A Comprehensive Approach to ACL Injury

An Honors Thesis

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Abstract

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Injuries to the ACL are common occurrences in athletics today. Knowing how to effectively treat these injuries requires skills from all areas of athletic training knowledge, from anatomy to rehabilitation. This thesis serves as a guide to ACL injuries, beginning with anatomy and physiology of the ACL, predisposing factors, evaluation, surgical options and eventually ending with rehabilitation. Although this guide is not patient specific, as all injuries are unique, it can be utilized as a tool with any ACL injury.
Anatomy

The knee consists of the tibiofemoral and patellofemoral joints. Due to the extreme stress placed on the knee during weight bearing and locomotion, the knee is one of the most traumatized joints. The stability of the knee joint depends primarily on the ligaments, joint capsule and surrounding muscles. One ligament in particular, the anterior cruciate ligament (ACL), plays a highly specialized role in maintaining overall knee stability and kinematics.

Ligaments are composed of densely packed collagen fibers arranged parallel to tensile forces in order to provide stability. Collagen is a protein that helps to strengthen the structure of tissues, such as ligaments. Primarily type I collagen, small amounts of type III and trace amounts of types V, X, XII and XIV collagen comprise the densely packed collagen fibers of the ligaments. Elastin, proteoglycans and water are also present. Protein and polysaccharides comprise proteoglycans. Proteoglycans attract water molecules which provide lubrication and assist the tissue in resisting compressive forces. Elastin is a protein fiber capable of stretching and returning to its original form. Elastin fibers interweave with collagen fibers, adding elasticity, preventing ligamentous tears.

The ACL itself is a two-bundle ligament consisting of anteromedial and posterolateral bundles that connect the femur and the tibia. Specifically, the ACL originates from the anterior portion of the intercondylar eminence of the tibia and extends to the posterolateral aspect of the intercondylar fossa of the femur. The other cruciate ligament in the knee, the posterior cruciate ligament
(PCL), runs the opposite course in the knee, crossing from the posterior part of the tibia to the anterior portion of the femur.\textsuperscript{1-10} The ACL is both intraarticular and extrasynovial.\textsuperscript{1-10} The ACL's location inside the articular surface explains why it is considered an intraarticular ligament.\textsuperscript{1-10} Extrasynovial refers to the ACL's location outside the knee synovium, a layer of synovial fluid which surrounds the knee.\textsuperscript{1-10}

Knowledge of the ACL's anatomy is crucial to understanding its overall functioning in the knee joint.\textsuperscript{1-13} The ACL and the surrounding musculature greatly influence knee joint motion and in a larger sense, total body movement.\textsuperscript{1-13}

Blood vessels from the middle geniculart artery supply the proximal portion of the ACL. Branches of the lateral and medial inferior geniculate artery supply the distal portion of the ACL.\textsuperscript{3,4,10} These blood vessels travel into the ACL with a transverse orientation and align parallel to the collagen bundles.\textsuperscript{3,4,10} Distribution of blood supply is not similar for all sections of the ACL.\textsuperscript{3,4,10} Avascular areas can be found at the insertion sites and within the areas of fibrocartilage-like cells that are align within the collagen bundles thus leading to poor healing potential.\textsuperscript{3,4,10}

Some studies have revealed that the major origin of neural supply to the ACL is the tibial nerve, mostly found in the subsynovial layer and near the insertions of the ACL.\textsuperscript{3,4,10} Ruffini fibers and free nerve endings are found in the ACL.\textsuperscript{3,4,10} Ruffini fibers are slowly adapting stretch receptors.\textsuperscript{3,4,10} Free nerve endings are pain fibers that are activated by abnormal mechanical deformation and inflammatory agents, such as histamine.\textsuperscript{3,4,10}
The femoral attachment of the ACL is described as having an oval or semi-circular shape with an average diameter of 18 mm. The tibial attachment was found to be more oval in shape than circular with an average diameter of 17 mm. A normal ACL, averaging 38 mm in length and 10 mm in width, fans out towards its insertion at the tibia.

The two bundles of the ACL are the anteromedial (AM) and posterolateral (PL) bundles, referencing to their anatomic positions of their tibial insertion. The AM bundle originates in the most proximal part of the femoral origin and inserts at the anteromedial aspect of the tibial insertion. Fibers of the PM originate distally at the femoral origin and insert on the posterolateral aspect of the tibial insertion. The posterolateral bundle is considered to be the larger of the two bundles, although the anteromedial bundle is greater in length.

The anteromedial and posterolateral bundles maintain distinct functional differences during knee motion. Functional differences are based entirely on the tension patterning of the ACL during extension and flexion. In knee extension, the posterolateral bundle becomes taut while the anteromedial bundle is lax. The opposite is true with knee flexion, where the anteromedial bundle is taut and the posterolateral bundle is relaxed.

Ligaments and supporting soft tissue structures govern the movement of the knee joint, which is capable of movement in six degrees of freedom: three rotations and three translations. By relating movement to three principles axes, the description of knee motion can be better accomplished. The tibial shaft axis lies proximal-distally with internal-external rotation. The epicondylar axis
lies medial-laterally with flexion-extension rotation, and the anteroposterior axis lies anterior-posteriorally with varus-valgus rotation.4,6,7,9

The ACL serves as a static stabilizer of the knee against four distinct motions of the knee joint: anterior translation of the tibia on the femur, internal rotation of the tibia on the femur, external rotation of the tibia on the femur and hyperextension of the tibiofemoral joint.1-5,7,9,11-13 The ACL also works in conjunction with the posterior collateral ligament (PCL) during the screw home mechanism.1,5,7,9,11-13 In the knee’s screw home mechanism the knee moves into extension as tibia externally rotates.1-5,7,9,11-13 As the tibia externally rotates in the final degrees of extension, the ACL unwinds and the PCL winds.1-5,7,9 The amount of strain depends upon the type of movement.1-5,7,9 During passive range of motion (PROM), the amount of tensile stress placed on the ACL is minimized when the tibia remains in non-rotated or neutral position.1-5,9,11-13 In the final 15 degrees of extension, internally rotating the tibia increases the stress placed on the ACL while externally rotating the tibia decreases the stress.1-5,9,11-13 In PROM, both varus forces and valgus forces increase stress placed on the ACL.1-5,9,11-13 During active range of motion (AROM) the amount of tension placed on the ACL is greatest between 0 and 30 degrees of flexion.1-5,9,11-13 Resisted range of motion (RROM) increases the amount of tension placed on the ACL between 0 and 45 degrees of flexion.1-5,9,11-13 The strain on the anteromedial bundle was lowest at 35 degrees of flexion, increasing as the knee moved into full extension.1-5,9,11-13 The posterolateral bundle experienced more stress at knee flexion angles under 45 degrees.1-5,9,11-13
In addition to the ligaments that guide and restrain knee motion, the muscles surrounding the knee also assist in the kinematics of an intact knee. 1,2,4,10,11-13 Knee flexion is assisted by the biceps femoris, semitendinosus, semimembranosus, gracilis, sartorius, gastrocnemius, popliteus and plantaris muscles in closed chain motions. 1,2,4,10,11-13 The vastus medialis, vastus lateralis, vastus intermedius and rectus femoris cause knee extension. 1,2,4,10,11-13 The biceps femoris causes external rotation of the tibia. 1,2,4,10,11-13 Internal rotation is caused by the popliteus, gracilis, semitendinosus, semimembranosus and sartorius muscles. 1,2,4,10,11-13 The iliotibial band on the lateral side of the knee acts as a dynamic lateral stabilizer of the patellafemoral joints. 1,2,4,10,11-13

While the muscle activity assists in the kinematics of the knee, it also introduces stress and forces experienced by the ACL. 1,2,4,10,11-13 The quadriceps exert an anterior shear force on the tibia when the knee is between 5 and 60 degrees of flexion. 1,2,4,10,11-13 The quadriceps exert a posterior shear force when the knee is flexed between 75 and 90 degrees during weight bearing, due to the posterior tilt of the tibial plateau 1,2,4,10,11-13 Passive extension of the knee was found to generate forces in the ACL only during the last 10 degrees of extension. 1,2,4,10,11-13 Hamstring activity significantly reduces anterior tibial translation and unloads the ACL during knee extension. 1,2,4,10,11-13

Cooperation of all ligaments, muscles, tendons and bones surrounding the ACL within the knee joint is vital to the healthy functioning of the ACL. Only after fully examining and understanding the ACL can injuries to this area be properly diagnosed and future injuries prevented.
Predisposing Factors to ACL Injury

Several factors, both intrinsic and extrinsic, have been the subject of recent investigations in the search for predictors of ACL injuries. Examples of such factors include, but are not limited to: anatomical structure, strength imbalances, landing biomechanics and the female gender.\textsuperscript{1,2,6,15-17} Much of the information about the predisposing factors is conflicting and marginal at best. However, identifying these possible factors may help to develop prevention programs that minimize ACL injury.

Lower extremity malalignments detract from the efficiency and overall functioning of the knee joint, thus contributing to potential ACL dysfunctions.\textsuperscript{1,2,6,15-17} Excessive foot pronation, knee recurvatum, external tibial torsion or a combination of these postural faults might all contribute to ACL injuries.\textsuperscript{1,2,6,15-17}

Foot pronation is defined as the decelerating phase of movement during the contact phase of gait.\textsuperscript{1,2,15-17} The subtalar joint is a tri-planar single-axis hinge joint connecting the talus and the calcaneus.\textsuperscript{15} The subtalar joint also includes the posterior surface of the navicular bone, which articulates with the head of the talus.\textsuperscript{15} During normal gait, subtalar joint eversion is maximal when the foot first contacts the ground and lessens during heel rise and lift-off.\textsuperscript{15} One of the components of foot pronation is subtalar joint eversion.\textsuperscript{15} Excessive eversion causes tibial internal rotation.\textsuperscript{1,2,6,15-17} Since the ACL tightens with tibial internal
rotation, an increase in tibial internal rotation will excessively load the ACL, possibly leading to an ACL injury.\textsuperscript{1,2,6,15-17}

A measure of excessive pronation commonly employed by clinicians is the navicular drop test.\textsuperscript{15} This test measures the distance between the original height of the navicular in a seated, non-weightbearing subtalar joint-neutral position, and the weightbearing subtalar joint position.\textsuperscript{15} Data has indicated that excessive pronation measured by the navicular drop test is associated with ACL-injured patients versus noninjured patients.\textsuperscript{15}

Genu recurvatum or knee hyperextension may increase an athlete’s susceptibility to ACL injuries.\textsuperscript{1,2,6,15-17} Genu recurvatum is characterized by soft tissue laxities of the posterior, posterolateral and posteromedial joint structures of the knee.\textsuperscript{1,2,15,17} Occasional hyperextension during ambulation repetitively overloads these soft tissue structures leading to chronic tensile strain on the ACL over time.\textsuperscript{15} Measures of genu recurvatum indicate joint laxity, which is another intrinsic factor associated with ACL injuries.\textsuperscript{1,2,15}

Another intrinsic factor associated with ACL injuries is external tibial torsion.\textsuperscript{1,2,15} Using the thigh-foot angle measurement, torsional deformities can be assessed.\textsuperscript{15} The thigh-foot angle is the angular difference between the axis of the thigh and the foot as viewed directly down the knee flexed to 90 degrees.\textsuperscript{15} The thigh-foot value can either increase or decrease with age.\textsuperscript{15} Planting the foot in a position of increased external rotation may result in increased tension on the ACL ligament, increasing the susceptibility to injury of the ACL.\textsuperscript{1,2,6,15-17}
Increased femoral anteversion, which is excessive internal rotation of the femoral shaft in stance, may result in an increased Q-angle.\textsuperscript{1,2,15} Q-angle is measured from the middle of the patella to the anterior superior spine of the ilium and the tubercle of the tibia through the center of the patella.\textsuperscript{1,2,15} Normal Q-angles measure 10 degrees for men and 15 degrees for women.\textsuperscript{1,2,15} Normal femoral anteversion measures 15 degrees.\textsuperscript{1,2,15} Increased femoral anteversion may lead to increased external tibial torsion or increased internal rotation of the femur, thereby increasing Q angle measurements.\textsuperscript{1,2,15} Changes in either femoral anteversion or Q-angle can predispose one to ACL injuries due to malalignment of the knee.\textsuperscript{1,2,15}

Strength imbalances are possible causes of ACL injury.\textsuperscript{1,2,6,15-17} Dynamic stabilization of the knee centers around the action of the quadriceps and the hamstrings.\textsuperscript{1,2,6,15-17} Researchers believe that deficits in hamstring strength relative to quadriceps strength could predispose an athlete to ACL injuries.\textsuperscript{1,2,6,15-17} Why are the hamstrings such an important part of knee functioning? Hamstrings act as protagonists to the ACL, providing resistance to tibial anterior translation and rotary stability.\textsuperscript{15,17} Eccentric contraction of the hamstrings promotes hip stabilization.\textsuperscript{15} Eccentric contraction of the quadriceps promotes knee stabilization.\textsuperscript{15} Forceful hamstring contraction stabilizes hip flexion, helping to counteract the tendency of the quadriceps to cause anterior translation of the tibia on the femur.\textsuperscript{15} Increasing hamstring contraction can protect against the rotational and translational stresses of the knee joint.\textsuperscript{15,17} Thus, hamstring strength deficits may be indicative of future ACL pathologies. Increasing knee
flexion allows the hamstring muscles to co-contract with the quadriceps, providing a posterior force on the knee and ultimately greater knee stability.12

Weak hip adductor and abductors will not stabilize the knee, resulting in greater valgus movement, thereby increasing the likelihood of an ACL injury.15,17 Hip abductors prevent excessive hip adduction and internal rotation.15,17 Weak hip abductors may cause external rotation and knee varus, factors associated with increased tension on the ACL.15,17 Weak hip abductors may allow the femur to internally rotate and the knee to move into a valgus position, thus increasing the tension on the ACL.15,17

Poor biomechanics and landing techniques contribute to the risk of ACL injury.1,2,6,15-17 Pronated or supinated feet when landing, greater degrees of hip flexion with internal rotation when landing and knee hyperextension when landing are all probable factors of ACL injury.1,2,6,15-17 Foot pronation and supination often result in knee valgus or varus, respectfully. Valgus force results in knock knees.1,2,15 Varus force results in bowlegged knees.1,2,15 In valgus loading, the ACL becomes tense before other ligaments, becoming the primary ligament for resisting valgus force.15

Hyperextension of the knee when decelerating or landing contributes to causes of ACL injuries. While landing, the tibia and femur pinch the ACL, often causing it to rupture.1,2,6,15-17 During normal deceleration, the legs flex in the sagittal plane and not in the frontal plane, meaning that the hip extensors, knee extensors and ankle plantarflexors all contract eccentrically to absorb the impact force from landing and consequently protect the ACL from injury.15,17 If, during
deceleration, the hamstrings and quadriceps were tensed and the knee was not flexed, muscles of the frontal plane would be forced to absorb the impact, therefore causing hyperextension of the knee.\textsuperscript{15,17}

The well-documented increase in ACL injury rates among females compared to males suggests that gender might predispose females to ACL injuries.\textsuperscript{1,2,6,15-17} Females intrinsically exhibit several of the predisposing alignment factors already mentioned: Q-angle, weakened hip abductors and adductors, and increased knee valgus mechanics during jump-landings.\textsuperscript{1,2,6,15-17} Researchers have also found that hamstring to quadriceps strength ratios were significantly lower in females compared to males.\textsuperscript{15} In addition, hormones may influence ACL injuries in females, by contributing to ligament laxity.\textsuperscript{1,6} The ACL has receptor sites for estrogen, progesterone and relaxin, all hormones related to menstruation.\textsuperscript{1,6} Research confirms that increased estrogen levels, especially during the week prior to or after the start of the menstrual cycle, diminish collagen synthesis, thus reducing ACL ligament strength.\textsuperscript{1,6} Despite these findings, conflicting data exists, making this a controversial issue, although at this time more data discredits the idea that hormone fluxuations influence ACL laxity and ultimately lead to ACL dysfunction.\textsuperscript{1,6}

Identification of these predisposing factors only serves to provide further explanation as to the pathogenesis of ACL injury. Knowledge of the risk factors may allow modification of muscular imbalances, poor biomechanics and some anatomical structures, ultimately leading to the prevention of ACL injuries.
Evaluation

Every injury evaluation incorporates three unique areas of assessment in order to arrive at an injury diagnosis: history, observation and assessment. The history behind the injury seeks to answer how the injury happened. Through observation of the patient, the clinician is able to identify signs associated with the injury, in addition to structural abnormalities linked with the injury. Assessment of the injury includes ROM, strength assessments and special testing to rule out differential diagnoses.

Evaluation of any suspected knee injury, especially those pertaining to the ACL, begins with taking a complete history of the events leading up to the injury. Determining how the injury occurred, otherwise known as the mechanism of injury (MOI) can assist in evaluating the extent of ACL injuries.\textsuperscript{1,2,5,6,9,15,17-19} Other pertinent questions asked to gather a history include\textsuperscript{1,2,5,6,9,15,17-19}:

- What happened?
- How did it happen?
- When did it happen?
- Did you hear a snap, crack or a pop?
- Location of the pain?
- Pain level on a scale of 1 to 10
- Past history of injury?
- Was there swelling?
- If there was swelling, how fast did the swelling appear?
- Does the knee give way or lock?
- Is there clicking or grinding?
- Is there any numbness or tingling?
- Have you taken anything for the pain?
- Have you done anything to treat the injury?

Mechanism of injury causing ACL injury can be defined as either contact or noncontact.\textsuperscript{1,2,6,15} When the ACL sustains injury from a direct blow to the knee, the mechanism of injury is defined as a contact mechanism.\textsuperscript{1,2,6,15} The most
common noncontact mechanism occurs with the tibia in external rotation with a valgus knee. A less common noncontact mechanism occurs when the lower body is in a position of forward flexion, the hip is in adduction, the femur is in internal rotation, the knee is in 20 to 30 degrees of flexion and the tibia is in external rotation. Another noncontact mechanism of injury often stems from abrupt deceleration, a cutting maneuver on a planted foot, or hyperextension of the knee with the tibia in internal rotation.

The location of pain reported allows the clinician to distinguish between differential injuries. Often, the location of pain arising from the ACL is described as being “beneath the kneecap” or “inside the knee.” The patient may often report hearing a snapping or popping noise associated with the mechanism of injury. It is not uncommon for the athlete to report feeling no pain after an initial popping sensation. After ruling out injuries to the patella and possible fractures, these sounds are often indicative of an ACL tear. Questions regarding previous knee injuries aid in establishing the norms for the knee. For example, a prior ACL injury in the knee might have left the knee with an increased degree of ACL laxity or a decreased range of motion. Knowing what is normal for the individual’s knee helps to identify an injury.

The next step in evaluating a possible ACL injury involves visual inspection of the knee. Signs and symptoms of possible ACL injury include rapid swelling at the joint line that may extravasate distally over time. Loss of range of motion is often seen when swelling accompanies ACL injuries, specifically loss of knee extension. Intraarticular swelling and the tension
placed on the ACL limits knee range of motion. Following ACL injury, the athlete is often unable to ambulate without assistance.

Further evaluation of the injured ACL requires palpation of bony structures and soft tissue structures. Pain is not generally reported with palpations following an ACL injury, although it is important to palpate knee structures to rule out other differential diagnoses. The clinician should palpate the following bony and soft tissue structures:

**Bony Palpations:**
- Medial tibial plateau
- Medial femoral condyle
- Medial epicondyle
- Adductor tubercle
- Gerdy’s tubercle
- Lateral tibial plateau

**Soft Tissue Palpations:**
- Vastus medialis
- Vastus lateralis
- Vastus intermedius
- Rectus femoris
- Sartorius
- Patellar tendon
- Anterior joint capsule
- Medial collateral ligament
- Pes anserine insertion (sartorius, gracilis, semitendinosus...)
- Lateral epicondyle
- Head of the fibula
- Tibial tuberosity
- Superior patellar border
- Inferior patellar border
- Lateral femoral condyle
- Medial joint capsule
- Semitendinosus
- Semimembranosus
- Popliteus
- Medial and lateral heads of the gastrocnemius
- Biceps femoris
- Lateral collateral ligament
- Lateral joint capsule
- Illiotibial band (IT band)

After inspecting knee anatomy, the patient’s range of motion is assessed, actively, passively and with resistance. Flexion, extension, internal rotation
and external rotation are the motions assessed. Having the patient actively perform these motions quickly reveals any gross restrictions in the range of knee motion. After active range of motion (AROM), passive range of motion (PROM) is evaluated. The clinician passively takes the patient through the individual motions of the knee and evaluates the quality of the end-feel. Resistive range of motion (RROM) assesses muscle weakness that may further highlight the area, as well as reveal weaknesses that must be addressed in rehab.

After assessing knee range of motion, special tests are performed to determine ligamentous integrity of the ACL. Currently, there are three special tests used in evaluating ACL integrity: Lachman’s test, anterior-drawer test and pivot shift test. Although Lachman’s test is considered the gold-standard test for assessing ACL integrity, the other tests have their unique advantages.

The Lachman test is considered the most accurate and sensitive special test of ACL laxity. Secondary ligament structures are in a more relaxed position and hamstring contraction is reduced, allowing for increased accuracy. Since this test is performed in a position closer to extension, the effects of profuse intraarticular swelling on the accuracy of the test are diminished. During a Lachman’s test, the patient is supine and the knee is positioned in 20 degrees of flexion. While a posterior pressure is applied to stabilize the femur, the tibia is drawn anteriorly. An increased amount of anterior tibial translation compared to the non-injured knee is defined as a positive test, indicating ACL injury. When the posterolateral bundle is severed, the
amount of anterior displacement of the tibia on the femur in the extended position increases.\textsuperscript{5} Since the placement of the knee during the Lachman test is closest to knee extension, the test best indicates injury to the posterolateral bundle.\textsuperscript{5}

Difficulty performing the Lachman test on patients with bulky legs, joint rotation and lack of patient relaxation can influence the accuracy of the Lachman test.\textsuperscript{1,2,5,9,19} A modified Lachman test, known as the drop leg Lachman test, overcomes these problems.\textsuperscript{1,5,19} The drop leg Lachman test is performed with the patient supine and the leg to be examined abducted off the side of the table and flexed to 25 degrees.\textsuperscript{1,5,19} Maintenance of the angles of flexion and rotation are due to the examiner holding the foot between his or her legs.\textsuperscript{1,5,19} The thigh of the patient is stabilized with one of the clinician's hands while the free hand provides an anteriorly directed force as in the traditional Lachman's test.\textsuperscript{1,5,19} Research concluded that the drop leg Lachman test offers several advantages over the traditional Lachman test including: increased sensitivity, reproducibility, and ease when performed.\textsuperscript{1,5,19}

The anterior drawer test also attempts to determine the integrity of the ACL by displacing the tibia anteriorly on the femur but with the knee placed in 90 degrees of flexion.\textsuperscript{1,2,5,9,19} As with the Lachman test, an increased amount of anterior tibial translation compared to the non-injured knee indicates ACL injury.\textsuperscript{1,2,5,9,19} Anterior drawer best indicates injury to the anteromedial bundle of the ACL.\textsuperscript{1,5} The anteromedial bundle of the ACL becomes taut during knee flexion, meaning that anterior tibial translation cannot occur in the flexed position unless this bundle is torn.\textsuperscript{1,5}
Results of the anterior drawer test are often misleading, due to common problems associated with the test.\textsuperscript{1,5} Hamstring guarding may mask anterior displacement of the tibia on the femur.\textsuperscript{5,7} Effusion within the knee joint itself can effect the range of motion of the knee, possibly preventing anterior tibial translation.\textsuperscript{1,5} Flexing the knee to 90 degrees already causes anterior displacement of the tibia, perhaps masking the amount of further tibial displacement during the test.\textsuperscript{1,5} Due to these common drawbacks, results from both the anterior drawer and Lachman test should be considered when making a diagnosis.

The pivot-shift test is another special tests designed to assess ACL deformity. With the patient lying supine, one hand presses against the head of the fibula and the other grasps the patient's ankle.\textsuperscript{1,2} The leg begins in internal rotation with the knee in full extension.\textsuperscript{1,2} The clinician then moves thigh and knee into flexion while simultaneously applying valgus axial forces to the knee.\textsuperscript{1,2} If there is damage to the ACL, the lateral tibial plateau will be subluxated in full extension and reduce itself at 20 degrees of knee flexion.\textsuperscript{1,2} Problems associated with the Lachman test can also plague this test.\textsuperscript{1,2} Therefore, this test should be performed in correlation with the anterior drawer test.

Diagnostic tests are designed to confirm or refute the suspicions of the clinician with regards to ACL injury. The most common imaging technique used in the evaluation of orthopedic injuries is radiography.\textsuperscript{1,2} X-ray examinations are best used for examining high-density tissues, such as bone.\textsuperscript{1,2} Although soft tissues cannot be imaged using x-rays, swelling within the soft tissue and even outlines of soft tissue can be identified.\textsuperscript{1,2} The presence of swelling may indicate
an ACL injury or rule out differential diagnoses. The most common diagnostic
tool associated with identification of ACL injury is magnetic resonance imaging
(MRI).\textsuperscript{1,2} MRI offers superior visualization of the body’s soft tissue structures,
including those that are swollen and inflamed. Despite the expense associated
with this diagnostic tool, physicians widely employ it to assess ligament
injuries.\textsuperscript{1,2}

Sometimes after a complete evaluation of the knee, a clinician might have
some reservations about whether the injury affects solely the ACL or involves
other structures as well. The rotary forces placed on the knee make isolated
trauma to the ACL highly unlikely.\textsuperscript{1,2,6,15,17} Possible differential diagnoses of
ACL injury include anterolateral rotatory instability, an Unhappy Triad,
posteromedial rotatory instability, meniscal tears, collateral ligament sprains and
posterolateral rotary instability.\textsuperscript{1,2} An unhappy triad typically includes injury to
the ACL, the medial meniscus and the medial collateral ligament or it can be
injury to the ACL, the lateral meniscus and the lateral collateral ligament.\textsuperscript{1,2} It is
important to rule out these other injuries prior to diagnosing an isolated ACL
injury.

Surgical Procedures

The main goal of surgery is to reestablish knee joint stability.\textsuperscript{20} Currently,
there are 3 surgical approaches, 4 graft choices and 2 methods of fixation used for
ACL reconstruction. The approaches include: miniarthrotomy through the
patellar tendon defect, arthroscopy-assisted and endoscopic techniques.\textsuperscript{8,20-26}
Possible graft choices include the bone-patellar tendon-bone graft, the quadriceps tendon graft and the semitendinosus/gracilis tendon graft and allografts.\textsuperscript{8,20-28} Indirect and direct fixation methods also exist. Cross-pins, polyester tape-titanium button and suture-posts are methods of indirect fixation.\textsuperscript{8,21} Interference screws, staples and washers are methods of direct fixation.\textsuperscript{8,21}

When determining which type of autograft to use, it is important to understand the structural and mechanical properties of the intact ACL. Replacement grafts should be similar to the intact ACL in tensile strength and dimensional properties in order to reproduce optimal functioning.\textsuperscript{8} Any autograft has less risk of an adverse inflammatory reaction to the tissue and almost no risk of disease transmission.\textsuperscript{8}

Of the three common autograft choices, the bone-patellar tendon-bone graft is the most popular.\textsuperscript{8,20-28} When harvesting this graft, 8 to 11 mm wide is taken from the central third of the patellar tendon along with its adjacent patellar and tibial bone plugs.\textsuperscript{8,20,23,24,27} This has been a popular choice because of its high ultimate tensile load (about 2300 N), stiffness (about 620 N/mm) and the bony attachments.\textsuperscript{8} The attachment zone of this graft displays chondral transition between tendon and bone.\textsuperscript{24} The healing of bone to bone is much faster, taking only 4-6 weeks, thus providing mechanical stability much faster than other graft choices, namely a hamstring graft.\textsuperscript{8,24,28} Disadvantages to using the bone-patellar tendon-bone graft include weakening of the graft with aging extension deficits, developing patellar tendonitis or developing anterior knee pain.\textsuperscript{22,24}
Lately, the use of the hamstring tendon graft has gained more attention. This graft is a quadruple-stranded semitendinosus/gracilis tendon graft, where both the semitendinosus and gracilis tendons are folded in half and then combined.\textsuperscript{22,24-27} The semitendinosus/gracilis tendon graft, which is typically 10 mm wide and round, has dimensions comparable to an intact ACL.\textsuperscript{8} The ultimate tensile load has been reported to be as high as 4108 N prior to surgery, which is much higher than the bone-patellar tendon-bone graft.\textsuperscript{8} Another advantage of the graft is that the quadruple semitendinosus/gracilis tendon graft may better stimulate the function of the two-bundle ACL, since this graft is multi-bundled.\textsuperscript{8} The mechanical properties of the hamstring tendons have shown to be better preserved as the patient ages, another advantage of this graft choice.\textsuperscript{24} Disadvantages of this procedure include: increased joint laxity, muscular deficits in knee flexion and time needed for tendon to bone healing compared to the patellar tendon graft.\textsuperscript{8,22,24}

Another graft choice gaining recent attention is the quadriceps tendon graft. Some studies have demonstrated that the ultimate tensile load for this graft has been 2352 N at the time of harvest.\textsuperscript{8} The quadriceps tendon graft is comparable in size to the original ACL.\textsuperscript{8} Although the quadriceps tendon is an adequate graft choice, its use has been limited to revision ACL surgeries due to the popularity of the aforementioned graft options.

The last graft choice available are soft tissue grafts harvested from human donors, other than the patient, otherwise known as allografts. A common misconception with allografts is that only a cadaver ACL is used. Common
allografts for ACL reconstruction include the patellar tendon and Achilles tendon in addition to a cadaver ACL. Advantages of allografts include a decrease in surgery time, avoidance of donor site morbidity, and less postoperative pain. Disadvantages to allografts include a decrease in tensile properties with sterilization, risk of disease transmission and slower incorporation time than autografts. Allografts are frequently used in revision ligament reconstructions, in patients who are not elite athletes, and in cases where autografts could not be harvested from the body.

There are widespread debates over which graft choice is best for ACL reconstructive surgery. Although there are both advantages and disadvantages to selecting a particular graft choice over another, the bone-patellar tendon-bone autograft reigns as the most popular in the United States.

Bone-Patellar Tendon-Bone Procedure

Equally as important as graft selection is the selection of the surgical approach to the ACL reconstruction. Currently, three surgical procedures exist to repair the ACL: the bone-patellar tendon-bone procedure, the hamstring procedure and the miniarthrotyomy procedure.

The bone-patellar tendon-bone surgical procedure uses the endoscopic technique to harvest the patellar tendon and fixate it to attachment sites on the tibia and the femur.

A tourniquet is placed high on the proximal thigh prior to placing the extremity in a padded leg holder. Preoperatively, 1 gram of cephalosporin
(antibiotic) is administered for protection against infections. Prior to placing the leg in the leg holder, it is important to examine both legs for comparison of the standard special tests: pivot shit, Lachman and anterior drawer tests. Duraprep, an antiseptic, is applied to the skin around the knee joint. Sixty milligrams of intramuscular ketoraloc tromethamine, a pain medication, is administered at the beginning of the surgical procedure and 30 mg is administered en route to the recovery room.

Patellar tendon harvest and preparation is the next sequence of events in the endoscopic procedure. A 3 to 3.5 inch longitudinal incision centering over the medial aspect of the patellar tendon is created. The central third of the patellar tendon was removed, along with the bone plugs from the tibia and the femur. An oscillating blade then makes cuts in the patella and tibial tubercle. Cutting into the patella reduces the potential for stress fractures of the patella. Cutting into the tibial tubercle maximizes the amount of bone for attachments of the patellar tendon. Freeing the fat from the tendon and trimming the bone blocks to fit the femoral and tibial bone tunnels concludes graft preparation.

Creation of portals allows for insertion of the arthroscope. Using the patellar tendon as a landmark, the surgeon places the knee in flexion and creates the portals with a small pin. The inferolateral portal lies on the lateral and inferior edge of the patellar tendon. The surgeon establishes an inferomedial portal on the medial edge of the patellar tendon, directly in line with the
inferolateral portal.\textsuperscript{23,24} A superomedial portal is created on the superior and medial edge of the patellar tendon.\textsuperscript{23,24}

Notchplasty, performed with an arthroscopic shaver or buzz, involves removal of remnant ACL tissue and bone from the tibial insertion site\textsuperscript{23,24} (Figure 1). A notchplasty is only necessary if excess scar tissue impedes visualization of graft placement or if the surgeon believes the intercondylar walls would impinge the graft.\textsuperscript{23,24}

Tibial tunnel preparation allows for the ACL to insert anatomically into the knee. The surgeon selects a site midway within the tibia (an 11 o’clock orientation on the right knee and one o’clock orientation on the left knee) with the knee in flexion.\textsuperscript{23,24} A reamer drills a pin at a 50 to 55 degree angle into the entrance site until the pin lines up with the posterior edge of the lateral meniscus.\textsuperscript{23,24}

Femoral tunnel preparation occurs with the knee in 75 to 90 degrees of flexion.\textsuperscript{23,24} A femoral pin placement guide is passed backwards from the tibial tunnel and drilled approximately 1.5 inches into the femur.\textsuperscript{23,24} A reamer inserted backwards through the tibial tunnel up to the femoral region creates a hole deeper than the longest bone plug.\textsuperscript{23,24}

The graft is then pushed backwards through the tibial tunnel with assistance from an arthroscopic grasping instrument\textsuperscript{23,24} (Figure 2). A Nitenol pin is passed through the inferomedial portal to a position between 11:30 and 12:30 on the clock.\textsuperscript{23,24} After flexing the knee to 100-110 degrees, the pin is further advanced until it bottoms out.\textsuperscript{23,24} A cannulated screw is inserted to half of its
length, the Nitenol pin is removed back out the tunnel through which it was inserted and the screw is completely fixated\textsuperscript{23,24} (Figure 3). Once the graft has been secured, the openings are sutured.\textsuperscript{23,24} The knee is then assessed for normal range of motion, thus completing the surgical procedure.\textsuperscript{23,24}

Hamstring Procedure

The operative technique using the semitendinosus tendon uses the endoscopic technique to place a quadruple-stranded hamstring tendon.\textsuperscript{22,24-26} As with the endoscopic bone-patellar tendon-bone technique, the surgeon examines the patient’s knee after the patient receives either a general or regional anesthetic.\textsuperscript{22,24-26} Both knees are assessed with the pivot-shift test, Lachman’s and anterior drawer tests.\textsuperscript{8,22-26}

After examination, the limb is prepared for surgery. A tourniquet is placed proximally on the operative extremity and the non-operative extremity is positioned in a well-padded leg holder.\textsuperscript{22,24-26} The surgeon places the operative extremity in an arthroscopic leg holder at the level of the tourniquet, allowing for unobstructed access to the extremity throughout the entire surgical procedure.\textsuperscript{22,24-26}

The surgeon delineates anatomical landmarks, and establishes anteromedial and anterolateral portals. If needed, posteromedial and posterolateral portals are established.\textsuperscript{22,24-26} The surgeon inserts an arthroscope through the anterolateral portal in order to conduct a thorough evaluation of the entire knee.\textsuperscript{22,24-26}
Harvest of the hamstring tendons begins with a 2 to 3-cm oblique incision made directly over the pes anserinus in line with the hamstring tendons.\textsuperscript{22,24-26} The surgeon captures the semitendinosus with an angled clamp.\textsuperscript{22,24-26} With the knee flexed and the hip in external rotation, also known as a figure-four position, a tendon harvester is placed around the distal end of the semitendinosus tendon.\textsuperscript{22,24-26} An angled clamp applies gentle countertraction to the distal end of the tendon, forcing the tendon to release proximally as the harvester advances.\textsuperscript{22,24-26} Once the semitendinosus tendon has been harvested proximally, the distal tendon insertions are sharply removed from the tibia.\textsuperscript{22,24-26} Graft preparation begins with removal of all muscle fibers.\textsuperscript{22,24-26} A nonabsorbable suture attaches 3-4 cm from the tendon end with maximal manual tension applied to tension the graft.\textsuperscript{22,24-26} The tendons pass through a suture loop to form a four-strand construct.\textsuperscript{22,24-26} The diameter of the snuggest-fitting calibrated cylinder through which the four-strand construct is pulled defines the diameter of the four-bundle graft.\textsuperscript{22,24-26} At this point, preparation of the graft is complete.

The surgeon then performs the notchplasty with the knee flexed to about 90 degrees and with a bump under the knee.\textsuperscript{22,24-26} A notchplasty removes sufficient amount of bone from the lateral and anterior aspects of the intercondylar notch prior to creation and positioning of the tibial tunnels.\textsuperscript{22,24-26} A notchplasty allows for placement of the ACL graft without lateral or anterior graft impingement.\textsuperscript{22,24-26} Creating the tibial tunnel involves use of a commercial aiming guide to place a guidewire for tunnel reaming.\textsuperscript{22,24-26} The guidewire typically enters the anteromedial aspect of the tibia and emerges within the
posterior portion of the native anterior cruciate ligament insertion on the tibia.\textsuperscript{22,24-26} (Figure 4). The creation of the femoral tunnel occurs after placement of a guidewire backwards through the tibial tunnel into the center of the selected tunnel location.\textsuperscript{22,24-26} Femoral tunnel creation occurs posteriorly, superiorly and laterally within the femoral notch (the one o’clock position for the right knee and the eleven o’clock position for the left knee).\textsuperscript{26} (Figure 5). Elongation of the femoral tunnel takes place after femoral tunnel creation, beginning at the superior most portion of the primary femoral tunnel and emerging at the anterolateral femoral cortex.\textsuperscript{22,24-26} (Figure 6). An Endobutton establishes femoral fixation.\textsuperscript{22-24-26} The Endobutton consists of two sutures placed in the outermost openings and two of the free hamstring tendon ends placed through the closed polyester loop.\textsuperscript{22,24-26} The sutures aid in passing the Endobutton lengthwise through the tibial and femoral tunnel, but are flipped to set the Endobutton on the anterolateral femoral cortex.\textsuperscript{26} (Figure 7). A biabsorbable screw, selected by the surgeon, fixes the hamstring graft to the femoral tunnel.\textsuperscript{22,24-26} Lastly, another biabsorbable screw, drilled in an anteromedial to posterolateral direction with the knee in 15 to 20 degrees of flexion, fixates the tibia.\textsuperscript{22,24-26} (Figure 8). Assessment for range of motion and lack of impingement is the final step in the surgical process prior to closure of the openings in the leg.\textsuperscript{26}

**Miniarthrotomy**

Reconstruction of the ACL using a miniarthrotomy technique with a patellar tendon graft is considered to be the old way of performing ACL
reconstruction. This technique has proven its worth by producing excellent results.

As with the other surgical techniques, a general anesthetic or a spinal block is given to the patient prior to performing an in-depth assessment of the knee. A tourniquet is placed high on the proximal thigh. The surgeon pre-operatively injects 20 mL of 0.25% bupivacaine hydrochloride (antiseptic) with epinephrine intraarticularly into the knee. The extremity undergoes betadine and alcohol preparation prior to placement in a leg holder.

The arthroscopic procedure is then performed prior to the reconstructive procedure with the purpose of evaluating damage in addition to the ACL. After the arthroscopic procedure, a skin incision is made from the medial inferior pole of the patella to the level of the tibial tubercle. This incision is made with the knee in 20-30 degrees of flexion. This incision allows for eventual harvesting of the now exposed patellar tendon. A medial miniarthrotomy, performed by electrocautery, exposes the tibial plateau and the intercondylar notch.

The next step in the surgery involves the creation of the femoral exit tunnel using electrocautery. With the knee put into a 90-degree position, the surgeon creates an oblique lateral skin incision 2 inches above the superior pole of the patella. Studies demonstrate that the oblique incision heals better and with fewer associated wound problems than the traditional horizontal incision. Dissection is carried down to the iliotibial band, exposing the vastus lateralis muscle. A Slocum retractor placed under the vastus lateralis and over the anterior cortex or layer of the femur exposes the lateral femoral cortex.
Notchplasty, or clearing of the lateral aspect of the intercondylar notch, follows the creation of the lateral oblique incision. A curette performs the notchplasty, removing all of the ACL scar tissue from the lateral aspect of the intercondylar notch.

Creation of the tibial tunnel is next. Guidepin positioning begins about 4 cm below the joint line on the anteromedial tibia. The guidepin is directed to a predetermined target on the medial tibial plateau (9 o’clock for the right knee and 3 o’clock for the left knee). A cannulated reamer passes over the guide, effectively creating the tibial tunnel.

With the knee in figure-four position, the surgeon places the guide pin through the femur, along the border of the PCL and out the lateral cortex. The guide pin is overdrilled with a cannulated reamer, thus creating the femoral tunnel.

The last part of the reconstructive procedure involves harvesting the patellar tendon along with its patellar and tibial bone blocks. Each bone block receives three drill holes with a 1/16-inch drill bit so that sutures can be passed through the drill holes. These sutures assist in graft passage and secure the graft to the fixation buttons. The patellar bone plug is guided into the tibial tunnel and the suture ends are tied to a ligament-fixation button. The sutures of the tibial bone block are passed into the femoral tunnel with assistance from a suture passer. The sutures are removed from the suture passer and tied to the ligament-fixation button. The ligament-fixation button is tied down to the lateral femoral cortex. With the knee placed in 30 degrees of flexion, the tibial sutures are
pulled, so that the patellar bone plug advances in the tibial tunnel, removing any slack in the femoral button fixation. Assessment for range of motion with particular attention to hyperextension and closure of the open wounds completes the miniarthrotomy.

All three of these surgical procedures vary slightly in their procedures and fixation techniques. However, all three of these surgeries have a common characteristic in that all demonstrate positive outcomes and are considered to be successful surgical procedures.

Rehabilitation

The importance of rehabilitation after any injury should not be overlooked. However, rehabilitation after ACL injury and reconstruction is vital to returning the patient to the pre-injury level of activity. Currently, there are two schools of thought concerning rehabilitation. One school of thought advocates traditional rehabilitation protocols and the other supports accelerated rehabilitation protocols. While the two may differ in regards to the time frames, the goals of rehabilitation are similar: restore the stability, strength and range of motion of the knee joint.

There have been widespread debates concerning implementation of the accelerated rehabilitation program versus the traditional rehabilitation program. Accelerated protocols, aside from accomplishing goals in a shorter time frame, tend to focus on the concepts of proprioception and agility much more than traditional protocols. Accelerated protocols are thought to be more functional than traditional protocols. More traditional protocols
emphasize the concepts of strength and motion over a longer time frame to accomplish set goals.\textsuperscript{1,2,29-38} The rehabilitation program is dependent upon many factors, including the type of surgical procedure performed and the type of graft used.\textsuperscript{1,2,29-38} Ultimately, the decision regarding the rehabilitation protocol is made by the physician.

The accelerated rehabilitation protocol includes four phases of rehabilitation, beginning with the time interval after the knee injury prior to surgery and ending with return to activity.\textsuperscript{1,2,29,31,33-35} This protocol emphasizes full knee extension within 2-3 weeks, immediate weight bearing, and closed-chain exercises post surgical repair.\textsuperscript{1,2,29-38}

The first phase of the accelerated rehabilitation program can also be referred to as the preoperative phase.\textsuperscript{1,2,29,35} This phase actually begins after the patient sustains the knee injury and ends with surgery.\textsuperscript{1,2,29,35} Goals of this phase include: reducing swelling, inflammation and pain while restoring normal range of motion.\textsuperscript{1,2,29,34,35,39-41} Application of cryotherapy is one method to prevent additional swelling and inflammation, while reducing pain.\textsuperscript{1,2,29,34,35,39-41} Cryotherapy cools the tissues, inducing vasoconstriction, and reducing blood flow and edema in damaged tissues.\textsuperscript{1,2,29,34,35,39-41} Research has also shown that cooling of the tissues results in a reduced neuronal pain signal.\textsuperscript{40} The preoperative phase is identical with traditional rehabilitation protocols.

The two weeks following ACL surgery comprises the second phase of the accelerated protocol.\textsuperscript{1,2,29,35} Obtaining full knee extension, improving knee flexion, decreasing joint effusion, improving quadriceps control and beginning
weight bearing are goals of this phase.\textsuperscript{1,2,29,35} Passive range of motion (PROM) is begun on the first postoperative day to promote knee flexion and extension.\textsuperscript{1,2,29,35}

Active exercises involving contracture of the musculature responsible for controlling knee function is important as well. Quadriceps sets with simultaneous hamstring cocontraction are implemented on the first day following surgery.\textsuperscript{1,2,29,35} Quadriceps sets reduce the risk of quadriceps shutdown, improve neuromuscular control, aid in the reabsorption of joint effusion and provide superior mobilization of the patella.\textsuperscript{1,2,29,35} Quadriceps sets with hamstring cocontraction minimizes the amount of anterior translation of the tibia on the femur, thus reducing shear forces on the joint and strain on the ACL.\textsuperscript{1,2,29,35} Quadriceps sets with cocontraction should be avoided through the 0 to 45 degree range to allow for complete healing of the unattached semitendinosus tendon.\textsuperscript{1,2,29,34,35}

Since regaining full knee extension is a huge priority, exercises are implemented into rehab the day following the initial ACL reconstructive surgery. As pain subsides, prone leg hangs to promote full knee extension can be initiated into the protocol.\textsuperscript{1,2,29,32,34,35} Another prolonged extension stretch places the patient in the long sitting position.\textsuperscript{1,2,29,32,35} The leg is extended with a towel roll under the heel and a weight is applied to the proximal thigh.\textsuperscript{1,2,29,32,35} Active knee extension is encouraged in the range of 90 to 30 degrees.\textsuperscript{1,2,29,32,35} Passive knee flexion to 90 degrees can be performed by sitting on the edge of the bed and lowering the involved extremity with the uninvolved extremity.\textsuperscript{1,2,29,32,35} Wall slides can be initiated after the patient has achieved 80 to 90 degrees of knee
flexion.\textsuperscript{1,2,29,32,35} Heel slides and active-assistive flexion promote knee flexion ROM.\textsuperscript{1,2,29,32,35}

Hamstring curls are added to the accelerated rehabilitation program and progress as tolerated by the patient with gravity, cuff weights, manual resistance or rubber tubing.\textsuperscript{1,2,29,32,35} Hamstring curls are avoided until the later stages of the third phase if the graft is the semitendinosus tendon.\textsuperscript{1,2,29,30,32,35} Patellar mobilization in all directions begun in this phase of rehab allows for full knee flexion-extension motion and tibial rotation.\textsuperscript{1,2,29,32,35}

Controlling swelling and muscle function is another priority of the clinician in the early phase of rehab, as these factors determine how soon the patient can progress through the rehab. Cryotherapy techniques help decrease joint effusion during this phase of accelerated rehabilitation.\textsuperscript{1,2,29,34,35,39-41} Neuromuscular stimulation is often used to increase quadriceps control and reeducate the muscles involved in knee joint motion.\textsuperscript{1,2,29,35}

While straight leg exercises improve quadriceps control, controversy exists over whether to incorporate them into the rehab protocol.\textsuperscript{1,2,29,32,35} Research shows that isolated quadriceps contraction increases stresses placed on the reconstructed ligament.\textsuperscript{1,2,29-35} Internally or externally rotating the leg recruits hip abductors or adductors to help raise the involved leg, taking stress off of the ACL and maintaining hip musculature strength.\textsuperscript{1,2,29-35}

An emphasis is placed on weightbearing in the accelerated protocol as literature demonstrates that axial loading limits anterior tibial displacement, resulting in reduced strain on the reconstructed ligament.\textsuperscript{1,2,29,30,34,35} Standing toe
raises and mini-squats can be introduced into the protocol 2 weeks post-op if
tolerated by the patient. The patient may begin some closed chain
exercises, like mini-squats and stationary biking, although controversy exists over
whether to begin these in the second phase or the third phase.

The traditional rehabilitation protocol is similar to the above accelerated
protocol with the exception of the emphasis on weightbearing is delayed and that
the second phase can last up to 6 weeks post-operatively.

Phase three of the accelerated protocol encompasses 3 to 5 weeks
postoperatively. For a traditional protocol, phase three would be between
6 weeks to 3 months.

During this segment of rehab, full extension with minimal swelling
continues to be the primary focus for both the accelerated rehab protocol and the
traditional rehab protocol. Full knee extension is normally achieved by
week 4 with the accelerated program and by week 6 with the standard
protocol. Weights are added to prone hangs to help gain full
extension. Short-arc quad exercise may help the patient to achieve the
final degrees of knee extension. Manual resistance or a weight can be
applied to the ankle to progress the short-arc quad exercise. Continuing
with stretching allows the patient to maintain flexibility, another important
component of rehabilitation.

A progression of exercises with increasing difficulty not only furthers the
rehab program along by requiring that the patient work the ACL to heal and
strengthen it. Adding weights to the straight leg raises progresses the patient’s leg
Biking on a stationary bicycle normally begins during this phase of the traditional rehabilitation protocol if knee flexion ROM is adequate. Hamstring curls are added during this third phase of the traditional rehabilitation protocol, beginning with a low weight and fewer repetitions, progressing by increasing weight as tolerated by the patient. Caution is exercised with hamstring graft patients and the exercise is stopped if aggravated. Restoration of full flexion at 135 degrees is usually achieved during this phase of rehabilitation. Side leg raises implemented in this phase of rehab focuses on hip musculature strength. The patient continues with progressive resistive exercises (PREs) during this phase of rehabilitation as tolerated, with emphasis upon hamstring strengthening, quadriceps strengthening and hip strengthening.

Closed chain kinetic exercises are also initiated at this stage in the traditional rehab program and additional closed chain kinetic exercises are added to the accelerated program. Closed kinetic chain exercises are performed with the knee near full extension, the foot on a surface and the entire limb loaded, resulting in joint compression and joint stability. Closed kinetic chain exercises include mini-squats, wall sits, leg presses and step-ups. The patient begins mini-squats and leg presses on both legs, progressing to a single leg as tolerated or if the patient has begun these exercises in the previous stage of rehab. Progression of the patient with wall sits involves increasing the sitting time. Increasing the height of the step progresses the step-ups.
Proprioceptive training begins during this stage of rehabilitation as well. Weight-shifting exercises are a form of proprioceptive training and can be progressed from two legs to a single leg stance.\textsuperscript{1,2,29-38} Proprioceptive training continues on the BAPS board with two legs and progressing to one.\textsuperscript{1,2,29-38}

Phase four of the accelerated rehab protocol begins at five weeks and lasts through the return to sport.\textsuperscript{1,2,29-38} Phase four of a standard rehab protocol begins at 3 months and lasts until return to play.\textsuperscript{1,2,29-38} An isokinetic strength evaluation is performed at this stage to determine the strength of the involved extremity in relation to the uninvolved extremity. If the involved extremity has 70\% strength of the contralateral limb's strength, the patient can begin jogging, eventually progressing to running and sprinting.\textsuperscript{1,2,29-38} If the patient does not have 70\% of the contralateral strength, trampoline exercises may be incorporated until the patient is strong enough for a running program.\textsuperscript{1,2,29-38} Trampoline exercises could include hopping on both legs and then progressing to single leg hopping or lightly jogging on the trampoline where there are less stresses placed on the ACL.\textsuperscript{1,2,29-38} The patient may also start to incorporate cariocas, lateral shuffles and jumping rope at this point as well.\textsuperscript{1,2,29-38} These exercises are more functional and sport specific than the exercises in previous phases and must be tailored to fit the individual patient.\textsuperscript{1,2,29-38} Agility drills can be progressed by decreasing the time that the patient has to complete the exercise or increasing the distance that the athlete must cover, as with cariocas.\textsuperscript{1,2,29-38} Once the basic agility skills are mastered, figure eights can progress the agility portion of this phase.\textsuperscript{1,2,29-38} Decreasing the distance between cones can increase the difficulty of the figure
eights by forcing the patient to pivot more quickly to create figure eights between the cones. Decreasing the time that the patient has to complete the drill also increases the difficulty of the exercise. Strength training and maintenance of ROM are still important and exercises should be progressed during this final phase of rehab.

A functional exercise progression is individualized to fit the patient’s sport or activities of daily living. Running, sprinting, hopping and agility exercises are all included in this functional assessment. The patient progresses through the running exercises and agility exercises starting at half speed and progressing to full speed. Hopping drills progress from both feet to one foot. If the patient meets all of these criterion and is okayed by a physician, he or she can return to functional activities. An accelerated rehab program typically lasts 4-6 months, while a traditional program lasts one year, although this is dependent upon the patient’s progression and must be tailored for each individual patient.

Although this paper spotlights all essential components of the ACL, some information may vary from patient to patient. Each ACL injury is unique and should be treated as such. Knowledge of the different aspects concerning the ACL, I hope, allows for better treatment of every ACL injury.
Figure 1
Figure 2

Figure 3
Figure 4
Figure 5

Figure 6
Figure 7
Figure 8
References


