  - 75 bursts/sec
- 10 contractions
- 10” on/50” off
  - Stimulus produces full, sustained quad contraction with evidence of superior patellar glide
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%)

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
  - Stop and Holds
- Cycling for ROM
  - Arc of motion to stretch
  - 100 to 110 for full revolutions

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
Quadriiceps Isometric Matrix

<table>
<thead>
<tr>
<th>Knee Position</th>
<th>Hip Position</th>
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<tbody>
<tr>
<td>0°</td>
<td>0°</td>
</tr>
<tr>
<td>45°</td>
<td>45°</td>
</tr>
<tr>
<td>90°</td>
<td>90°</td>
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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

Additional Interventions for Terminal Knee Extension
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

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.
Approximately 40° of knee flexion occurs passively. PF of ankle by gastrosoleus indirectly causes passive knee flexion.

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

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 (~ 6°) 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

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.

3 Types of Motor Tasks

- Discrete
  - Beginning and end

- Serial
  - Sequence of discrete tasks

- Continuous
  - No beginning/end
Environment for Motor Learning

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

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

**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

**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?

<table>
<thead>
<tr>
<th>Blocked</th>
<th>Random</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Segments of task or whole task, repeated</td>
<td>• Slight variations of task in random order</td>
</tr>
<tr>
<td>• Static conditions.</td>
<td>• Either different segments or different conditions of the whole task.</td>
</tr>
<tr>
<td>• Early stages of learning</td>
<td>• Later stages of learning</td>
</tr>
<tr>
<td>• Permanent behavior change?</td>
<td>• Permanent behavior change?</td>
</tr>
</tbody>
</table>

• 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
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

• 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

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

Electromechanical Dynamometry

- Gold standard for measuring quadriceps strength in clinical studies¹
  - Highly reliable²
  - Requires extensive equipment
  - Expensive

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

1 Repetition Max (1-RM)

Testing Procedure:

- Alternating limbs
- Fully extend knees
- 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
Leg Press – 1-RM

Standard Leg Press Machine
- Knee at 90°, Hip ~ 90°
- Compensation avoided
  • Gastro-Soleus minimized
  • Opposite limb suspended

Results:
- Over-estimated quadriceps strength compared to Biodex

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

Handheld Dynamometry - Quadriceps

Without Fixation  With Fixation
Handheld Dynamometry - Hamstrings

Without Fixation  With Fixation

Functional Strength Testing

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

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
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.


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

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

Strengthening of the Quadriceps During the Motor Control Phase
Muscle Performance


**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.
  

**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
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.

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)

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
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- 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

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

2009 ACSM Recommendations for Resistance Training

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

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

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 exercise
- Sequencing, velocity, and frequency is same as strength training
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:
  - 2-3 d for novice, 3-4 d for intermediate, 4-5 d for advanced

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

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
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)

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!

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 1 lb 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!
Alternative to Repetition Maximum for Dosing

- Borg Perceived Exertion Scale
  - Begin in hard to very hard range
    - 0 to 20 Scale: 13-17
    - 0 to 10 Scale: 3-7
  - 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

<table>
<thead>
<tr>
<th>Borg Perceived Exertion Scale</th>
<th>Least Effort</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7</td>
<td>very, very light</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>very light</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>fairly light</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>Endurance Training Zone 2</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>somewhat hard</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>hard</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>Strength Training Zone 5</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>very hard</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>19</td>
<td>very, very hard</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>9</td>
</tr>
</tbody>
</table>

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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.

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 <8 or >10
ACSM Guidelines for Resistance Training

<table>
<thead>
<tr>
<th>% of 1 Repetition Maximum for Common Quadriceps Exercises</th>
</tr>
</thead>
<tbody>
<tr>
<td>60%</td>
</tr>
<tr>
<td>Strength (Novice)</td>
</tr>
<tr>
<td>Strength (Advanced)</td>
</tr>
<tr>
<td>Muscular Endurance</td>
</tr>
<tr>
<td>Muscular Power</td>
</tr>
</tbody>
</table>

Daily Adjustable Progressive Resistance Exercise

<table>
<thead>
<tr>
<th>Target Training Weight</th>
<th>Set 1: Training % of 1RM that corresponds to goal of training</th>
<th>Strength Reps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warm-up 1</td>
<td>50%</td>
<td>Upper End of Rep Range</td>
</tr>
<tr>
<td>Warm-up 2</td>
<td>75%</td>
<td>Lower End of Rep Range</td>
</tr>
<tr>
<td>Training 1</td>
<td>100%</td>
<td>Maximum Achievable Reps</td>
</tr>
<tr>
<td>Training 2</td>
<td>See Chart</td>
<td>Maximum Achievable Reps</td>
</tr>
</tbody>
</table>

Reps During Set | 4th Set | Next Session
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; Lower End of Rep Range</td>
<td>Decrease by 5-10%</td>
<td>No change</td>
</tr>
<tr>
<td>Within the Rep Range</td>
<td>No change</td>
<td>No change</td>
</tr>
<tr>
<td>&gt; Upper End of Rep Range</td>
<td>Increase by 5-10%</td>
<td>Increase by 5-10%</td>
</tr>
</tbody>
</table>

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
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 ballpark!

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

<table>
<thead>
<tr>
<th>% of Training Weight</th>
<th>Strength Reps</th>
<th>Strength Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target Training Weight</td>
<td>(80%)</td>
<td></td>
</tr>
<tr>
<td>Warm-up 1</td>
<td>50% (40%)</td>
<td></td>
</tr>
<tr>
<td>Warm-up 2</td>
<td>75% (60%)</td>
<td></td>
</tr>
<tr>
<td>Training 1</td>
<td>100% (80%)</td>
<td></td>
</tr>
<tr>
<td>Training 2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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%

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

<table>
<thead>
<tr>
<th>% of Training Weight</th>
<th>Strength Reps</th>
<th>Endurance Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target Training Weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warm-up 1</td>
<td>50%</td>
<td></td>
</tr>
<tr>
<td>Warm-up 2</td>
<td>75%</td>
<td></td>
</tr>
<tr>
<td>Training 1</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>Training 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Next Session</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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%
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

Therapeutic Exercise in the Motor Control Phase

**Stretching**
- Squat, Leg Press
  - Preferential Squat, Single Leg Squat
  - Wall Sits
- Lunges, Split Squats
- Step-Ups/Downs
- Hamstring Progression
  - Bridges: If hamstring work on physioball
  - Isolated to prone HAMStretcher
- 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

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

30° Squat

60° Squat

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Sit to Stand

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

Anterior View

Lateral View

Anterior View

Lateral View
THE ROLE OF THE HAMSTRINGS AND CORE IN SECONDARY INJURY

- 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
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?

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

Injured females demonstrated poor trunk proprioception
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
  - peak frontal plane pelvis angle during the SCD

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

- 158 professional male athletes
- 26 ACL Re-Rupture
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Re-injured within first 6m of RTS
- 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

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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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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%
- NNT for All injuries – 11
- NNT for Lower Limb Injuries – 16
11/10/2017

- #1 time loss injury in major/minor league baseball
  - (Ahmad, 2014)
- 1 in 3 HS strains will recur in first 2 weeks 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 8/9 wks for a <5% reoccurrence!
  - (Orchard, 2005)
Hamstring Function

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

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 semimembranosus
  - Mild initial symptoms but...prolonged rehab

PROGNOSTICS

<table>
<thead>
<tr>
<th>Exam Finding</th>
<th>Prognosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injury proximity to incision site</td>
<td>More proximal the injury = greater time to return</td>
</tr>
<tr>
<td>Mechanism of injury (Kisling, 2017)</td>
<td>Stretch injuries take longer than high speed running injuries</td>
</tr>
<tr>
<td>Location of injury within muscle complex (Kisling, 2017)</td>
<td>Proximal free tendon takes longer than MTJ injuries</td>
</tr>
<tr>
<td>Time to walk (Kisling, 2017)</td>
<td>&gt; 1 day to walk pain-free following injury - likely to require &gt; 3 months of rehabilitation prior to RTS</td>
</tr>
<tr>
<td>Active knee extension deficit &gt;10° (Moore et al. 2014, Reurink et al. 2015)</td>
<td></td>
</tr>
</tbody>
</table>
Be Sure to Examine

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

Where are we testing strength?

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

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 (33% injuries)
  - Control group (66% injuries)
Eccentric Literature Continued

- Sole, 2001:
  - Decreased strength and EMG activation in a lengthened hamstring 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.

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

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 neuroplasticity (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
    - (Pyke et al 2014)
  - A longer eccentric phase duration (ie: 44+) can increase hypertrophy / strength
    - (Patena et al 2016)
What to do now?

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

- Minimum effective dose = $2 \times 4$  2x/week
- 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)

What to do now?

- Early eccentrics a must...

### Nordic Hamstring Curl Recommended Progression

<table>
<thead>
<tr>
<th>Week</th>
<th>Session/Week</th>
<th>Sets</th>
<th>Reps</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>3</td>
<td>6-8</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>3</td>
<td>8-10</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>3</td>
<td>12, 10, 8</td>
</tr>
<tr>
<td>11+</td>
<td>1-2</td>
<td>3</td>
<td>12, 10, 8</td>
</tr>
</tbody>
</table>

Not Just Nordics
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

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

Andrew D. Lynch, PT, PhD
Assistant Professor

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, Kelley Fitzgerald, James J Irrgang, Scott Jones, Benjamin R Handelsman, David A Breneser and John D Childs

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)
  - If the trunk leaned or elevated one side compared with the other, +1 point

- **Pelvis plane.**
  - If pelvis rotated or elevated one side compared with the other, +1 point

- **Knee position.**
  - If knee deviated medially and the tibial tuberosity crossed an imaginary vertical line over the 2nd toe, +1 point
  - If 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 subject stepped 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
205 adolescent female athletes
- Pre-season screen in gait lab
- 9 ACL injuries

Greater knee abduction:
- IC: 8.4° > in injured
- Peak: 7.6° > in injured
- Both predictive of future injury

Peak knee flexion 10° < in injured
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.

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.
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 and 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.

<table>
<thead>
<tr>
<th></th>
<th>Drop-down</th>
<th>DVJ</th>
<th>Drop-down</th>
<th>DVJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip flexion</td>
<td>12.2 ± 1.2</td>
<td>10.2 ± 1.2</td>
<td>16 ± 1.1</td>
<td>15 ± 1.1</td>
</tr>
<tr>
<td>Knee flexion</td>
<td>90 ± 5.5</td>
<td>58.3 ± 14.1</td>
<td>92.7 ± 5.5</td>
<td>96.4 ± 13.1</td>
</tr>
<tr>
<td>Rearfoot</td>
<td>0.8 ± 1.2</td>
<td>0.0 ± 0.0</td>
<td>0.2 ± 0.2</td>
<td>0.4 ± 0.4</td>
</tr>
</tbody>
</table>

Single Leg Squat

Step and Hold
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
  - \( \frac{\text{reach}}{\text{limb length}} \times 100 \)
  - Can compare bilaterally
- Individual reaches can be compared side to side
  - A 4cm difference in anterior reach may be predictive of future injury

Lateral View
- 16 women
  - 23y.o. (SD=2)
- Squat as low as possible
- Smooth controlled motion
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

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 – 53% (85% CI 46%-69%)

Ardern CL et al. BJSM 2014

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

Return to Competitive Sports After ACL-R

Percent Return to Competitive Sports By Age Group:

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Percent Return to Competitive Sports</th>
</tr>
</thead>
<tbody>
<tr>
<td>High School Athletes (14 to 18 yrs. old)</td>
<td>71%</td>
</tr>
<tr>
<td>College Athletes (19 to 23 yrs. old)</td>
<td>92%</td>
</tr>
<tr>
<td>Beyond College (≥ 24 yrs. old)</td>
<td>19%</td>
</tr>
<tr>
<td>Overall</td>
<td>54%</td>
</tr>
</tbody>
</table>

Yabroudi et al. Unpublished Data
Return to Competitive Sports After ACL-R

Reasons for Not Returning to Sports:

<table>
<thead>
<tr>
<th>Reason</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fear of Re-Injury</td>
<td>62.5%</td>
</tr>
<tr>
<td>Ongoing Problems with Knee</td>
<td>43.8%</td>
</tr>
<tr>
<td>Lack of Confidence</td>
<td>37.5%</td>
</tr>
<tr>
<td>Work or Family Obligations</td>
<td>25.0%</td>
</tr>
<tr>
<td>No Longer Eligible for Competition</td>
<td>22.9%</td>
</tr>
</tbody>
</table>

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
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

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

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
Department of Physical Therapy

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

Department of Physical Therapy

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

Department of Physical Therapy

Progress to Hopping, Sprinting and Cutting
- MD clearance
- 10 single leg squats with ≥90% external weight vs. uninjured
- No compensation patterns or medial collapse with jumps
Functional Tests

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

Functional Testing - Pro Agility Test

10-Yd Lower Extremity Function Test:
- Sprint/Back Pedal
- Side Shuffle
- Carioca
- Sprint
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 c/o of inflammation
  - Increased effusion
- First return to practice and contact
- Then return to games