EARLY ACL POSTOPERATIVE EXERCISE AND STRESS

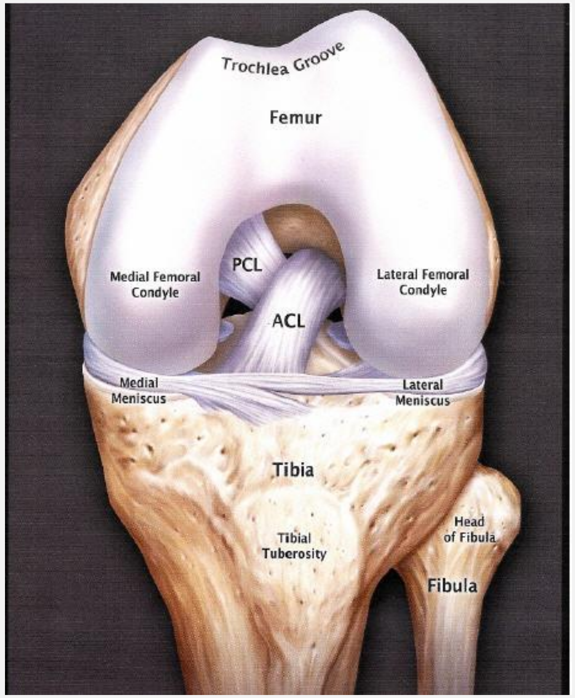
KAISER PERMANENTE ORTHOPAEDIC AND SPORTS REHABILITATION FELLOWHIP

OBJECTIVES

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

ANANTOMY

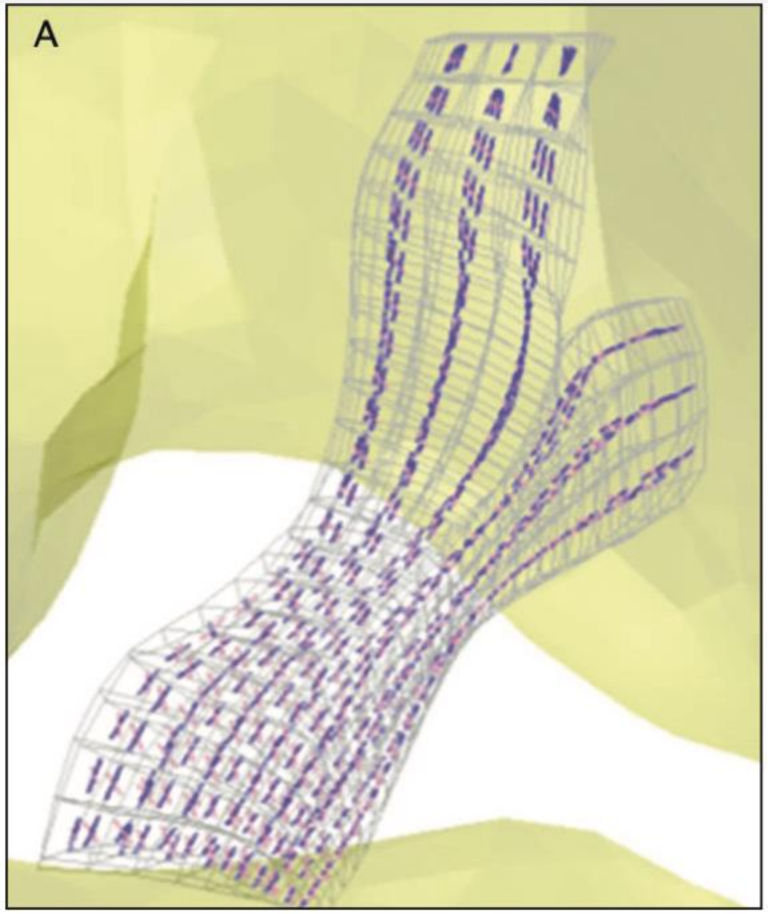
- Dense regular connective tissue bundles made of **type I** collagen-positive fibers
- These bundles are protected by dense irregular thin **type III** collagen-positive fibrils.
- With **nerves** and **mechanoreceptors** for pain and proprioception
- **Blood supply** from middle geniculate artery with braches 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

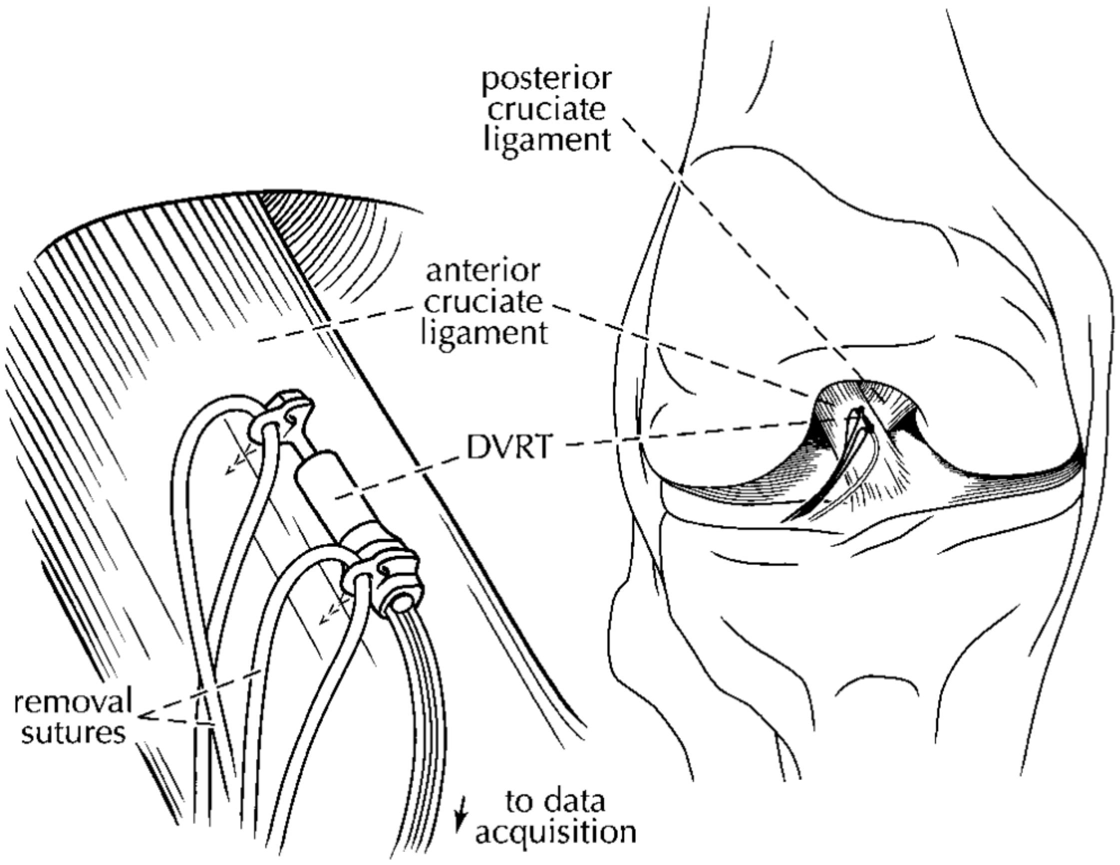


Figure 1. The DVRT was inserted arthroscopically into the anteromedial band of the ACL.

EXPERIMENTAL BIOMECHANICAL EQUATION MODEL FOR STRESS MEASUREMENTS

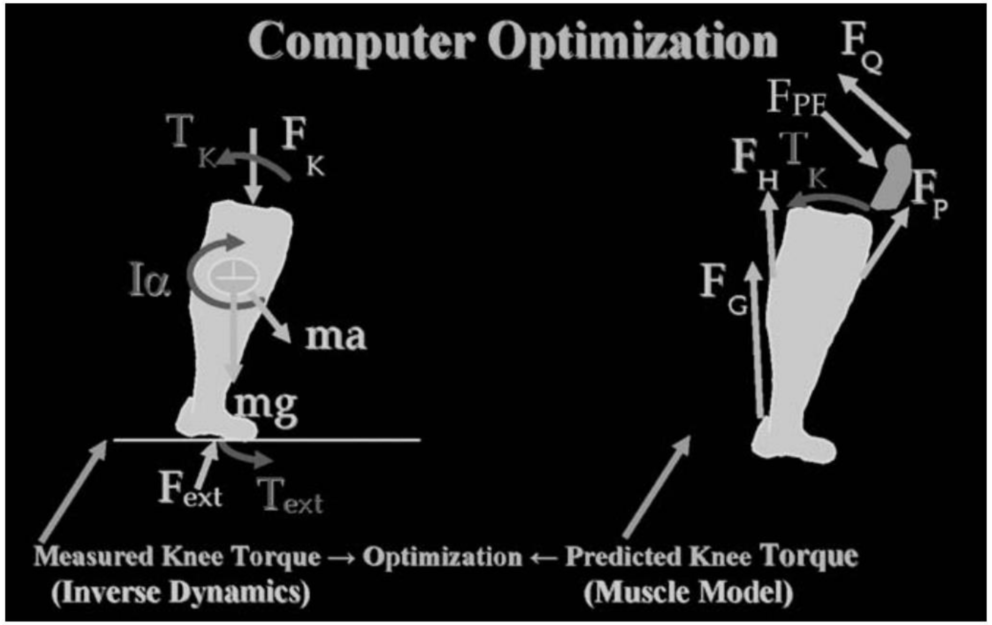


Fig. 2. Computer optimization with input from measured knee torque from inverse dynamics and predicted knee torque from muscle model, where T_K = resultant knee torque, F_K = resultant knee force, I = moment of inertia about leg center of mass, α = angular acceleration of leg, m = mass of leg, a = linear acceleration of leg, g is gravitation constant 9.80 m/s^2, F_{ext} = external force acting on foot, T_{ext} = external torque acting on foot, F_Q = quadriceps force, F_P = patellar tendon force, F_H = hamstrings force, and F_G = 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.

- **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)**

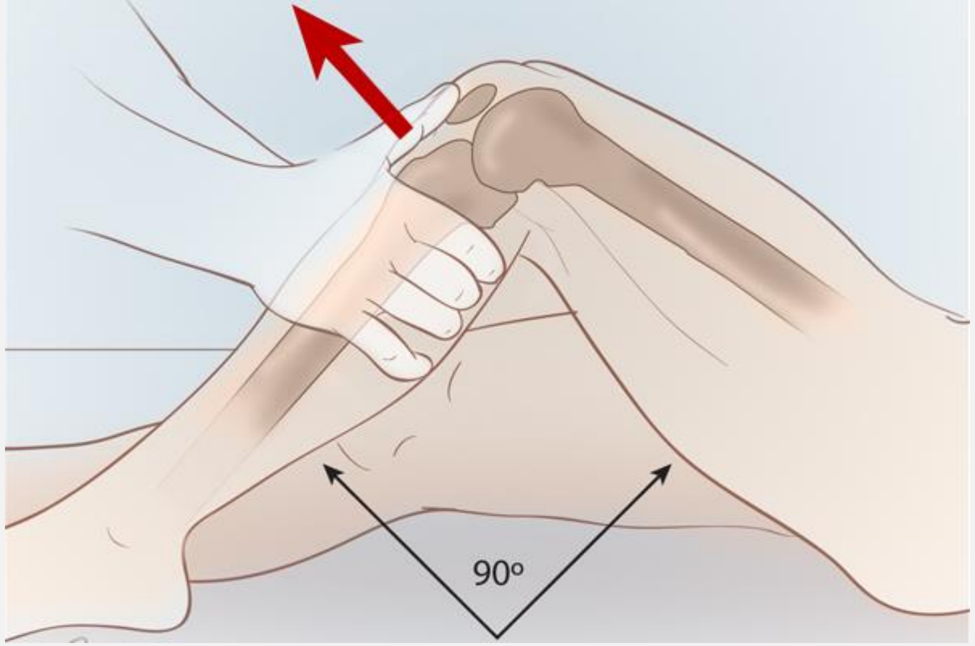
Further in this Presentation:

IN VIVO= % strain

Experimental Biomechanical Model = ACL forces (N)

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

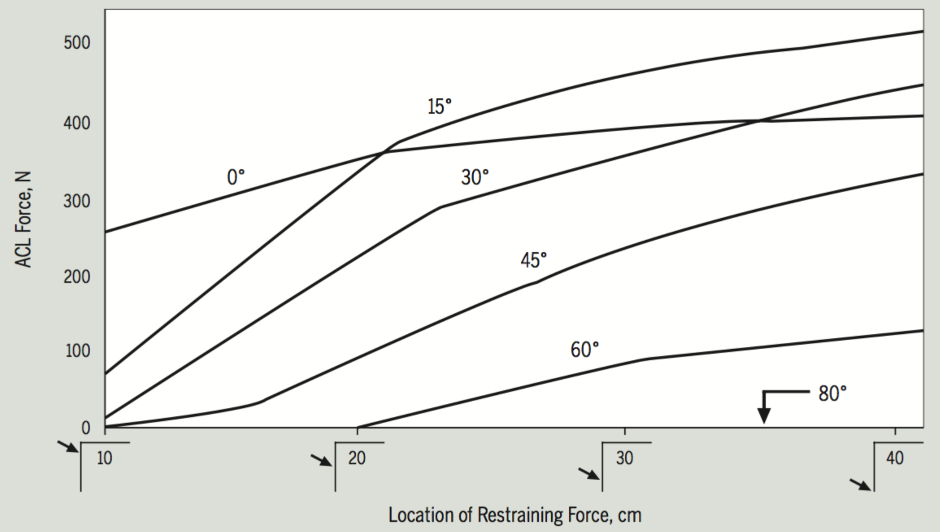


FIGURE. Changes in ACL loading during the seated knee extension exercise with proximal or distal resistance applied on the lower leg. The location of the restraining force is given relative to the distance from the knee joint. Given a constant external knee torque applied to the leg, moving the restraining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

Non–Weight-Bearing Exercises			
Author	**Exercise**	**Peak ACL Force (N)**	**Knee Flexion Angle (°)**
Toutoungi et al[57]	Isokinetic seated knee extension (0°-90° of knee flexion) at 60°/s	349	35 to 40
	Isokinetic seated knee extension (0°-90° of knee flexion) at 120°/s	325	35 to 40
	Isokinetic seated knee extension (0°-90° of knee flexion) at 180°/s	254	35 to 40
	Isokinetic seated knee flexion (0°-90° of knee flexion) at 60°/s	0	
	Isokinetic seated knee flexion (0°-90° of knee flexion) at 120°/s	0	
	Isokinetic seated knee flexion (0°-90° of knee flexion) at 180°/s	0	
	Isometric seated knee extension	396	35 to 40
	Isometric seated knee flexion	0	

Author	Exercise	Peak ACL Force (N)	Knee Flexion Angle (°)
	Level-ground walking	355	16.8
Shelburne et al[54]	Level-ground walking	303	15 to 20

EXERCISES TO IMPLEMENT

Weight-Bearing Exercises			
Author	**Exercise**	**Anterior Shear Force (N)**	**Knee Flexion Angle (°)**
Wilk et al[62]	Barbell squat (0°-90° of knee flexion) using 12 repetitions of maximum resistance*	0	
	Leg press (0°-90° of knee flexion) using 12 repetitions of maximum resistance*	0	
Nagura et al[40]	Full squat (0°-140° of knee flexion) using no external resistance	66	10.9
	Rising from kneeling	111	40.9
	Level-ground walking	355	16.8
	Stair climbing	146	50.8
Pflum et al[44]	Double-foot drop landing	220	33 to 48
Toutoungi et al[57]	Squat (0°-90° of knee flexion) with heel off the ground without external resistance	95	<50
	Squat (0°-90° of knee flexion) with heel on the ground without external resistance	28	<50
	Single-leg squat (0°-90° of knee flexion) without external resistance	142	<50
Kulas et al[35]	Single-leg squat (0°-90° of knee flexion) without external resistance	124	15 to 25
Shelburne et al[54]	Level-ground walking	303	15 to 20
Shelburne and Pandy[50]	Dynamic squat-to-stand	20	25
Pflum et al[44]	Double-foot drop landing stepping off a 60-cm platform	253	33 to 48
Shin et al[55]	Single-leg landing from running to a stop	1294	25 to 30

- 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

Weight-Bearing Exercises			
Author	**Exercise**	**Peak ACL Force (N)**	**Knee Flexion Angle (°)**
Escamilla et al[12]	Barbell squat (0°-90° of knee flexion) using 12 repetitions of maximum resistance*	0	
	Leg press (0°-90° of knee flexion) using 12 repetitions of maximum resistance*	0	
Escamilla et al[13]	Barbell squat (0°-90° of knee flexion) with narrow stance using 12 repetitions of maximum resistance*	0	
	Barbell squat (0°-90° of knee flexion) with wide stance using 12 repetitions of maximum resistance*	0	
	Leg press (0°-90° of knee flexion) with narrow stance with high foot placement using 12 repetitions of maximum resistance*	0	
	Leg press (0°-90° of knee flexion) with wide stance with high foot placement using 12 repetitions of maximum resistance*	0	
	Leg press (0°-90° of knee flexion) with narrow stance with low foot placement using 12 repetitions of maximum resistance*	0	
	Leg press (0°-90° of knee flexion) with wide stance with low foot placement using 12 repetitions of maximum resistance*	0	

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

EXERCISES TO IMPLEMENT

Author	Exercise	Peak ACL Force (N)	Knee Flexion Angle (°)
Escamilla et al[14]	Wall squat (0°-90° of knee flexion) with heels positioned far from the wall using 12 repetitions of maximum dumbbell resistance*	0	
	Wall squat (0°-90° of knee flexion) with heels positioned close to the wall using 12 repetitions of maximum dumbbell resistance*	0	
	Single-leg squat (0°-90° of knee flexion) using 12 repetitions of maximum dumbbell resistance*	59	30
Escamilla et al[15]	Forward lunge (0°-90° of knee flexion) while taking a long step forward using 12 repetitions of maximum dumbbell resistance*	0	
	Forward lunge (0°-90° of knee flexion) while taking a short step forward using 12 repetitions of maximum dumbbell resistance*	0	
Escamilla et al[16]	Forward lunge (0°-90° of knee flexion) while taking a normal-length step forward using 12 repetitions of maximum dumbbell resistance*	0	
	Side lunge (0°-90° of knee flexion) while taking a normal-length step sideways using 12 repetitions of maximum dumbbell resistance*	0	
	Lunging forward and sideways (0°-90° of knee flexion) while taking a normal-length step using 12 repetitions of maximum dumbbell resistance*	0	
	Lunging forward and sideways (0°-90° of knee flexion) while keeping both feet stationary using 12 repetitions of maximum dumbbell resistance*	0	

- **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

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

IMPLEMENTATION

- 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

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