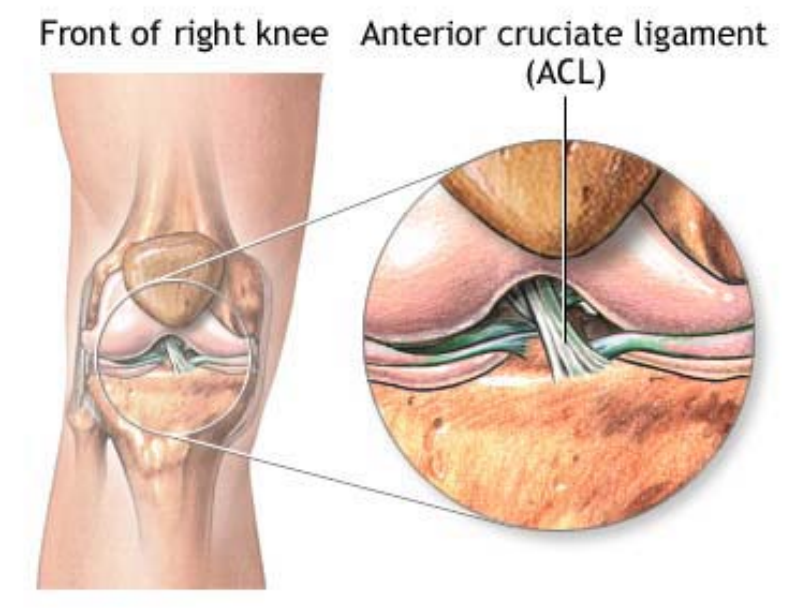
Anterior Cruciate Ligament Reconstruction



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KYLE HOPPES & ANGELA LAUTEN
DPT CANDIDATES 2013

Objectives

- To understand risk factors associated with ACL injury
- To understand normal anatomy & biomechanics of the ACL as it relates to rehab activities
- To gain new insight into the surgical procedure: graft selection & fixation
- To understand healing properties of tissues & how this affects the rehab timeline

Objectives

- To understand the need for criterion-based progression
- Describe functional outcome measures appropriate for patients following ACLR
- List the factors necessary for consideration to start return-to-play training

The Need

- 41% of athletes returning to prior level of activity (Davies, 2013; Arden et al., 2011)
  - Performance reduced by 1/3rd when returning from ACLR
- 4-fold increase in re-injury following ACLR (Creighton et al., 2010)
- Lack of standardization/"best" practice (Creighton et al., 2010)
- 13% of 264 articles report using outcome measures (Barber-Westin & Noyes, 2011)
- 40-90% develop OA within 10 years (Davies, 2013)

The Issues

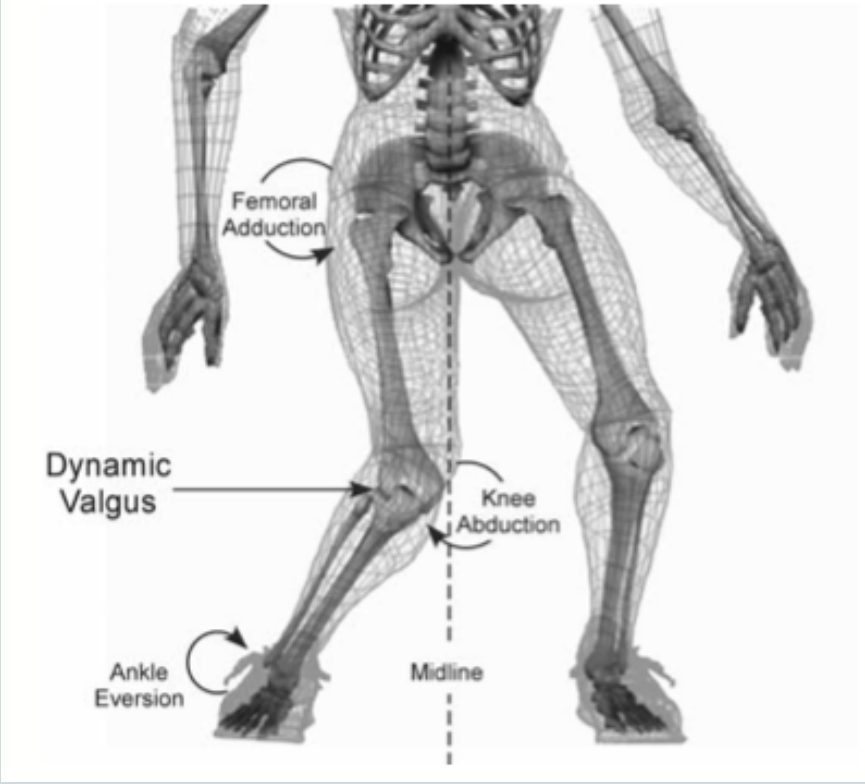
- 20-25% of patients experience unsatisfactory results at 7-10yrs following ACLR (Jung et al, 2009)
  - 15-25% continue to suffer pain & instability
- ACL disruption alters knee kinematics (Dargel et al, 2007)
- Current ACLR techniques do not seem to fully restore normal physiology of movement (Getgood & Spalding, 2012)
- Multifactorial causes of ACLR failure (Hosseini et al, 2012)
- Rehab protocols are irrespective of age & graft selection (Heijne & Werner, 2007)

Considerations

- Risk factors for ACL injury
- Mechanisms/factors in injury
- Anatomy & biomechanics of the ACL
- Key factors influencing the outcome of ACLR
  - Graft selection
  - Graft fixation
  - Rate of graft healing
  - Optimal post-op rehab?

Risk Factors for ACL Injury (Smith et al., 2012)

- Neuromuscular
  - Different postures & landing biomechanics
  - Reduced core proprioception
- Anatomic
  - Knee geometry
    - Intercondylar notch width
  - Generalized/knee laxity
  - Static alignment



Risk Factors for ACL Injury (Smith et al., 2012)

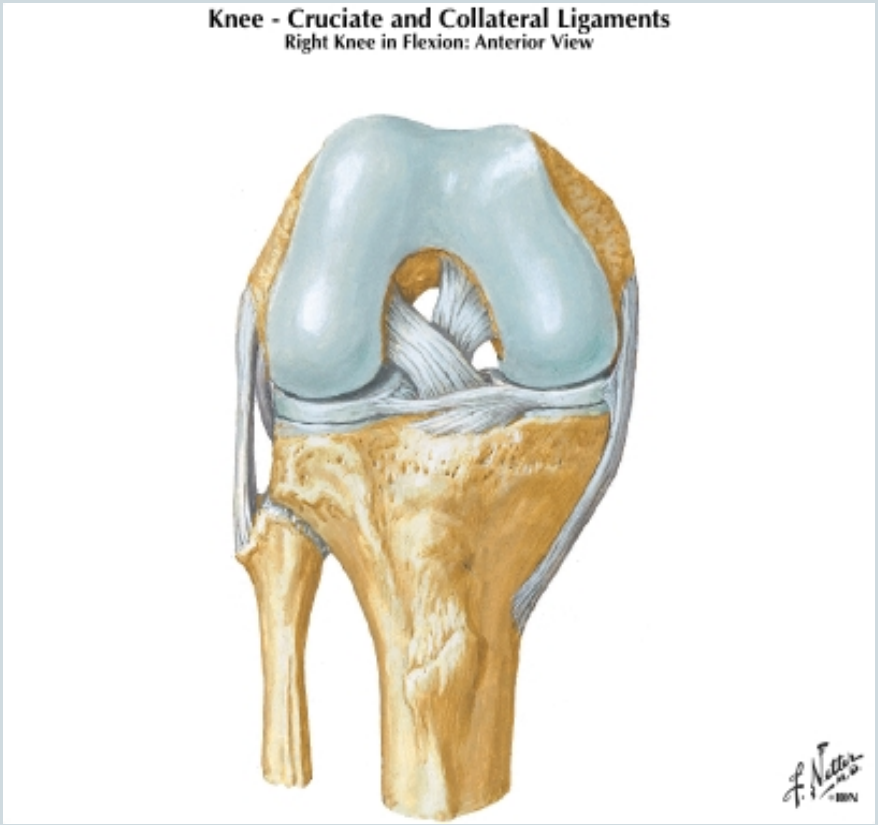
- Intrinsic risk factors
  - Gender differences
  - Hormones
  - Genetic
  - Previous injury
- Extrinsic risk factors
  - Weather
  - Type & condition of playing surface
  - Footwear

Mechanisms & Factors in Injury (Dargel et al., 2007)

- Active quad pull
- Isolated disruption vs concomitant injuries
  - Lesions to medial/lateral meniscus as well as to MCL reported in ~80% of cases
  - Minor/major bruising of chondral or subchondral structures
- Concept of primary & secondary restraints

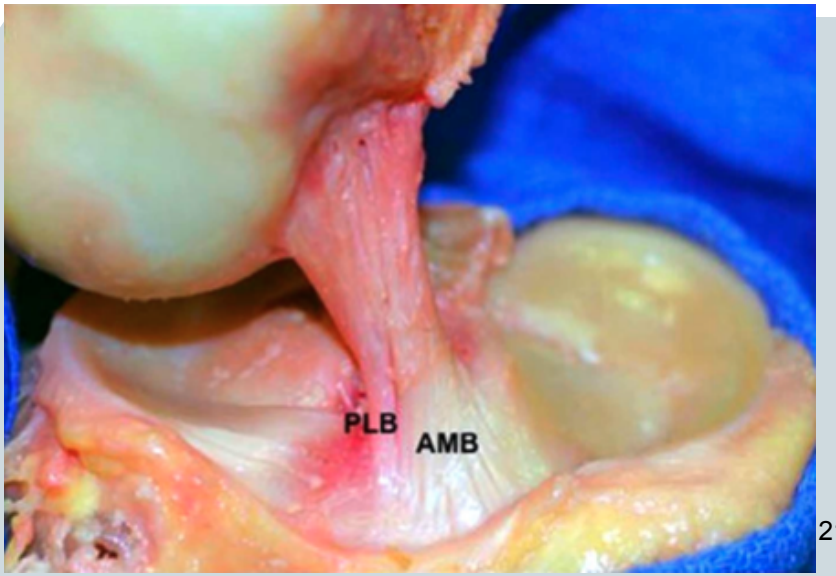
Anatomy/Physiology of the ACL

- Dense connective tissue containing parallel rows of fibroblasts & type I collagen
- Originates from posteromedial aspect of lateral femoral condyle
- Inserts into anterolateral aspect of medial tibial spine



Anatomy/Physiology of the ACL

- Divided into 2 bundles:
  - Anteromedial (AM) bundle
    - Mean length = 33mm
  - Posterolateral (PL) bundle
    - Mean length = 18mm



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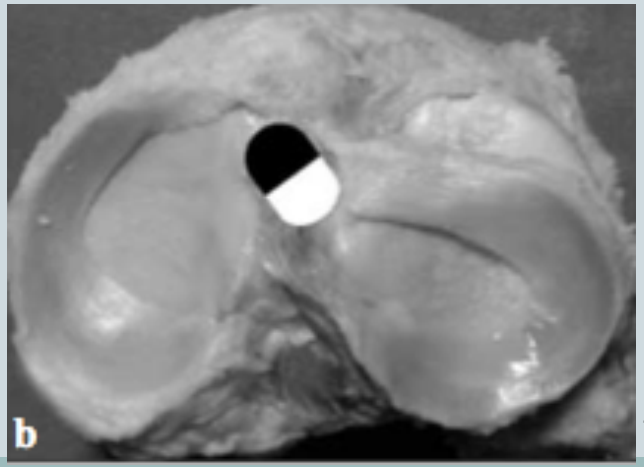

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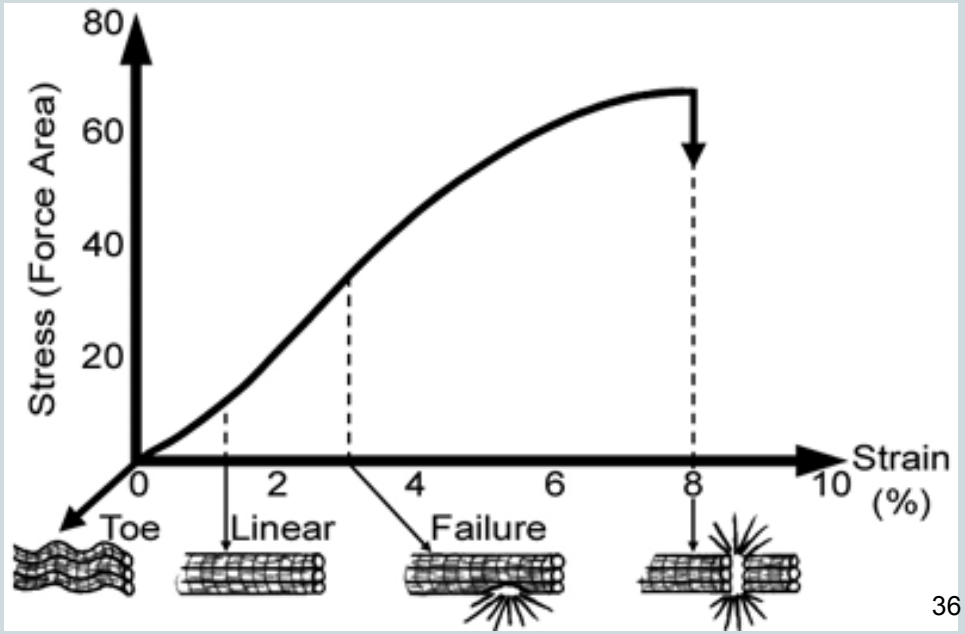
Biomechanics of the ACL

- Primary restraint
  - Anterior translation of tibia on femur
  - Hyperextension
  - Rotation (IR of tibia on femur)
- Secondary restraint:
  - Varus/valgus
- Each bundle has different kinematic roles (Gabriel et al., 2004)
  - AM bundle = more taut in knee flex (~90deg)
  - PL bundle = more taut in knee ext (<30deg)
  - In-situ forces of each bundle under different loads

Biomechanics of the ACL



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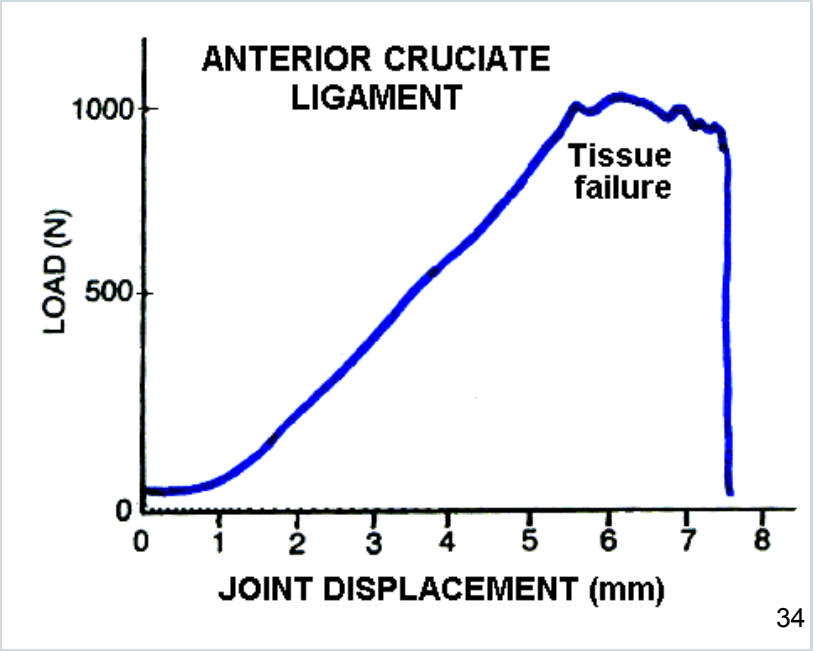

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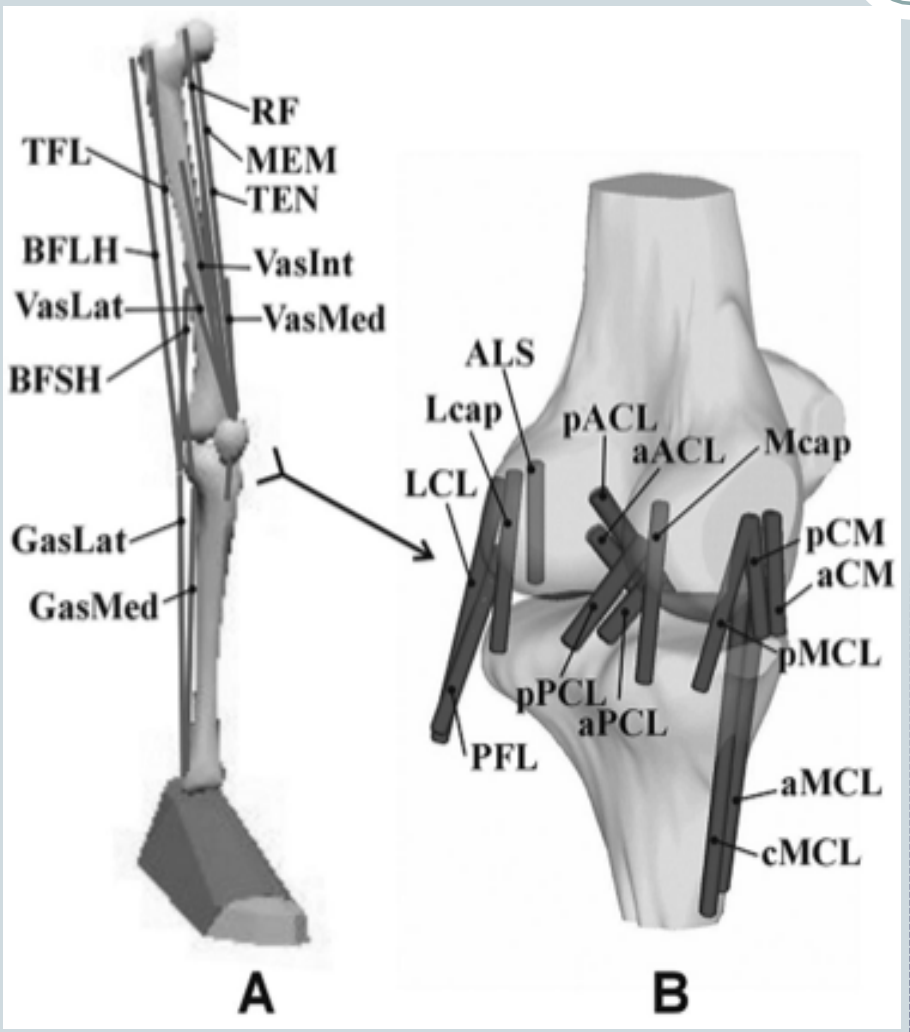
Biomechanics of the ACL

- Native femur-ACL-tibia complex (FATC) (Woo et al., 2006)
  - Ultimate failure load avg: 2160±157 N
  - Stiffness avg: 242±28 N/mm
- Effects of aging (Woo et al., 1991)
  - Ultimate failure load avg: 495±85 N
  - Stiffness avg: 124±16 N/mm

Effects of specimen age and orientation on the structural properties of the FATC (mean ± SEM)

Age group	Specimen orientation	Stiffness (N/mm)	Ultimate load (N)	Energy absorbed (N-m)
Younger (22–35)	Anatomical	242 ± 28	2160 ± 157	11.6 ± 1.7
	Tibial	218 ± 27	1602 ± 167	8.3 ± 2.0
Middle (40–50)	Anatomical	220 ± 24	1503 ± 83	6.1 ± 0.5
	Tibial	192 ± 17	1160 ± 104	4.3 ± 0.5
Older (60–97)	Anatomical	180 ± 25	658 ± 129	1.8 ± 0.5
	Tibial	124 ± 16	495 ± 85	1.4 ± 0.3

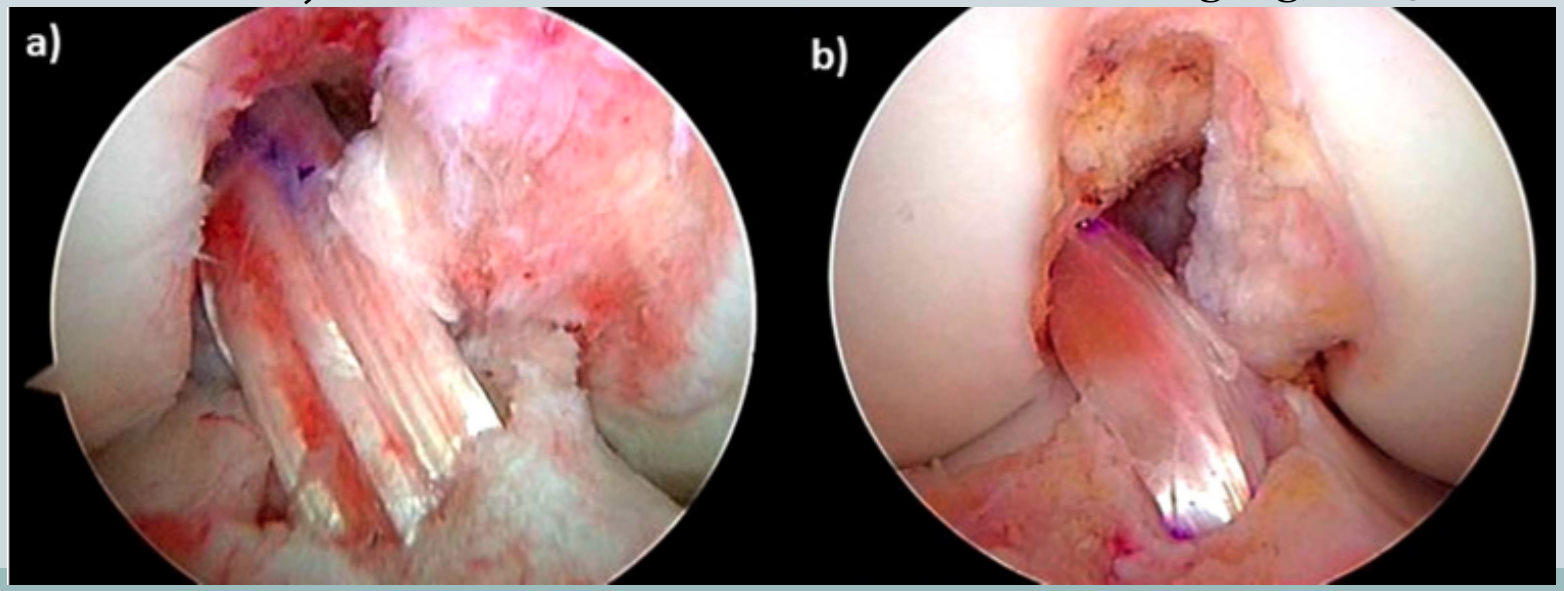
Biomechanics of Normal Walking (Shelburne et al., 2005)



- Pattern of force in the ACL explained almost entirely by anterior pull of patellar tendon
- Intact knee
  - Peak ACL force occurs at midstance, ~303N
    - Force explained by balance of muscle forces, joint contact forces, & ground reaction forces (GRF) applied to the leg
- ACL-deficient knee
  - Increase in anterior tibial translation
    - Effects on MCL force

Goal of ACLR

- To restore ACL function & normal knee joint kinematics
- Anatomical restoration = functional restoration of the ACL to its native dimensions, collagen orientation, & insertion sites (Yabroudi & Irrgang, 2013)



Key Factors that Influence the Outcome of ACLR

GRAFT SELECTION

GRAFT FIXATION

RATE OF GRAFT HEALING

OPTIMAL POST-OP REHAB?

Graft Selection

Autografts

- Bone-patellar-tendon bone (BPTB)
- Hamstring (HS) grafts:
  - Double stranded
  - Quadruple stranded
- Quadriceps tendon

Allografts

- BPTB
- HS
- Tibialis anterior tendon
- Tibialis posterior tendon
- Achilles tendon
- Fascia lata

Autografts: BPTB Advantages

- High strength & stiffness
- Consistency of size of graft
- Bone plugs on both ends of graft – facilitates better fixation & incorporation
- High success rate
- No risk of disease transmission
- No immunogenic response

Autografts: BPTB Disadvantages

- Harvest site morbidity:
  - Anterior knee pain, pain when kneeling
  - Possible patellar fx or late patellar tendon rupture
- Quad weakness
- Extensor deficit
- Patellofemoral pain
- Loss of motion

Autografts: HS grafts

Advantages

- Less donor site morbidity?
- Less anterior knee pain
- No extensor mechanism dysfunction

Disadvantages

- No pre-op assessment of graft thickness
  - Variability in HS size
- Soft tissue to bone healing (slower rate)
- Knee flexor strength deficits
- Graft tunnel motion or enlargement

Allografts: General Advantages

- No associated donor site morbidity
- No weakening of extensor/flexor apparatus
- Shorter operating time (no graft harvest)
- Larger and predictable graft sizes
- Greater availability
  - Appropriate for revision surgery, multi-ligament injury, or in the presence of patellar baja
- Less pain

Allografts: General Disadvantages

- Delayed graft incorporation
- Immunogenic response of the host to the graft
- Risk of disease transmission (bacterial/viral)
- Sterilization techniques (Baer & Harner, 2007)
  - Radiation & high failure rates
  - Compromising properties of graft – doses above 2Mrad
- Graft cost
- Large age-related differences
  - Structural properties of graft

Graft References

Autografts

- Dheerendra et al, 2012
- Dargel et al, 2007
- Karlsson et al, 2011
- Woo et al, 2006
- Hsu et al, 2010
- Baer & Harner, 2007
- Meuffels et al, 2012

Allografts

- Dheerendra et al, 2012
- Prodromos et al, 2007
- Sun et al, 2009
- Baer & Harner, 2007
- Woo et al, 1991
- Meuffels et al, 2012
- Gulotta & Rodeo, 2007

Biomechanical properties of grafts (Baer & Harner, 2007)

Graft Type	Ultimate Tensile Load	Stiffness	Cross-Sectional Area (CSA)
Native ACL	*~2160 N*	*242 N/mm*	*44mm²*
BPTB auto	2977 N	620 N/mm	35mm²
HS auto: quadruple strand	4090 N	776 N/mm	53mm²
Tib Ant allo	4122 N	460 N/mm	48.2mm²
Tib Post allo	3594 N	370 N/mm	44.4mm²
Achilles tendon allo	4617 N	685 N/mm	67mm²

Is one graft better than the other?

- Several studies have demonstrated comparable results between the grafts in terms of laxity, IKDC scores, & return to activity
  - Barrett et al., 2005
    - BPTB auto vs. allo, pts 40yo & older – both graft choices highly effective
  - Rihn et al., 2006
    - BPTB auto vs allo, pts 25-40yo – 94% (autos) & 95% (allos) rated their activity levels as normal/nearly normal

Is one graft better than the other? (Mohtadi et. al, 2011)

- 2011 Cochrane review – BPTB vs. HS autografts
  - No difference in re-rupture rate or IKDC scores
  - All tests for knee stability favored BPTB grafts
  - BPTB group: knee ext loss; HS group: knee flex loss
  - Conclusion:
    - Current evidence insufficient to recommend either of the 2 grafts for ACLR

Indications/Recommendations for Graft Selection (Vyas et al., 2012)

- Depends on several factors:
  - Pt preference, age, activity level, physical requirements, expected outcomes, timeline for return to play, associated ligament injuries, medical comorbidities, previous surgery, tissue availability, & surgeon preference/experience
- Common indications for autograft:
  - Young, very active pts
  - Pts 30-40yo who are highly involved in athletics
- Common indications for allograft:
  - Mild-mod active pt >40yo w/ symptomatic instability
  - Multi-ligament reconstruction or revision ACLR
  - Cases were autograft tissue is inadequate
  - Pt preference

BOTTOM LINE (Baer & Harner, 2007)

- No graft choice can match completely the characteristics & function of the native ACL
- The ideal graft choice should:
  - Have similar biomechanical properties to that of the native ACL
  - Have low morbidity
  - Incorporate quickly
  - Be able to restore functional stability to the knee over the *long term*
    - Taking into account: pt preference, activity level, prior surgery, comorbidities, & goals!

Key Factors that Influence the Outcome of ACLR

GRAFT SELECTION

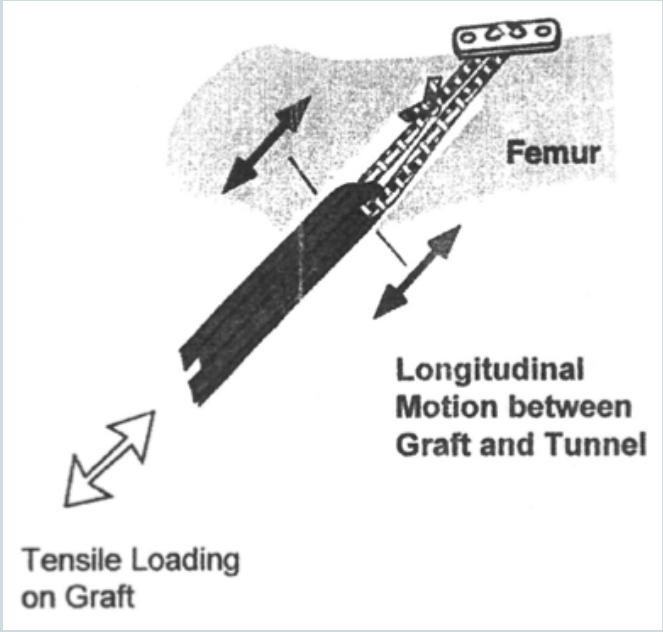
GRAFT FIXATION

RATE OF GRAFT HEALING

OPTIMAL POST-OP REHAB?

Graft Fixation (Dargel et al., 2007; Brand et al., 2000)

- Fixation devices generally fail to reconstruct complex nature of native FATC
- A graft & its fixation devices are loaded, therefore displacement is affected by direction of force & stiffness of graft+fixation
  - Bungee-cord effect
    - Longitudinal
  - Windshield-wiper effect
    - Transverse
- Fixation = weakest link early on



Key Factors that Influence the Outcome of ACLR

GRAFT SELECTION

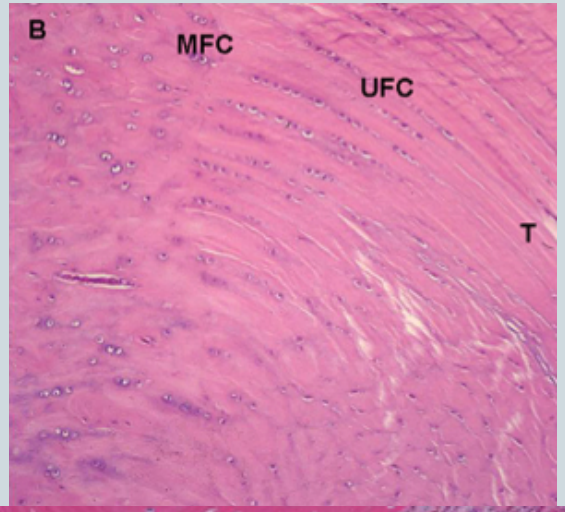
GRAFT FIXATION

RATE OF GRAFT HEALING

OPTIMAL POST-OP REHAB?

Healing (Baer & Harner, 2007)

- All grafts undergo a sequential process of healing & ligamentization
  - Inflammation & graft necrosis
    - 1-2mos after surgery
  - Revascularization & cell repopulation
    - 20 days to 6mos after surgery
    - Changes in material properties of graft
  - Remodeling
    - May take up to 18mos to occur



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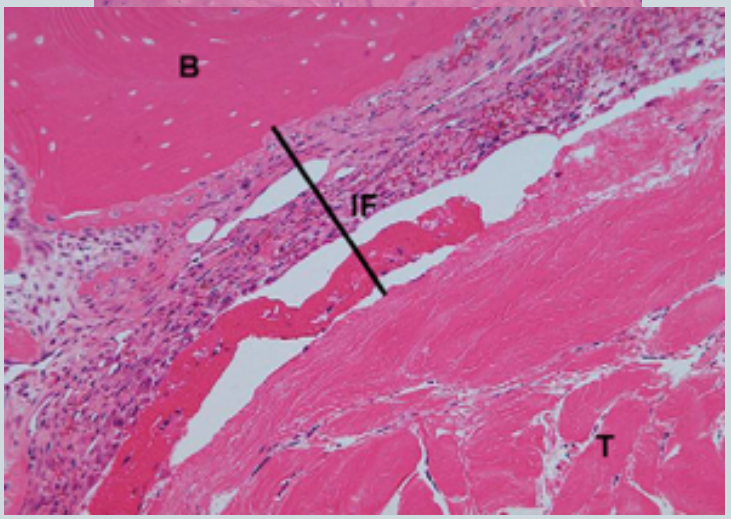

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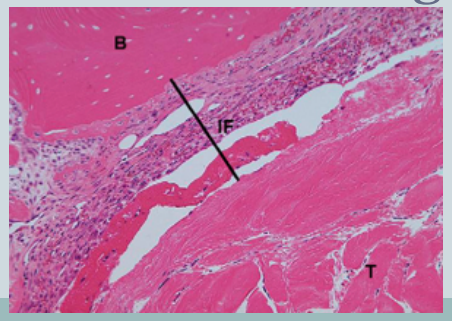
Bone-to-bone Healing (Gulotta & Rodeo, 2007)

- Incorporation relatively quick: 6-8wks
  - At 6wks, weakest point becomes the junction of the graft bone plug & native insertion of patellar tendon (if autograft)
- Components of tendon-to-bone healing
- Factors that may impede healing:
  - Length of tendon portion in BPTB grafts is greater than the intra-articular ACL length
  - Presence of synovial fluid at graft-tunnel interface

Tendon-to-bone Healing (Gulotta & Rodeo, 2007)

- Takes considerably longer, often 8-12wks to mature
- Strength of soft-tissue bone interface may increase most during 1st 4wks after ACLR
- Factors that may impede healing:
  - Presence of inflammation at graft site = scar formation
  - Slow/limited bone ingrowth into tendon graft
  - Graft-tunnel motion
  - Insufficient # of undifferentiated progenitor cells at healing interface – age!
  - Lack of coordinated signaling cascade



Allograft Tissue Healing

- Slower rate than autograft tissue (Baer & Harner, 2007)
  - Prolonged inflammatory stage, delayed remodeling of collagen fibers
- Strength of fixations & maturation of graft are delayed (Escamilla et al., 2012; Gulotta & Rodeo, 2007)
  - Greater decrease in implantation structural properties
  - Slower rate of biologic incorporation
- Remodeling phase – graft loses tensile strength initially (Gulotta & Rodeo, 2007)
- **Accelerated protocols should be utilized with caution (Escamilla et al., 2012; Vyas et al., 2012)

Factors in Healing & Considerations for Rehab

- Age-related changes (Woo et al., 1991)
  - Properties of ligaments/tendons can change with advancing age & activity level
- Stress/loading
  - Ligaments & grafts remodel according to applied motion & stress
  - Graft fixation remains the weak link in early post-op period
- Blood supply
- Graft type

Key Factors that Influence the Outcome of ACLR

GRAFT SELECTION

GRAFT FIXATION

RATE OF GRAFT HEALING

OPTIMAL POST-OP REHAB?

Optimal Rehab? (Yabroudi & Irrgang, 2013)

- Depends on:
  - Surgical procedure
  - Concomitant surgical procedures performed
  - Pt's previous level of activity/fitness
  - Response to surgery & rehab
  - Desired activity level after surgery
- Progression affected by several factors:
  - Surgical procedure: anatomic/nonanatomic?
  - Graft type
  - Presence of associated injuries
  - Pt variation

Goals of ACLR Rehab (Yabroudi & Irrgang, 2013)

- Several goals remain constant:
  - Early ROM
  - Preservation of quad function
  - Progression of functional activities
  - Not exceeding limits of the involved tissue's healing properties

Goals of ACLR Rehab (Yabroudi & Irrgang, 2013)

Table 1
Summary of the primary goals for each stage of rehabilitation after anatomic ACL reconstruction

Early Postoperative	Strengthening and Neuromuscular Control	Return to Activity and Sports
Controlling pain and edema	Progression of strengthening	Complete the entire functional rehabilitation spectrum
Protecting the healing graft	Neuromuscular control	Make a full return to the patient's previous level of daily, occupational and athletic activity, and sport participation
Minimizing the effects of immobilization	Improving balance	
Obtaining full passive and active extension of the knee symmetric to the noninvolved knee	Preparation for the return to activity and sports stage	
Achieving 100° to 120° of knee flexion		
Preserving quadriceps muscle function		
Restore the ability to perform straight-leg raise without a quadriceps lag		
Progression to full weight bearing		
Achieving normal gait		

Optimal Rehab? More things to Consider…

- Effect of quad activity on ACL loading
  - Relative increase
- Influence of knee flex angle
  - The “danger zone”: 0-30deg
- Hamstring co-contraction
  - Not effective at small knee flex angles

General Progression

- Early Rehabilitation Goals (Myer et al., 2006)
  - ROM
  - Decrease swelling/effusion
  - Patellar Mobility (Wilk et al., 2012)
  - Gait
  - Body Weight Strengthening Exercises
    - Quad set, SLR, Heel slides
  - Strength Training: OKC vs CKC

*Controlled, with ROM & strengthening guidelines

General Progression

- Late Rehabilitation Activities (Myer et al., 2006)
  - Jogging/Running
  - Jumping/Hopping
  - Sport Specific Drills (cutting, shuffling)

*Less restricted, leading to variation in practice

Accelerated vs. Nonaccelerated

- Early weight-bearing and ROM (Beynnon et al, 2011; DeCarlo et al, 1992)
  - Laxity the same or better in Accelerated
- Brace in extension (Melegati et al, 2003)
- Addition of sport-specific drills (Wright et al, 2008; Beynnon et al, 2011; DeCarlo et al, 1992; Roi et al, 2005)
- Criterion-based progression (Roi et al, 2005)

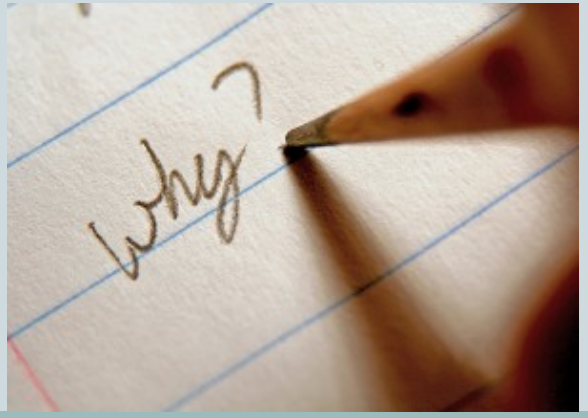
OKC versus CKC

- Minimize strain on the healing graft (Yu and Garrett, 2007):
  - 1st 3 months: Limited arc of motion between 90-60 flexion for OKC; 0-60 flexion for CKC
  - 3-4 months post: OKC thru full arc as tolerated by the joint
  - OKC flexion can increase hamstring strength
    - Avoid in 1st 4-6 weeks if meniscus is also repaired
- Eclectic Approach combining both OKC and CKC (Glass et al, 2010)

Why Criterion-Based Progression?

(Davies, 2013; Roi et al, 2005; Myer et al, 2006)

- Provides objective measures that allow for patients to see deficits compared to subjective comments/ feelings
- Justifies rationale for sport restriction
- Evidence for payers
- Sets benchmarks/goals for athletes to strive for



Progression Criteria

- Factors that *should* influence decision making:
  - Sex
  - Age
  - PMHx
  - Prior surgeries
  - Current surgery (graft selection, technique)
  - SxS
  - Motivation
  - Psychological health of athlete
  - Imaging studies
  - Concomitant injuries

Progression Criteria

- Pain/Swelling: incomplete healing if present (Creighton et al, 2010)
- ROM:
  - 0-100 degrees in initial 2 weeks (Wilk et al, 2012)
  - Full ROM before intense strength training/sports drills
- Strength Training: No extensor lag (Myer et al, 2006; Wilk et al, 2012)
- Normal Gait (Myer et al, 2006)
- Dynamic Stability (Wilk et al, 2012; Davies, 2013; Myer et al, 2006)

Initiation of Sport Specific Drills
(Davies, 2013)

- Physician's okay
- Patient's subjective comments/pain ratings
- Stage of tissue healing/strength of graft
- Patient's objective scores WNL
- Rehabilitation path

Initiation of Sport Specific Drills

- Negative Pivot Shift/No patient report of "giving away" (Myer et al, 2006)
- IKDC >70 (Myer et al, 2006)
- Quad Peak Torque/Body Weight (@180 deg/sec): 60-65% males; 50-55% females (Wilk et al, 1994)
- Dynamic Stability during ADLs/ambulation (Myer et al, 2006; Wilk et al, 2012)

What to Work on

- Single limb strength and stability (Fitzgerald et al, 2000)
  - Single limb squats or lunges
  - Surface Modifications (Wilk et al, 2012)
- Treadmill running/walking (Myer et al, 2006)
  - Improve symmetry
- Squats (Myer et al, 2006; Ohkoshi et al, 1991)
  - Even distribution (<20% difference)
- Landing on single limb
- Endurance
- Plyometric Training (Myer GD, Ford KR et al, 2006)

Outcome Measures

- ROM
- Swelling
- Isokinetic Strength

Functional Tests:

- Y-Balance Test
- Star Excursion Balance Test
- Hop Tests

Patient Reported:

- IKDC
- Cincinnati Knee Rating Scale
- KOOS

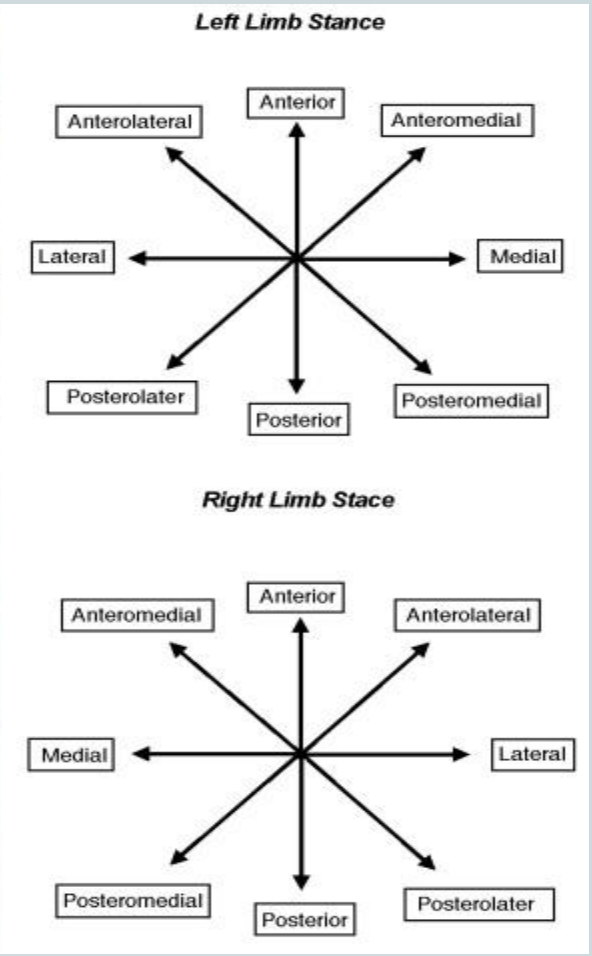
Return-to-Play:

Tegner

Psychometric Properties of Outcome Measures for ACLR

- **International Knee Documentation Committee (IKDC):** 3-subscales measuring subjective symptoms, sport/activity, and function (Irrgang et al, 2009)
- **Cincinnati Knee Rating System:** 13-section patient report of pain, swelling, sports, and work (Barber-Westin et al, 1999)
- **Knee Injury and Osteoarthritis Outcome Score (KOOS):** 5-subscales that measure: Pain, Symptoms, ADLs, Sport/Rec, and QoL (Salavanti et al, 2011;Wang et al, 2010)
- **Tegner Activity Scale:** 11-point scale to rate level of activity/sport participation (Briggs et al, 2009)

Star Excursion Balance Test



Perez and Vicen, 2011

Y-Balance Test

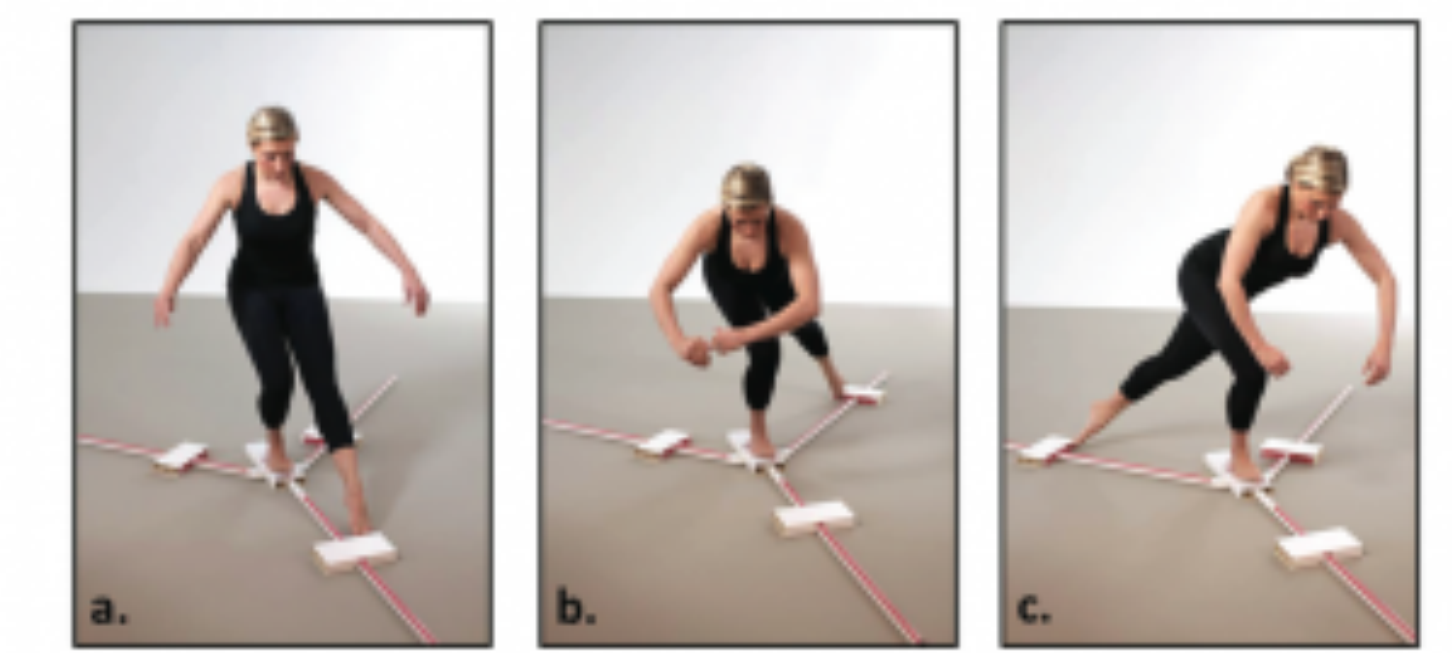
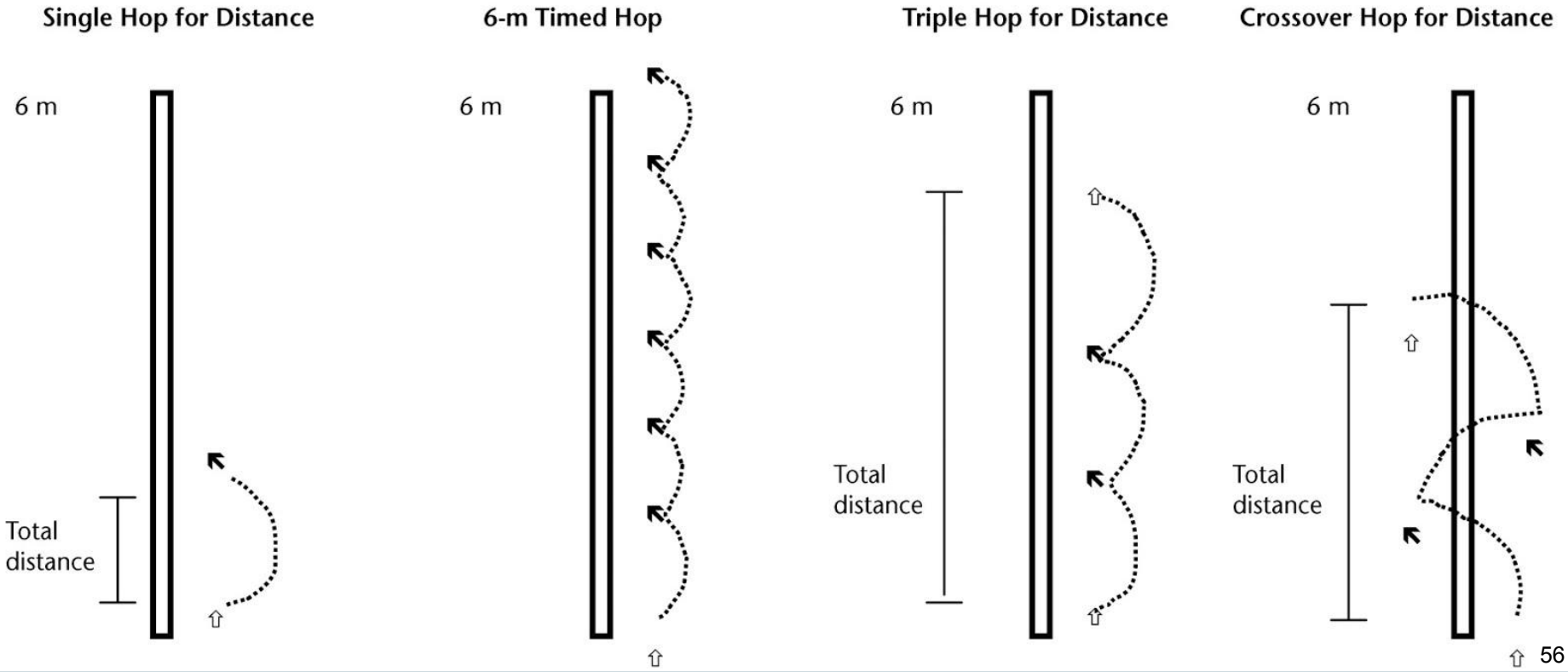


Figure 1. *The three reach directions of the Lower Quarter Y Balance Test (a. anterior, b. posteromedial, c. posterolateral).*

Hop Tests

- 85-90% of uninvolved side (Davies, 2013; Bise, 2013)



Reid et al, 2007

Return-to-Play
(Davies, 2013; Creighton et al, 2010)

- Considerations:
  - Type of Sport
    - High, Moderate, or Low Risk
- Clinician Risk
- External Pressures

Return-to-Play Criteria

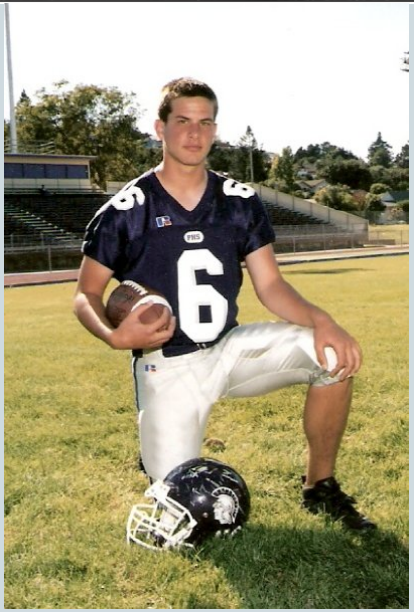
- **The "best" we have:**
  - ROM (Creighton et al, 2010; Barber-Westin and Noyes, 2011)
    - 70-100%, Full ROM, Pain-free
- **Laxity** (Davies, 2013; Barber-Westin and Noyes, 2011; DeCarlo, 1992)
  - 3mm (MAX) 2.5 or less preferred on Lachman or KT measurement
- **Thigh Circumference** (Creighton et al, 2010; Barber-Westin and Noyes, 2011)
  - <1cm difference
  - No Swelling or Effusion
  - Measurement sites

Return-to-Play Criteria

- Isokinetic Strength Measures (Barber-Westin and Noyes, 2011; Wilk et al 1994)
  - <10-15% side-to-side difference
- Functional Stability (Barber-Westin and Noyes, 2011; Davies 2013; Reid et al, 2007)
  - Functional Test Scores
  - Single-Leg Hop Tests (>85%-90%)
- Psychological Confidence (Creighton, 2010; Chmielewski, 2008)
  - Fear most common reason for not returning to sport

CONCLUSIONS

- Individual characteristics
- Biomechanics
- Graft types
- Healing of tissue properties
- Individual treatment and rehab
  - Outcome measures
  - Criterion-based progression



THANK YOU!!

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