Anterior Cruciate Ligament (ACL) Reconstruction in the Adult Athlete (Skeletally Mature) with Hamstring Graft

Anterior cruciate ligament (ACL) injuries affect males and females across a wide range of age and athletics.

About the Anterior Cruciate Ligament (ACL)

There are four main ligaments that stabilize the knee. The ACL is located in the center of the knee along with the posterior cruciate ligament (PCL). The ACL is responsible for stabilizing knee rotation that occurs during cutting and pivoting activities. The ACL is also a secondary restraint to knee hyperextension.

The ACL stabilizes the knee joint in two ways. First, the ligament acts as a passive restraint to excessive movement through its connection to the shin bone (tibia) and thigh bone (femur). Second, the ACL has mechanically sensitive nerve receptors, called proprioceptors, which sense the position of a joint. When a joint starts to exceed its normal range or speed of movement these proprioceptors will send a signal to the brain and spinal cord, which then stimulates the appropriate muscles to assist with stabilizing the joint.

Mechanism of Injury

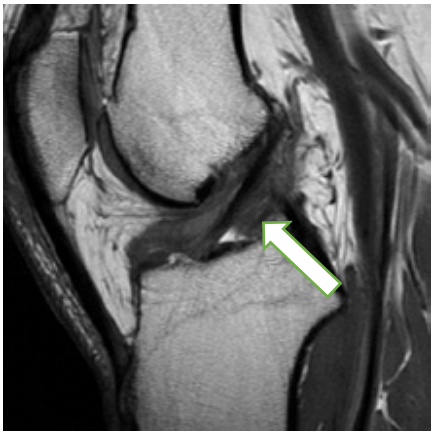
An ACL injury usually occurs without contact from another player. The most common form of non-contact injury is acceleration injury. An athlete often plants their foot on the ground to cut or change directions and the ACL cannot withstand the force placed on it, so it tears. This causes the knee to buckle or give out. The ACL also can be torn if the knee is forcefully hyperextended while landing from a jump. An ACL injury causes pain and a lot of swelling in the knee. Sometimes people say they felt or heard a "pop" in the knee. It is often hard to walk after an ACL tear. It is also usually hard to bend and straighten the knee all the way after the injury. Even once swelling goes down, people may feel like the knee "gives out" or feels unstable.

Although less common, contact ACL injuries occur. A common contact injury occurs when an athlete is hit from the side at the knee with the foot planted on the ground. These injuries often involve more than one ligament.

Research studies have attempted to determine what factors contribute to an increased injury risk, but ACL injuries are multi-factorial and cannot be isolated to a single cause.

Diagnosis of an ACL Injury

There are several ways to diagnose an ACL injury. A thorough history of how the injury occurred is important to know, but the physical examination is often the most reliable and least expensive method of diagnosis. A sports medicine physician, physical therapist or athletic trainer will assess the knee's laxity, compared to the uninjured knee, using a Lachman's test and an anterior drawer test.



Normal ACL

Torn ACL

Figure 1: *MRI images of the ACL of the knee*

They will also test the rotational stability component with a test called the pivot shift test. This test attempts to reproduce the athlete's sensation of buckling or giving out.

A magnetic resonance imaging (MRI) scan (see Figure 1) can visualize soft tissue and is a relatively accurate test in predicting an ACL tear. In a diagnostic arthroscopy, a surgeon looks inside the knee with a camera to determine an injury. This is the most definitive test but also the most expensive and invasive.

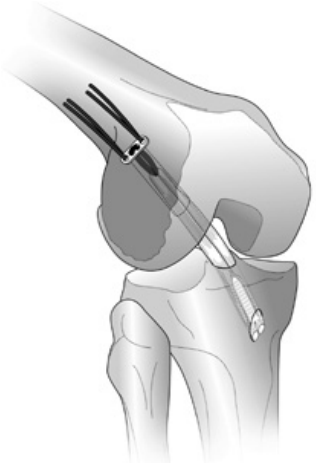


Figure 2: *Example of a hamstring tendon graft using an endobutton on the femoral side and a inference screw on the tibial side*

Consequences of an ACL Injury

When treating an ACL injury, the key is controlling the instability of the knee. Repeated instability not only hinders athletic performance, but more importantly increases the risk of further injury to the cartilage and other ligaments of the knee. Cutting and pivoting activities (common in sports like football, soccer, basketball and volleyball) are the most stressful for the ACL and are the activities most likely to reproduce the instability in an athlete with a torn ACL.

Treatment Options for an ACL Injury

The choices for treatment should be individualized and should consider an athlete's age, activity level, and the desire to return to sports which require significant cutting and pivoting or other highspeed movements. One form of conservative treatment is to modify the athlete's sports participation. This involves discontinuing sports involving cutting and pivoting, such as soccer or basketball. These sports could be replaced by sports that do not involve cutting and pivoting, such as swimming or running. Another form of conservative treatment is rehabilitation. Rehabilitation for an ACL injury focuses on improving an athlete's strength and stability with an emphasis on proprioception (positional awareness) and reactive muscular control to compensate for the torn ligament. For sports such as basketball, soccer and football, rehabilitation alone may not be enough to prevent instability. If instability persists, the athlete may undergo surgical reconstruction of the ligament to increase their potential to return to these sports. Surgical reconstruction involves replacing the torn ACL with a graft. For the athlete that is done, or nearly done growing, the surgical reconstruction involves placing a graft within drill holes (tunnels) in the thigh (femur) bone and shin (tibia) bone. There are several acceptable graft choices: hamstring tendon, patellar tendon, and quadriceps tendon. Factors such as other current injuries to the knee (ie. meniscus or MCL), pre-existing injuries, type of work or sport participation, and age may determine which of these three is best for you (See Figures 2 for hamstring graft).

All athletes will undergo six to twelve months of physical therapy. The post-operative physical therapy can be divided into five phases. During the first phase, the rehabilitative goals include protecting the healing graft, improving range of motion, decreasing swelling, and regaining leg muscle control. It is especially important to regain full extension very early post-operatively. When the knee is fully extended (straight) the ACL sits against the roof of the intracondylar notch. Thus it is important to achieve this early on, preventing scar tissue from forming in that space of the notch. (See Figure 5, ACL in flexion and in full extension).

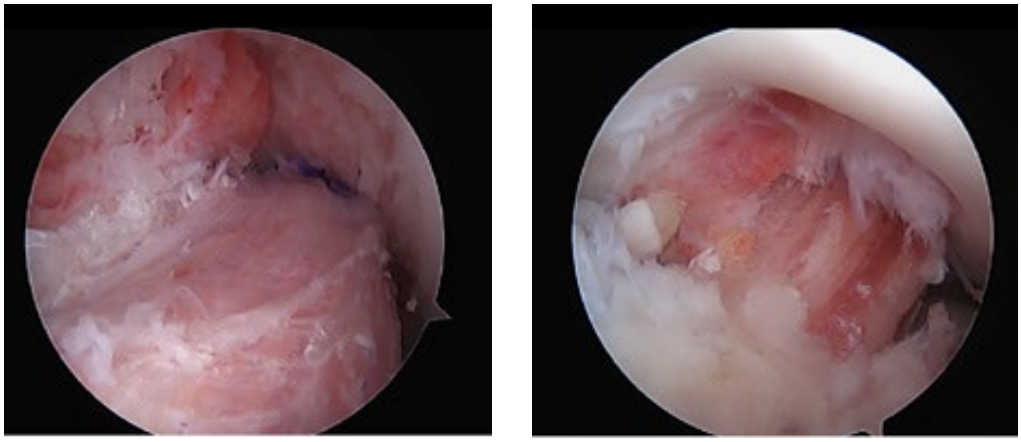


Figure 5: *Photos show the ACL graft, with the first photo shot with the knee in flexion and the second photo shot with the knee in full extension.*

In phase two, the goal is to focus on restoring proper body alignment and control with basic movements, such as walking, squats, and balance. This phase continues to build lower extremity and core (trunk) strength. In phase three, the focus shifts to developing good movement control with impact activities and more complex movements, such as a lunge with a rotational component. Developing movement control and eliminating apprehension while cutting and pivoting is the primary goal of phase four. At this time, there is also more focus on single leg impact and push off with change of direction. The final phase transitions the athlete from performing intense cutting and pivoting activities in a controlled environment to an environment that more closely replicates their sport, including return to team practices with progressive decrease in limitations.

When returning to sports and higher-level activities, there is the risk of the new ACL graft tearing if there is a new injury to the knee. The risk of this happening in young athletes/individuals (< 18 years old) is at least twice as high as it is in older adults. It is reported to be as high as 15-30% in these younger individuals. Reasons for this are unclear but likely to do a few different things including the type of surgery, continued physical maturation, and return to more intense or competitive high-level activity. Due to this high risk of re-injury, your physical therapist and doctor will put you through a series of progressive tests to determine when it is most safe to return to activity and sports. There is good evidence to show that the risk of re-injury goes down significantly by passing all return to sport testing and delaying return to sport to be after 9 months post-operatively.

Phase I (Surgery to 4 weeks after surgery)	
Appointments	• Rehabilitation appointments begin post-op day 1 and should be 2 times per week during this phase.
Rehabilitation Goals	• Protection of healing graft fixation • Regaining flexion and extension range of motion • Restore quadriceps function and leg control • Adherence to home exercise program (HEP) and precautions

Precautions	• Weightbearing: Begin with partial weight bearing and progress to weight bearing as tolerated when patient is safe to load the surgical leg more.
	• Brace: Post-operative extension brace for 2-4 weeks, wean from brace locked to brace unlocked to no brace as patient establishes leg control, pain control and safe gait mechanics.
	• Range of Motion (ROM): Goal of 0-90 degrees within 1 week, moving toward full flexion after the first 4 weeks. The goal in the first phase is to achieve hyperextension equal to the other side, unless excessive hypermobility exists. Generally, 5 degrees of hyperextension should be a maximum.
	• Pain & Swelling Control: Place the ice/cooling pad over the front of the knee for 20-30 minutes, then shift the pad up so it is over the back and inside of the thigh for 20-30 minutes (this will provide some pain relief to the graft harvest site of the hamstrings). Do this after each exercise session and before bed.
	• Meniscal Repair:
	  ◦ For Drs. Baer, Day, and Spiker- no weightbearing flexion, respect and don't push through any compression type pain or discomfort when working on flexion range of motion
	  ◦ Dr. Scerpella- no change in precautions
	• Meniscal ROOT Repair:
	  ◦ Touch-down weight bearing (TDWB) in locked extension brace for 6 weeks. NWB flexion for 6 weeks
	  ◦ ROM 0-90 degrees, always in NWB position

Suggested Therapeutic Exercise	• Assisted range of motion (AROM) (seated knee flexion or supine wall slides) *For hamstring grafts limit the amount of active knee flexion requiring hamstring force as this can cause increase pain and soreness at the donor/graft harvest site.*

	• Knee extension range of motion (avoid hyperextension past 5 degrees)
	• Ankle pumps progressing to resisted ankle range of motion
	• Patellar mobilizations if needed
	• Quad Activation:
	  ○ Quad sets – 10 second sustained and 1 second rapid activation
	  ○ Straight leg raises in multiple directions
	  ○ Supine wall pushes
	  ○ *It is suggested to use NMES, see addendum for guidelines and parameters*
	• Mini Squats
	• Weight shifting drills
	• *For appropriate patients, Blood Flow Restriction Training is recommended, see addendum for guidelines and parameters*

Cardiovascular exercise	• None at this time

Progression criteria	• 4+ weeks AND:
	  1. Good quad set and open chain leg control
	  2. Full knee extension
	  3. Near normal gait without crutches
	  4. Minimal knee effusion

Phase II (begin after meeting Phase I criteria, usually 4 weeks after surgery)	
Appointments	• Rehabilitation appointments are 1-2 times per week
Rehabilitation Goals	• Normalize gait • Avoid overstressing the fixation site • Closed chain leg control for non-impact movement control • Adherence to HEP
Precautions	• Avoid over-loading the fixation site by utilizing low amplitude low velocity movements. • Avoid active inflammation or reactive swelling.
Suggested Therapeutic Exercise	ROM Exercises • Supine wall slides and knee to chest to improve knee flexion as needed. Full extension should be gained by this point • Stationary bike with low resistance. Note: Avoid using the stationary bike for more than 15 min as an aerobic exercise. Too much cyclical motion of the graft early on can have a negative effect on the graft. HEP Exercises • Gait drills- forward and backward march walk, soldier walk, sidestep, step overs, hurdle walk - Double leg balance drills- balance board, tandem balance, progressing to stationary single leg balance drills. Add visual perturbation and neurocognitive challenge as appropriate • Weight acceptance and control- shallow squat with lateral shifting, with sagittal shift, with shallow arc motions • Open chain strengthening for quadriceps isolation: - knee extension isometrics starting at 60 degrees knee flexion - long arc quad starting 90-45 degrees of flexion then with gradual progressive resistance (band, ankle weight, knee extension machine) and ROM • Closed chain strengthening for quadriceps and glutes – double leg squat progressions, split squats, step backs, leg press

	- Emphasis on appropriate and controlled forward knee travel to ensure athlete is not compensating for quadriceps weakness with CKC strength exercises • Progress speed of movement without adding impact to improve rate of force development and mechanics prior to impact progression (i.e. squat with OH med ball throw, slider lunge with speed) • Begin to use external focus of attention drills for double leg strengthening • Heel raises with emphasis on maintaining active knee extension to practice triple extension pattern • Bridging • Hip and core strengthening • *If patients are still demonstrating arthrogenic muscle inhibition or torque unsteadiness it is suggested to use NMES, see addendum for guidelines and parameters* • *For appropriate patients, Blood Flow Restriction Training is recommended, see addendum for guidelines and parameters*
Cardiovascular exercise	• Stationary bike with low resistance • Deep water running • Elliptical trainer
Progression criteria	• Normal gait • Symmetric weight acceptance for squats to 60 degrees • No reactive swelling after exercise or activity that lasts more than 12 hours.

Phase III (begin after meeting Phase II criteria, usually 11-12 weeks after surgery)

Appointments	• Rehabilitation appointments as needed. Usually every 1-2 weeks.
Rehabilitation Goals	• Continued Quadriceps and hamstring strength building - restoring symmetry, hamstring:quadriceps ration 60%, and strength relative to body weight • Normal running gait without side-to-side differences or compensations. • Normal double leg landing control without side-to-side differences or compensations for sub-maximal squat jump. • Adherence to HEP
Precautions	• Avoid reactive swelling or joint pain that lasts more than 12 hours.
Suggested Therapeutic Exercise	• Low amplitude low velocity agility drills; forward and backward skipping, side shuffle, skater's quick stepping, carioca, cross overs, backward jog, forward jog • Closed chain strengthening for quadriceps and glutes – progressing from double leg strengthening to single leg strengthening; lunge progressions and single leg squat progressions - Emphasis on controlling forward knee position to ensure athlete is not compensating for quadriceps weakness • Open chain strengthening for quadriceps isolation - continue progressive overload, may need to limit ROM to allow higher RPE during exercise due to length tension relationship of quadriceps (i.e. knee extension 90-30 deg) • Single leg balance exercise and progressions, progressing from stationary to deceleration in to holding posture and position

	• At ~12-14 weeks initiate low amplitude landing mechanics: med ball squat catches, shallow jump landings, chop and drop stops, etc. • Hip strengthening – especially oriented at neuromuscular control in prevention of hip adduction and landing stance • Core strength and stabilization – especially orientated at preventing frontal plane trunk lean during landing and single leg stance NOTE: neurocognitive strategies and external focus of attention should be utilized with the therapeutic exercises. Examples: 1. Dual task activities 2. Using foam rollers or bench/chair for biofeedback about hip and knee position 3. Using PVC pipe or bar for trunk lean and/or weight shifting 4. Reactive challenge a. One step challenges to start (i.e. when I say "Go" do a lunge") b. Progressing to Multi-Step or decision making (if I say "1" do a forward lunge, if I say "2" do a lateral lunge) c. Using color cues via fit lights or blaze pods as able, SwitchedOn (free app) for visual prompts, or therapist created drills with balls/cones of different colors • *If patients are still demonstrating arthrogenic muscle inhibition or torque unsteadiness it is suggested to use NMES, see addendum for guidelines and parameters* • *For appropriate patients, Blood Flow Restriction Training is recommended, see addendum for guidelines and parameters*
Cardiovascular exercise	• Deep water running and swimming • Elliptical trainer at moderate intensity Return to jog program should not be utilized as cardiovascular training, just movement re-training and impact progression.
Progression criteria	• Normal jogging gait • Good single leg balance

	• Less than 30% deficit on Biodex strength test --- ready to start impact loading. if patients have NOT achieved >70% quadriceps symmetry: they should NOT progress impact drills to protect their joint surfaces from excessive compressive force - Continue strength progression, rate of force development and speed work without impact. • No reactive swelling after exercise or activity

Phase IV (begin after meeting phase III criteria, usually 16-20 weeks after surgery)	
Rehabilitation appointments	• Rehabilitation appointments are once every 2-4 weeks
Rehabilitation goals	• Normal multi-planar high velocity without side-to-side differences or compensations. • Normal double leg and single leg landing control without side-to-side differences or compensations • Running without a limp • Adherence to HEP
Precautions	• No active reactive swelling or joint pain that lasts more than 12 hours.
Suggested therapeutic exercises	• Progressive agility drills; forward and backward skipping, side shuffle, skater's quick stepping, carioca, cross overs, forward jog, backward jog – increase amplitude and velocity • Landing mechanics – progressing from higher amplitude double leg to sling leg landing drills. Start uni-planar and gradually progress to multi-planar. Start with vertical challenges and drills prior to horizontal challenges and drills. • Movement control exercise beginning with low velocity, single plane activities and progressing to higher velocity, multi-plane activities • Unanticipated movement control drills, including cutting and pivoting • Agility ladder drills • Strength and control drills related to sport specific movements. • Sport/work specific balance and proprioceptive drills • Hip strengthening – especially orientated at neuromuscular control in prevention of hip adduction and landing stance

	• Core strength and stabilization- especially orientated at preventing frontal plane trunk lean during landing and single leg stance • Stretching for patient specific muscle imbalances NOTE: neurocognitive strategies and external focus of attention should be utilized with the therapeutic exercises. Examples: • Dual task for cognitive distraction • Single step cues/reactions: verbal or visual to promote visual scanning of outside environment • Multi-step commands: using color or number patterns • Partner reaction and competition to increase speed and effort • Cognitive challenges during movement or stabilization, such as quick math problems, counting backward, word association games, etc • *If patients are still demonstrating arthrogenic muscle inhibition or torque unsteadiness it is suggested to use NMES, see addendum for guidelines and parameters* • *For appropriate patients, Blood Flow Restriction Training is recommended, see addendum for guidelines and parameters*
Cardiovascular exercise	• Progressive running program. Design to use sport specific energy systems
Progression criteria	• Progressive testing will be completed. The patient should have less than 20% difference in Biodex strength test • Normal multi-planar low to medium velocity without side-to-side differences or compensations. • Normal double leg landing control without side-to-side differences or compensations • Running without a limp

Phase V (if meeting phase IV goals)	
Rehabilitation appointments	• Physician appointment 9 months after surgery (if needed) • Rehab every 2-3 weeks
Rehabilitation goals	• Sprint without a limp • Confidence and control with cutting and pivoting activities • Confidence and control with single leg plyometrics, including good mechanics • Graduated return to sport and work
Precautions	• Post-activity soreness should resolve within 24 hours • Avoid post-activity swelling
Suggested therapeutic exercises	• Progressing effort and complexity of hopping - Addition of multi-planar hop - Progress number of hops in a row emphasizing decreased ground contact time • Practice of cutting and pivoting, other change of direction - Starting with planned, wide cuts (open angle) gradually decreasing angle of cuts (sharper turns) progressing effort and speed - Add multiple pre-planned cuts in a row - Change of direction from forward run to drop step and vice versa - Gradually progressing from closed drills to open cutting drills under self-direction - Advancing reactive nature of cutting with visual and verbal cues - Promote visual scanning and reaction to sports-specific cues • Gradual re-introduction (*see practice continuum in references below)* NOTE: neurocognitive strategies and external focus of attention should be utilized with the therapeutic exercises. Examples:

	1. Using verbal or visual cues for "stop and go" 2. Color cues to indicate different types of cuts (different angles) 3. Partner led sports-specific defesive runs with cutting and change of direction 4. Task change on a cue with an additional task cue 5. Layering in multi-step commands utilizing visual scanning and neurocognitive challenge (decision making)
Cardiovascular exercise	• Replicate sport/work specific energy demands • Limited practice activities
Progression criteria	• Patient may return to sport after receiving clearance from the orthopedic surgeon and the physical therapist/athletic trainer. Progressive testing will be completed. The patient should have less than 10% difference in Biodex strength test, force plate jump and vertical hop tests, and functional horizontal hop tests.

NMES Suggested Treatment Parameters:

- Indications: poor quad activation or lack of torque steadiness at higher loads
- Amplitude/Intensity (mA): as high as patient can tolerate
- Pulse Width (μs): 100-400 μs
- Pulse Rate (Hz): 50-100 Hz
- Frequency: NMES should be dosed the same way you would dose quadriceps strengthening exercise; early in the rehabilitation process, this should be used every day or even multiple times a day. As the patient progresses and the intensity of their exercise increases, the frequency will likely change to 2-4 times a week.

BFR Suggested Treatment Parameters:

- Indications: Patient is at least 2 weeks post op and not having any incision healing issues, and also has inability to tolerate heavy loading because of post-op precautions (example: weight bearing), pain or swelling
- Intensity: 80% LOP at 20-30% one rep max. As with all exercise, dosage should be carefully determined and individualized to each patient
- Sets / Reps: 30 – 15 – 15 – 15 with 30 sec rest between each set with cuff inflated
- Exercises: Begin with one exercise within an 8-minute time period, progressing to adding a second exercise if indicated and taking a deflation break between exercises.
- Providers should have training or certification in BFR so they can adequately screen for indications, contra-indications, precautions and response to treatment.

Practice Continuum:

1. Movement Patterns: a. sprinting b. shuffle c. carioca d. zig-zag cutting and e. shuttle change of direction
2. Closed Drills – sport-specific drills without opposition in a controlled speed environment
3. One-on-one Drills (no-contact) – sport-specific drills/ activities where the athlete is expected to react to his/ her opponent without compensation
4. One-on-one Drills – full speed 1 on 1 drills with game necessary contact
5. Team Scrimmage (no-contact) – patients are asked to wear a different colored jersey to indicate their contact
6. restrictions during team scrimmaging when appropriate
7. Team Scrimmage – full scrimmaging
8. Restricted Play – progressing time and situational play as appropriate.
9. Full return to play

Patient may return to sport after receiving clearance from the orthopedic surgeon and the physical therapist/athletic trainer. Progressive testing will be completed. Patient should have less than 10% difference in Biodex strength test, force plate jump and hop tests and functional hop tests.

References:

1. Busam ML, Provencher MT, Bach BR,Jr. Complications of anterior cruciate ligament reconstruction with bonep atellartendon-bone constructs: care and prevention. Am J Sports Med. Feb 2008;36(2):379-394
2. Cooper RL, Taylor NF, Feller JA. A systematic review of the effect of proprioceptive and balance exercises on people with an injured or reconstructed anterior cruciate ligament. Res Sports Med. Apr-Jun 2005;13(2):163-178
3. Krych AJ, Jackson JD, Hoskin TL, Dahm DL. A meta-analysis of patellar tendon autograft versus patellar tendon allograft in anterior cruciate ligament reconstruction. Arthroscopy. Mar 2008;24(3):292-298
4. Moisala AS, Jarvela T, Kannus P, Jarvinen M. Muscle strength evaluations after ACL reconstruction. Int J Sports Med. Oct 2007;28(10):868-872
5. Myer GD, Paterno MV, Ford KR, Hewett TE. Neuromuscular training techniques to target deficits before return to sport after anterior cruciate ligament reconstruction. J Strength Cond Res. May 2008;22(3):987-1014
6. Myer GD, Paterno MV, Ford KR, Quatman CE, Hewett TE. Rehabilitation after anterior cruciate ligament reconstruction: criteria-based progression through the return-to sport phase. J Orthop Sports Phys Ther. Jun 2006;36(6):385-402
7. Palmieri-Smith RM, Thomas AC, WojtysEM. Maximizing quadriceps strength after ACL reconstruction. Clin Sports Med. Jul 2008;27(3):405-424, vii-ix
8. Pinczewski LA, Lyman J, Salmon LJ, Russell VJ, Roe J, Linklater J. A 10-year comparison of anterior cruciate ligament reconstructions with hamstring tendon and patellar tendon autograft: a controlled, prospective trial. Am J Sports Med. Apr 2007;35(4):564-574
9. Mininder S. Kocher, Sumeet Garg and Lyle J. Micheli, Physeal Sparing Reconstruction of the Anterior Cruciate Ligament In Skeletally Immature Prepubescent Children and Adolescents. Surgical Technique. J Bone Joint Surg Am. 2006:88:283-293. doi: 10.2106/ JVJA.D.0044`

These rehabilitation guidelines were developed collaboratively by UW Health Sports Rehabilitation and the UW Health Sports Medicine physician group.