EARLY ACL POSTOPERATIVE EXERCISE AND STRESS

KAISER PERMANENTE ORTHOPAEDIC AND SPORTS REHABILITATION FELLOWSHIP
OBJECTIVES

- Anatomy
- Biomechanics
- Post Surgical Healing
- In Vivo Vs. Biomechanical Equation Data
- Testing Post Op
- Exercise Safety and Stresses
- Implementation
ANATOMY

- Dense regular connective tissue bundles made of type I collagen-positive fibers.
- These bundles are protected by dense irregular thin type III collagen-positive fibrils.
- With nerves and mechanoreceptors for pain and proprioception.
- Blood supply from middle geniculate artery with branches into both lateral and medial inferior geniculate artery.
- 111 cadaveric knees
  - Width of 11-17mm and thickness of 3mm.
BIOMECHANICS OF ACL

• Fibers:
  • Anteriomedial Bundle
  • Posterolateral Bundle

• Native ACL can resist 2000N force

Posterior View ACL Fiber Stress Orientation
LIGAMENTIZATION/ HISTOLOGY OF ACL POSTOPERATIVE

- **3 Characteristic Stages of Graft Healing:**
  - **1. Early Healing Phase (1-4wks):** Graft necrosis and hypocellularity and no detectable revascularization of the graft tissue (noted weakness of graft at this time)
  - **2. Proliferation Phase (5-12wks):** Remodeling and revascularization due to growth factors from necrotic tissue and myofibroblasts
  - **3. Ligamentization Phase (12+wks):** Restructuring of the graft towards the properties of the intact ACL - max at 12 months

- **Autograft** of Bone –Tendon- Bone/ Hamstring / Quadriceps tendon (8-12 weeks)
- **Allograft** up to 2x as long as Autograft: Screws or other fixations and donor tissue adherence to healing is very low and slow
**IN VIVO STRESS MEASUREMENTS**

- **In vivo:** ACL strain is directly measured
  - Strain Sensors: Implantable force probes placed in or around the mid-substance of the tissue, most commonly in the anteromedial bundle of the ACL (ACL Strain %)
- Invasive/ Costly
- Mostly Only sagittal plane tested and immediately Post Op or during Op

*Figure 1. The DVRT was inserted arthroscopically into the anteromedial band of the ACL.*
Experimental Biomechanical Equation Model for Stress Measurements

- **Experimental Biomechanical Model** in many different ways but the main concern is that ACL loading is not measured directly, therefore, the models only provide an estimate.
- Electrodes acquire force of muscles for equation
- Resultant force and torque equilibrium equations calculated using inverse dynamics and the biomechanical knee model
- Then anteroposterior shear forces in the knee were calculated and adjusted to ligament orientations to estimate ACL forces (N)

Further in this Presentation:

**IN VIVO** = % strain

**Experimental Biomechanical Model** = ACL forces (N)

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**Fig. 2.** Computer optimization with input from measured knee torque from inverse dynamics and predicted knee torque from muscle model, where $T_k = \text{resultant knee torque}$, $F_k = \text{resultant knee force}$, $I = \text{moment of inertia about leg center of mass}$, $\alpha = \text{angular acceleration of leg}$, $m = \text{mass of leg}$, $a = \text{linear acceleration of leg}$, $g$ is gravitation constant $9.80 \text{ m/s}^2$, $F_{ext} = \text{external force acting on foot}$, $T_{ext} = \text{external torque acting on foot}$, $F_q = \text{quadriceps force}$, $F_p = \text{patellar tendon force}$, $F_h = \text{hamstrings force}$, and $F_c = \text{gastrocnemius force}$. *Note:* to simplify the drawing the equal and opposite forces and torques acting on the distal leg and proximal ankle are not shown.
POSTOPERATIVE TESTING STRESS

- Lachman Test: Gives anywhere from 100-150 N (22.5lb -34lb) on average to the Tibia 3.0-3.7% strain on ACL via implantable force probes.
- Anterior Drawer Test: 150 N on average, 34lb of force to the tibia 3.5% strain on ACL via implantable force probes.
OPEN CHAIN MMT TESTING

**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. Reproduced with permission.

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Peak ACL Force (N)</th>
<th>Knee Flexion Angle (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isokinetic seated knee extension (0°-90° of knee flexion) at 60°⁰</td>
<td>349</td>
<td>35 to 40</td>
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<tr>
<td>Isokinetic seated knee extension (0°-90° of knee flexion) at 120°⁰</td>
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<td>35 to 40</td>
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<td>Isokinetic seated knee extension (0°-90° of knee flexion) at 180°⁰</td>
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<tr>
<td>Isokinetic seated knee flexion (0°-90° of knee flexion) at 60°⁰</td>
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<td>Isokinetic seated knee flexion (0°-90° of knee flexion) at 120°⁰</td>
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<tr>
<td>Isokinetic seated knee flexion (0°-90° of knee flexion) at 180°⁰</td>
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<td>Isometric seated knee flexion</td>
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<td>Isometric seated knee flexion</td>
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<tbody>
<tr>
<td>Shelburne et al</td>
<td>Level-ground walking</td>
<td>355</td>
<td>16.8</td>
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<td>303</td>
<td>15 to 20</td>
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EXERCISES TO IMPLEMENT

- Squats (heel off/ heel on ground) (12 RM)
- Squat Full Depth (140)
- Leg press (12 RM)
- Double foot drop landing
- Single Leg Squat (Normal/ heel off / heel on ground)
EXERCISES TO IMPLEMENT

- Squats (Narrow Stance, Wide Stance) (12RM)
- Leg Press (Narrow high feet, Narrow low feet, Wide high feet, Wide low feet) (12RM)
EXERCISES TO IMPLEMENT

• **Experimental Biomechanical Model:** A6 camera Peak Performance motion analysis system
  - Wall Squat
  - Single leg Squat weighted (12 RM)
  - Lunge weighted (12RM) with Long/ Short step
  - Lunge weighted (12 RM) sideways and forwards with stationary feet and moving feet

• **In Vivo**
  - Bicycle (Cadence and Power output increases= no difference in ACL strain)
  - Stair climbing (Slow/Normal Cadence)
  - Step-up / Step-Down

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<tr>
<td>Escamilla et al</td>
<td>Wall squat (0°-90° of knee flexion) with heels positioned far from the wall using 12 repetitions of maximum dumbbell resistance*</td>
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<td>Wall squat (0°-90° of knee flexion) with heels positioned close to the wall using 12 repetitions of maximum dumbbell resistance*</td>
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<td>Single leg squat (0°-90° of knee flexion) using 12 repetitions of maximum dumbbell resistance*</td>
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<tr>
<td>Escamilla et al</td>
<td>Forward lunge (0°-90° of knee flexion) while taking a long step forward using 12 repetitions of maximum dumbbell resistance*</td>
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<td>Lunging forward and sideways (0°-90° of knee flexion) while taking a normal-length step using 12 repetitions of maximum dumbbell resistance*</td>
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TAKE AWAY

• Native ACL can withstand 2000N (440lb)

• Grafts are now said to be 80-100% as strong as Native if not stronger

• Weeks 1-4 Graft Progressively weakens (2x as long for Allografts)

• Walking 300-350N (66-77lb)

• Lachman’s 100-150N (22-33lb) / 3.0-3.7% strain

• Squats with anterior Tibofemoral glide Lead to 3x the force on ACL with knee >10cm in front of foot

• Squats with 30-40 degree trunk flexion turn on hamstrings to reduce ACL Strain

• Leg press, Full depth Squat, Double foot drop, Single leg squat, Lunge, Side Lunge, Bicycle, Stairs, Step Ups/ Down
• Ease patient fears about stressing or tearing ACL Graft with Objective Evidence Early Post Op
• Guide ACL class practice in early Phases using recommendations
• Know healing phases and Precautions
• Back Exercise choices with MD


