Anterior Cruciate Ligament Tears
Reconstruction and Rehabilitation

Mary Atkinson Smith ▼ W. Todd Smith ▼ Paul Kosko

Tears of the anterior cruciate ligament (ACL) are common knee injuries experienced by athletes and people with active lifestyles. It is important for members of the healthcare team to take an evidence-based approach to the diagnosis, surgical management, and postoperative rehabilitation of patients with an ACL-deficient knee. Mechanism of ACL injury and diagnostic testing is consistent throughout the literature. Patients frequently opt for ACL reconstruction, and many surgical techniques for ACL reconstruction are available with no clear consensus regarding superiority. Surgeon preference dictates the type of reconstruction and graft choice utilized. No standardized pre- and postoperative rehabilitation protocol exists. However, rehabilitation plays an important role in functional outcomes. A comprehensive rehabilitation program is needed pre- and postoperatively to produce positive patient outcomes.

Anterior cruciate ligament (ACL) tears are one of the most common musculoskeletal injuries among physically active individuals. Approximately 200,000 ACL injuries occur yearly, and close to 100,000 ACL injuries are addressed surgically in the United States each year (Meisterling, Schoderbek, & Andrews, 2009). The ACL provides anterior stability to the knee; therefore, ACL-deficient knees are at increased risk for articular cartilage damage, meniscal degeneration, and functional instability (Maletius & Messner, 1999). Anterior cruciate ligament reconstruction has become the standard surgical procedure in an attempt to prevent the development of these undesired musculoskeletal consequences. To encourage positive outcomes, orthopaedic registered nurse (RNs) and advanced practice registered nurses (APRNs) must possess a solid foundation regarding functional anatomy, common mechanisms of injury, risk factors, prevention strategies, basic concepts and controversies of surgical reconstruction, and the integral role of postoperative rehabilitation pertaining to the ACL and ACL tears. The purpose of this article was to provide orthopaedic RNs and APRNs with a review of pertinent ACL anatomy and knowledge of the epidemiology and pathophysiology of ACL tears, in addition to current surgical trends, controversies, and rehabilitation principles regarding ACL tears.

Anatomy and Function of the ACL

The ACL is composed of two distinct bundles that are named relative to their insertions on the tibia: the anterior-medial (AM) bundle and the posterior-lateral (PL) bundle (DeFranco & Bach, 2009). The AM and PL bundles are located in the intercondylar area of the knee (see Figures 1 and 2). The ACL originates from the medial aspect of the lateral femoral condyle and inserts between the tibial spines of the proximal tibia. The femoral origin is an oval marking approximately 18 mm (A-P) and 9 mm (C-C) with 29° angle to the midshaft of femur and 4 mm from the articular surface (see Figure 3) (Heming, Rand, & Steiner, 2007). The ACL insertion is much broader on the tibia. Dimensions are approximately 18.5 mm (A-P) and 10 mm (M-L) with the articular cartilage of the medial plateau being 2.0 mm away and the center of the ACL being close to 15 mm from the posterior cruciate ligament notch (see Figure 4) (Amis, Bull, & Lie, 2005). Numerous studies have shown that the AM bundle limits anterior tibial translation and the PL bundle provides more rotational control. The AM bundle tightens in flexion with the PL bundle relaxes; the opposite happens in extension. This reciprocating pattern suggests that individual bundles can be injured depending on the knee flexion pattern (Amis et al., 2005).

Epidemiology and Pathophysiology of ACL Tears

Noncontact injuries are the most common mechanism of ACL injury, but contact injuries do occur. The

Mary Atkinson Smith, DNP, FNP-BC, ONP-C, RNFA, CNOR, Board Certified Nurse Practitioner, Starkville Orthopedic Clinic, Starkville, Mississippi; and Adjunct Faculty, Capstone College of Nursing, University of Alabama, Tuscaloosa.

W. Todd Smith, MD, Board Certified Orthopedic Surgeon, Starkville Orthopedic Clinic, Starkville, Mississippi.

Paul Kosko, PT, DPT, SCS, Board Certified Specialist in Sports Physical Therapy, Drayer Physical Therapy, Starkville, Mississippi.
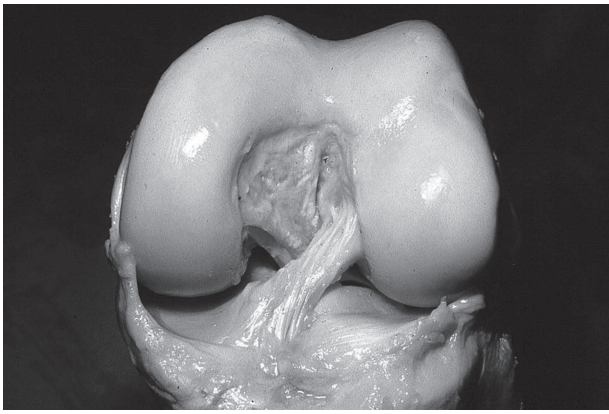
FIGURE 1. Cadaveric anterior cruciate ligament origin and insertion.

FIGURE 3. Sagittal view of anterior cruciate ligament insertion area on femur. The discreet bundles of the anterior cruciate ligament are seen. AM indicates anterior-medial; PL, posterior-lateral.

noncontact injury happens when the patient sustains a twisting or cutting motion through the knee with the foot planted. Direct contact injury occurs from a blow directly to the knee usually from a lateral or anterior direction (see Figure 5). Noncontact and direct contact ACL injuries occur more commonly among the athletic population and individuals who participate in high-risk activities.

Females show a higher incidence (4- to 6-fold increase) of ACL tears when compared with males (Beynnon, Johnson, Abate, Fleming, & Nichols, 2005).
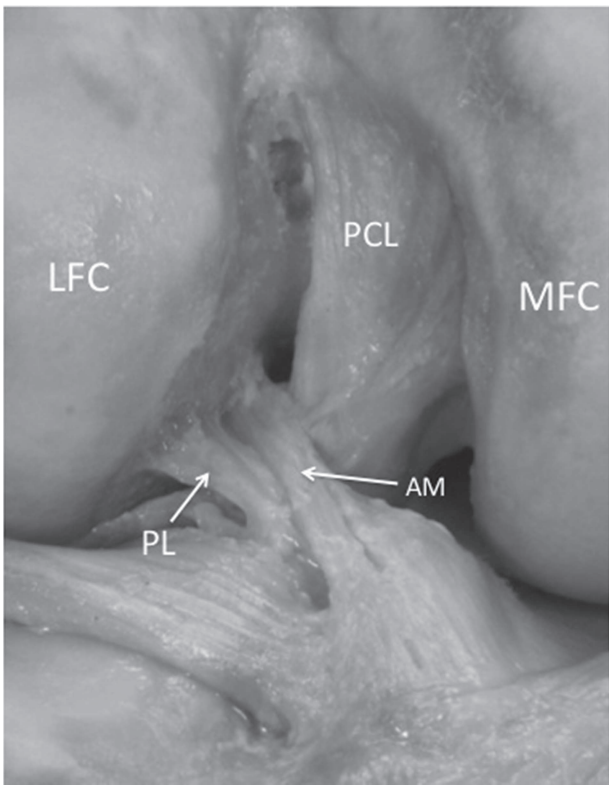

FIGURE 2. Tibial insertion of anterior cruciate ligament. Discreet bundles are seen between the medial femoral condyle (MFC) and lateral femoral condyle (LFC). AM indicates anterior-medial; PCL, posterior cruciate ligament; PL, posterior-lateral.
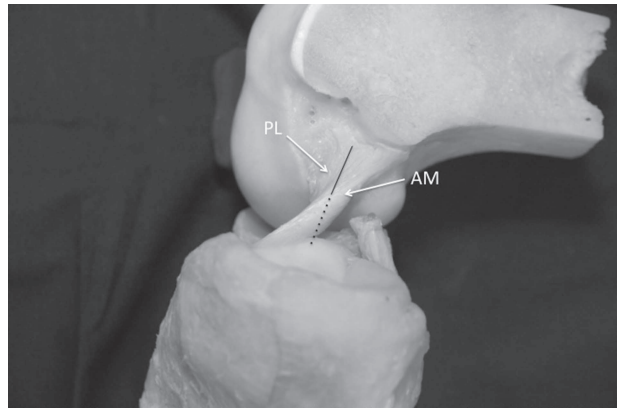
A higher incidence among females is contributed to hormonal factors, gait, jump-landing mechanics, and musculoskeletal differences. Among females, neuromuscular factors play some part in the multifactorial equation as it has been hypothesized that "deficits in core neuromuscular control can cause unstable behavior and allow for a higher probability of injury throughout the kinetic chain" (Smith et al., 2012). In jump-landing laboratory studies, those females who landed with less knee and hip flexion had increased knee valgus and quadriceps activation coupled with increased hip internal rotation and increased tibia rotation had larger ACL strain versus controls (Smith et al., 2012).

Anatomic differences of the ACL between males and females are well documented (Schultz et al., 2010). These differences include the Notch Width Index (NWI) and the tibial slope. The NWI is defined by the ratio of the width of the intercondylar notch to the width of the distal femur at the level of the popliteal groove has been reported by several authors to be a parameter correlated with higher ACL tears. Those with a NWI < 0.20 and a notch stenosis as defined by a notch width of less than 17 mm showed an increased incidence of ACL tears (Smith et al., 2012). Differences in tibial geometry identified by decreased concavity depth of the medial tibial plateau and increased slope have a higher incidence of ACL tears (Hashemi, Chandrashekar, Beynnon,
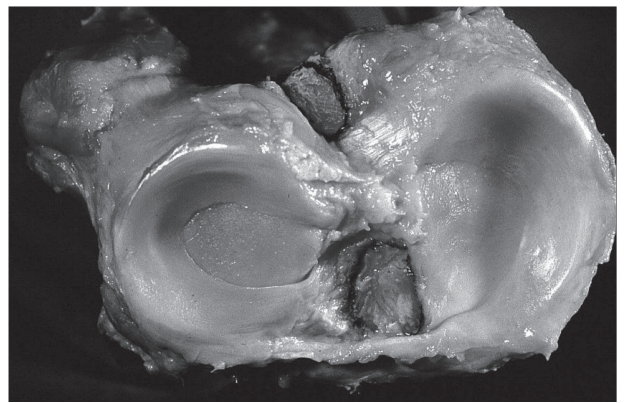

FIGURE 4. Tibial insertion area. Note the broad insertion area.

FIGURE 5. Direct blow to outside of left knee from opposing player producing anterior cruciate ligament/medial collateral injury.

FIGURE 6. Anterior cruciate ligament (ACL) tear with synovial cap on stump.

Slauterbeck, & Schutt, 2008; Schultz et al., 2010). Females tend to have a higher NWI and increased slope; therefore, females are more prone to ACL tears than males.

The ACL may tear anywhere along the point from its origin to the insertion. The fibers tear when the applied load exceeds the ultimate tensile load (~2,100 N) (West & Harner, 2005). The forces in the intact ACL range from 100 N during passive knee extension to 400 N with walking and up to 1,700 N with cutting and acceleration-deceleration (West & Harner, 2005). Unusual loading patterns and vectors transmit loads to the ACL exceeding its capacity leading to failure. The ACL may rupture entirely or at individual bundles. Rupture of the AM bundle may result in an increase in anterior translation in flexion, little or no increase in hyperextension, and little or no clinically evident increase in rotational instability (Furman, Marshall, & Girgis, 1976). Once torn, the ACL does not have the capacity to heal on its own and regain adequate function (Arnoczky, Rubin, & Marshall, 1979; Maekawa et al., 1996; O'Donoghue, Rockwood, Frank, Jack, & Kenyon 1966). A sufficient blood supply is required for healing to take place. An ACL tear is unable to heal on its own because the tear itself compromises the blood supply, disrupts the epiligamentous tissue, and creates an interposition of synovial fluid (see Figure 6). All of these factors prevent tissue healing.
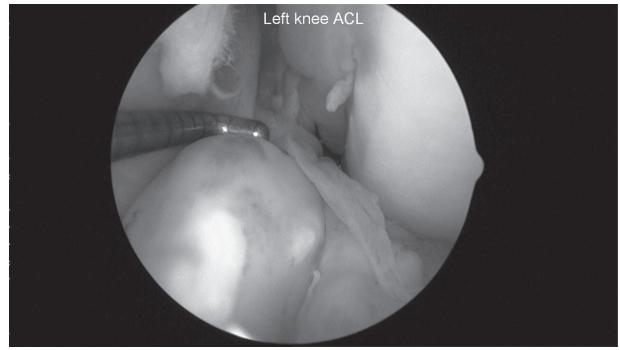
Diagnosing ACL Tears

An ACL tear is diagnosed by a thorough history, physical examination, and special diagnostic tests, to include specific clinical examination tests. Radiographs and magnetic resonance imaging (MRI) also play an important role in aiding the determination of an ACL. The history and physical examination findings will guide in the decision for further diagnostic testing; therefore, the history and physical examination should be systematic, complete, and focused, and the examiner should be comfortable and knowledgeable when it comes to performing the specific clinical examination tests. The findings produced from individual assessment and diagnostic studies aid in determining the presence of an ACL tear.

HISTORY AND PHYSICAL EXAMINATION

The history consists of gathering information regarding the mechanism of injury, in addition to other symptoms experienced by the athlete at the time of injury. Athletes who sustain an ACL tear will commonly feel and/or hear a "pop" as the ACL itself tears. They may also experience buckling of the affected knee, followed by the immediate development of a hemarthrosis. A hemarthrosis is common as the middle geniculate artery tears with the ACL; however, the lack of a hemarthrosis does not mean that the ACL is not disrupted. If the ACL tears from the femoral origin, the artery is spared and the typical hemarthrosis is avoided.

Diagnosis of ACL is incomplete without a focused physical examination. It is wise to examine the contralateral knee first to relax the patient and gain confidence. Other special examinations for concomitant pathology are used on the basis of history and index physical examination. Swelling, range-of-motion deficits, abrasions, and neurovascular examination should be noted in the initial encounter. The knee should also be examined for patella-femoral injury, meniscal tears, medial collateral and lateral collateral ligament injury, posterior cruciate ligament, and capsular injury (see Figure 7). The physical examination also includes specific clinical examination tests, which are discussed in the following section.

CLINICAL EXAMINATION TESTS

Clinical examination tests that are used to evaluate the integrity of the ACL include the Lachman test, anterior
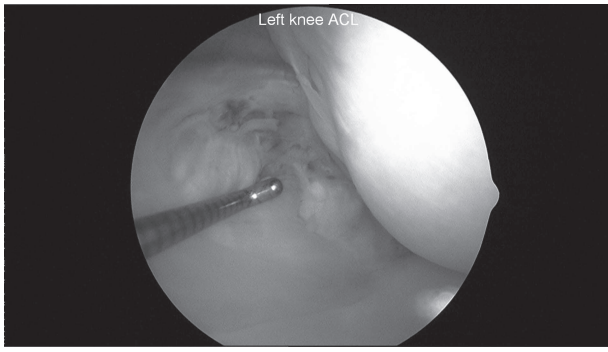
FIGURE 7. Deep medial collateral tear in conjunction with anterior cruciate ligament (ACL) tear.

drawer test, and pivot-shift test. The accuracy of these tests is highly dependent on having a relaxed and compliant patient. Often, with an acute ACL injury, patients will guard the knee while clinical examination tests are being conducted. Guarding, in the patient with an ACL tear, is often due to pain, hemarthrosis, and range-of-motion deficits.

The Lachman test (see Figure 8) is performed with the patient in the supine position with the affected knee at 30° of flexion. A bolster or bump under the affected knee is useful to help obtain 30° of flexion. The femur is stabilized and the tibia is translated anteriorly. Anterior tibial translation is quantified by the endpoint of the affected knee when compared with the unaffected knee (Torg, Conrad, & Kalen, 1976). The Lachman test is indicative of an ACL tear if there is increased anterior tibial translation when compared with the unaffected knee.

The Anterior Drawer Test (see Figure 9) is performed supine with the knee flexed to 90°. The examiner often sits on the foot to stabilize the limb. The proximal tibia is grasped and translated anteriorly. Translation is quantified using the American Medical Association Standard Nomenclature of Athletic Injuries (American Medical Association, 1968). Grade 1 injuries show tibial translation of 3–5 mm compared with noninjured knee. Grade 2 injures show 6–10 mm of laxity and Grade 3 injuries show greater than 10 mm.

FIGURE 8. The Lachman test. Reproduced with permission from Primal Pictures Limited 2009.

FIGURE 9. The Anterior Drawer test.

The Pivot Shift tests for anterior-lateral rotatory stability. It is often difficult in the nonanesthetized patient because of guarding. The test starts with the tibia internally rotated and a valgus stress applied to the knee. The knee is brought from full extension to 30° of flexion to elicit a pivot. A pivot indicates reduction of the tibia from an anterior-lateral subluxated position (see Figure 10).
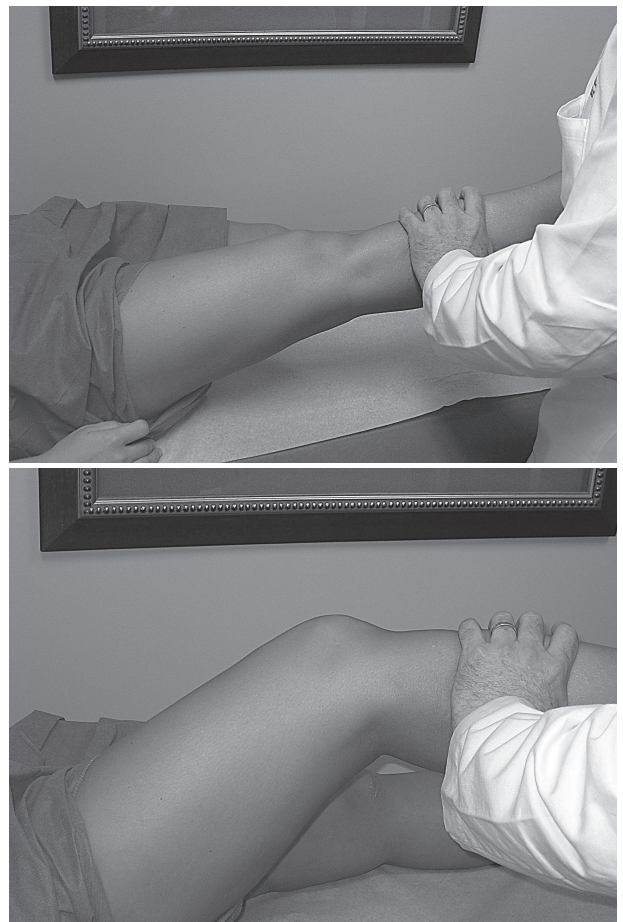

FIGURE 10. (a) Starting and (b) ending positions for the pivot shift test.
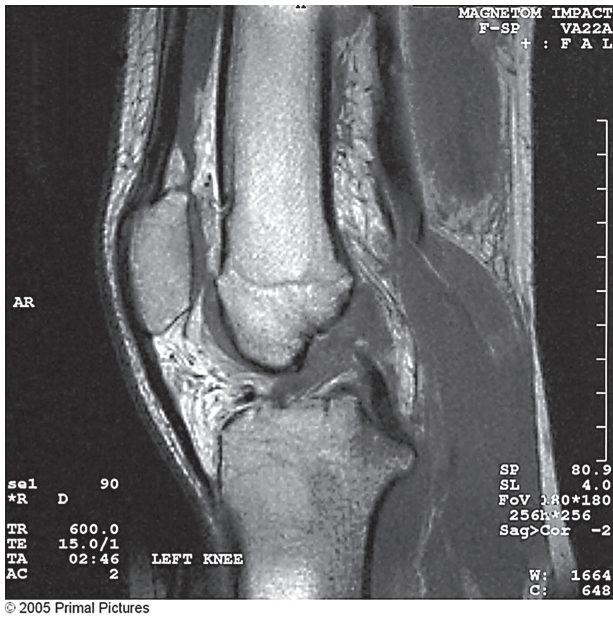
FIGURE 11. Sagital magnetic resonance imaging of knee showing disrupted anterior cruciate ligament. Reproduced with permission from Primal Pictures Limited 2009.

RADIOGRAPHS AND MRI

Radiographs are obtained as part of the initial evaluation of a suspected ACL tear. Radiographs may show tibial spinal avulsion, presence of a fracture, dislocation, malalignment, or coexisting degenerative changes. They are used to assess skeletal maturity and patella location of the patient with a suspected ACL tear.

Magnetic resonance imaging without contrast (see Figure 11) is recommended after routine radiographs have been obtained, and if the history and examination findings are suspicious for an ACL tear. Magnetic resonance imaging has a 95% accuracy rate regarding detection of ACL tears (Liu, Osti, Henry, & Bocchi, 1995). An MRI will help confirm the presence of an ACL tear, in addition to concomitant injuries that may not be detected upon physical examination such as bone bruising, meniscal injury, and injury to other ligaments of the knee. Magnetic resonance imaging also provides a preoperative evaluation of the intra-articular and extra-articular areas of the affected knee.

Management of ACL Tears

Orthopaedic RNs and APRNs should be knowledgeable of the various evidence-based recommendations pertaining to the management of ACL tears. This will allow for orthopaedic RNs and APRNs to appropriately inform patients regarding the available options for treatment of ACL tears. Patients with ACL tears may be treated operatively or nonoperatively. There are many factors that determine whether ACL reconstruction is or is not appropriate following an ACL tear, such as physical demands of the patient, significance of symptoms present, and the patient's own desires. If treated surgically, there are also several points to consider, when making the determination of the appropriate timing for

ACL reconstruction to take place, to ensure positive surgical outcomes.

NONOPERATIVE VS. OPERATIVE MANAGEMENT

Most young active patients with an ACL tear choose to proceed with ACL reconstruction. It is imperative to counsel patients regarding the techniques of the ACL reconstruction, the rehabilitation process, in addition to discussing the patient's perceived expectations. Anterior cruciate ligament reconstruction is usually recommended to athletes and patients with high functional demands. Physiological condition is more important than chronological age, when discussing ACL reconstruction with patients experiencing instability. It has been shown that age has little effect on patient outcomes (Ferrari & Bach, 2001) (see Figure 12). For some patients, a nonoperative approach is used to allow patients time to decide to what extent the ACL tear interferes with their quality of life.

Patients who choose operative or nonoperative treatment of an ACL tear should be made aware of the potential future implications of either plan of treatment. Risks of surgery for ACL reconstruction may include but are not limited to infection, graft/implant failure, arthrofibrosis of the knee, and the development of complex regional pain syndrome. A nonoperative approach may lead to recurrent instability of the knee, meniscal tearing, and the development of accelerated arthrosis (Beynnon et al., 2005).

Once diagnosed, patients should begin rehabilitation to reduce swelling and inflammation and achieve quadriceps firing, normalization of gait, and range of motion (Meisterling et al., 2009). Patients who desire ACL reconstruction should be encouraged to participate in preoperative rehabilitation. Surgery should be delayed in patients with severe swelling, quadriceps inhibition, and loss of motion. This represents a "reactive knee," and studies have shown that outcomes are poorer among these patients (Wasilewski, Covall, & Cohen, 1993). Surgery may not be scheduled until the patient has full extension to 120° of flexion, improved soft tissue swelling, quadriceps control, and decreased pain. The addition of postsurgical pain to postinjury pain will only perpetuate the inflammatory cascade, which may lead to undesired postsurgical outcomes (Beynnon et al., 2005).
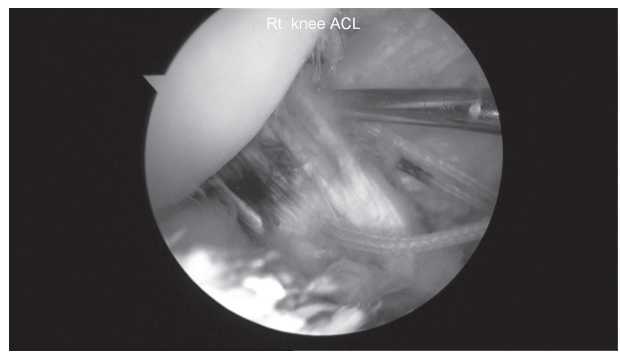

FIGURE 12. Anterior cruciate ligament (ACL) reconstruction using allograft in a 67-year-old highly functional patient with early degenerative changes.

Evolution of ACL Reconstruction

It is beyond the scope of this article to detail every aspect of ACL surgery, as much has changed in ACL reconstruction over the last 30 years (Beynnon et al., 2005). Surgeons will choose the procedure they feel most comfortable performing. This will create differences regionally, with respect to graft options, fixation techniques, and postoperative rehabilitation. Most orthopaedic surgeons perform arthroscopically assisted ACL reconstruction, using autograft or allograft tissue. Controversies in ACL reconstruction exist with regard to the utilization of autograft versus allograft, transtibial versus AM portal (AMP), and single versus double bundle (Beynnon et al., 2005). To improve the quality and safety of patient care, it is important for orthopaedic RNs and APRNs, in the clinical and perioperative setting, to be familiar with the various graft options, surgical techniques, and fixation devices.

AUTOGRAFT VS. ALLOGRAFT

Common autograft sources are bone-patella-bone (BPTB), quadrupled hamstring (HT), or quadriceps tendon (QT). Each has its own advantages and disadvantages with respect to harvest, strength, fixation type, donor site morbidity, and complications. The advantages of autograft tissue include no risk of immunologic rejection or disease transmission, preservation of biomechanical strength of the tissue, and decreased costs because no storage or sterilization is required (Beynnon et al., 2005). Autograft tissue has been linked to disadvantages such as increased operating room time, increased risk for donor site morbidity, and increased risk for alteration of the extensor or flexor mechanisms (Beynnon et al., 2005). The advantages of an allograft include no donor site morbidity, preservation of extensor or flexor mechanisms, decreased operative time, decreased incidence of arthrofibrosis, and improved cosmesis (Beynnon et al., 2005).

Disease transmission, failure, immunologic rejection, higher cost, storage, and sterilization all continue to be concerns with the use of allografts (Mroz, Joyce, Steinmetz, Lieberman, & Wang, 2008). A research study conducted in an ambulatory setting revealed that the autograft group had lower charges than the allograft group (Macaulay, Perfetti, & Levine, 2012). The decreased operating room time in the allograft group did not offset the price of the allograft. Bone-patella-bone, HT, and QT autografts have been going head to head in studies for some time with no clear winner in outcome studies; however, some points regarding autografts do bear mention: Anterior knee pain and anterior knee numbness are higher in BPTB, failure rate is slightly higher in HT, knee tightness is higher with BPTB and QT, and patient satisfaction is high in all (Shelton & Fagan, 2011). Roe et al. (2005) showed a greater prevalence of radiographic osteoarthritis at 7 years' follow-up on BPTB versus HT although excellent subjective results as evidenced by International Knee Documentation Committee evaluation and Lysholm scores.

Allograft tissue may commonly be used in revision cases and in the low demand patient needing stability and a less-intensive postoperative rehabilitation.

Allograft tissue is sterilized in different ways, and this variation makes controlled comparisons with autografts difficult. Macaulay et al. (2012) reported that allografts sterilized with osmotic treatment, oxidation, acetone solvent drying, and gamma irradiation had a 45% rupture rate at 6 years' follow-up. When choosing allograft tissue for ACL reconstructions, nonirradiated grafts in one study showed to be superior to irradiated grafts (Rappe, Horodyski, Meister, & Indelicato, 2007). Radiation sterilization has been shown in the literature to decrease biomechanical properties in a dose-dependent manner with the initial biomechanical strength of allografts being reduced by 15% after 2 Mrad of irradiation (Fideler, Vangsness, Lu, Orlando, & Moore, 1995). Studies have shown that sterilization with ethylene oxide has led to early failures and persistent synovitis; therefore, it is not recommended (Mroz et al., 2008). Currently, cryopreservation and gamma radiation (low dose < 3.0 Mrad) are the current recommended sterilization techniques (Mroz et al., 2008). Aseptic harvest and a cleaning process consisting of antibiotic soaks, multiple cultures, and low-dose radiation are the most commonly used method for producing a sterile ACL graft (West & Harner, 2005).

The literature does not support one graft source over the other when it comes to providing improved functional outcomes; however, the choice to utilize autograft versus allograft tissue may be more related to surgeon preference. Recent studies have found increased rates of graft failure in those who received an allograft and had a high activity level (Macaulay et al., 2012). Considering these results, an allograft may not be the best option in a young active patient. Differences do exist between autografts and allografts. It is important to discuss these differences with patients who will be undergoing ACL reconstruction.

TECHNIQUES OF ACL RECONSTRUCTION

Recent advances in the understanding of ACL anatomy have fostered the AMP technique when compared with the transtibial technique. In the AMP, the knee is hyperflexed and an additional portal is created with a spinal needle to place the femoral socket closer to the native origin of the ACL (see Figure 13). This contrasts with the traditional transtibial technique, in which the tibial tunnel is drilled first and the femoral socket is based on this tunnel. This technique places the femoral tunnel in a more vertical position, which some studies suggest compromises the rotational stability and nonanatomic reconstruction of the reconstructed ACL (Steiner et al., 2009).

Contemporary techniques, being discussed in the literature, include double-socket or "double-bundle" ACL reconstruction. Proponents of this technique point back to the native ACL being composed of two bundles (anterior-medial and posterior-lateral), with the surgical goals aimed at duplicating these two bundles. It stands to reason that attempting to reestablish the complex anatomy of the ACL is more advantageous; however, caution must be used when converting to a two-socket technique because the added complexity may negate the theoretical advantage (Beynnon et al., 2005). A meta-analysis, performed by Meredick, Kennan, Appleby, and Lubowitz (2008), showed no improved clinical outcomes
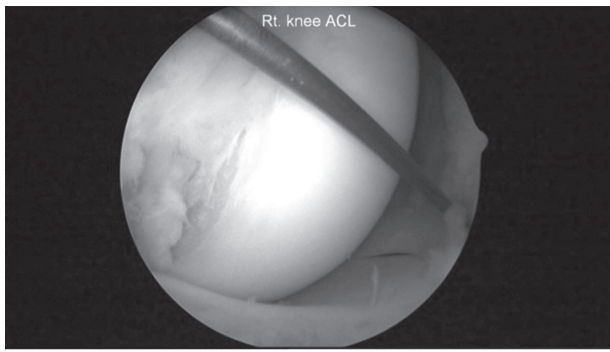
FIGURE 13. Spinal needle via anterior-medial portal to localize femoral origin prior to tunnel drilling. ACL indicates anterior cruciate ligament.

in a double bundle over a single bundle. Others have reported stability differences but lacked differences in subjective scoring measures (Macaulay et al., 2012).

FIXATION DEVICES

A myriad of devices are available commercially to provide fixation when reconstructing the ACL (see Figures 14). In the early postoperative recovery, the fixation is the weak link so surgeons strive to choose the fixation that will allow the graft to withstand the forces
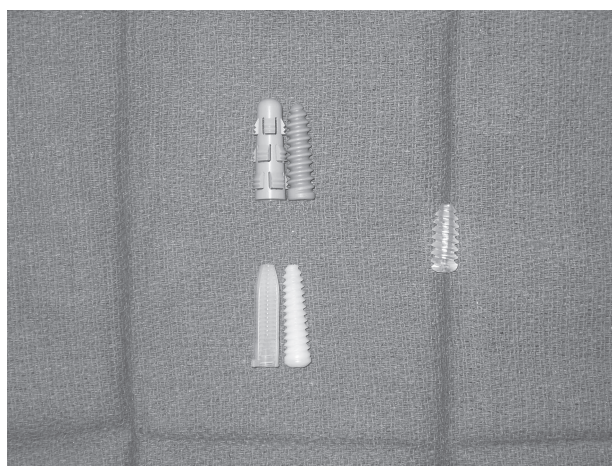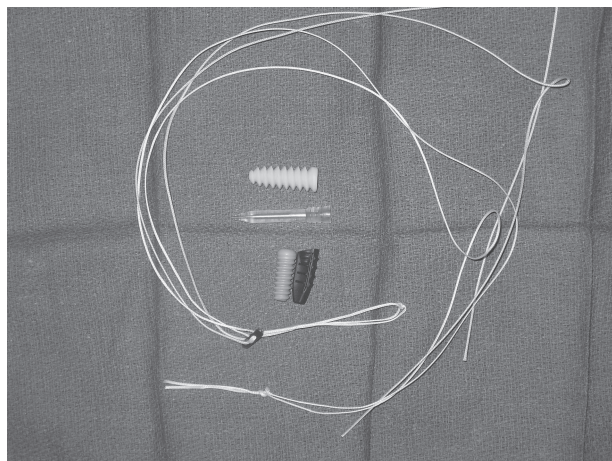
FIGURES 14. Various implant devices for femoral and tibial fixation.

generated with postoperative rehabilitation. The ligament substitutes (i.e., BPTB, HT, allograft) used to perform ACL reconstruction require a bony or soft tissue component to be fixed within a bone tunnel, or on the periosteum at a distance from the native ligament attachment site (Brand, Weiler, Caborn, Brown, & Johnson, 2000). Interference screws (metal and bioabsorbable), suspension devices (Smith & Nephew Endobutton, Arthex Tightrope), and cross pins (Athrex Transfix, Biomet Bonemulch Screw) exist to provide orthopaedic surgeons with a stable fixation platform to allow for postoperative rehabilitation. Choice of fixation is determined by individual orthopaedic surgeon preference.

Postoperative Rehabilitation

Orthopaedic RNs and APRNs should be aware that postoperative rehabilitation following ACL reconstruction is a lengthy, but integral process. Rehabilitation following an ACL reconstruction may last anywhere from 6 months to 1 year. It is important for orthopaedic RNs and APRNs to make patients aware of this vital commitment before and after ACL reconstruction. Patient compliance and commitment to the necessary postoperative rehabilitation process following ACL reconstruction serve to further enhance positive patient outcomes.

As mentioned earlier, exercises and modalities are initiated as soon as possible after an ACL tear and prior to surgical reconstruction of the ACL. The reasoning for this is to reduce pain, reduce joint effusion, improve range of motion (ROM) of the knee, and increase strength of the quadriceps. The focus should be placed on achieving full extension and flexion of the injured knee, and to eventually closely equal the uninjured knee (or at least 120° of flexion, and good to near normal quadriceps strength). Researchers have shown a correlation between increased knee joint effusion and quadriceps inhibition or arthrogenic muscle inhibition (Palmieri-Smith, Thomas, & Wojtys, 2008); therefore, it is very common to see that as a knee joint effusion reduces in the acutely torn ACL, quadriceps strength returns. Surgery can be considered when the patient is able to perform a straight leg raise without a quad lag (i.e., maintaining 0° of knee extension as the hip is flexed in the supine position). Postoperative rehabilitation following ACL reconstruction may be divided into four phases (Table 1). Phase 1 includes the first 4 weeks following surgery, phase 2 begins at the conclusion of the fourth postoperative week, phase 3 includes the introduction of impact loading activity, and phase 4 consists of full return to activity.

PHASE 1

Phase 1 of postoperative rehabilitation begins at the conclusion of the surgery. Starting on the day of surgery, postoperative bracing, cold therapy, ankle pumps, and isometric quadriceps exercises are begun (see Figure 15). The focus in the first phase of ACL rehabilitation is to reduce pain, achieve/maintain full knee extension, quell postoperative swelling, safely retard muscle atrophy, protect the graft site, and reduce the potential for a hemiarthrosis or an infection. The ability to prevent

TABLE 1. PHASES OF ACL REHABILITATION

	Goals	Treatment
Prior to surgery	1. Less than 2/10 pain on VAS (0-10) 2. Full extension ROM 3. Knee flexion ROM to preferably equal to the uninvolved knee or at least 120° 4. Good to near-normal quadriceps strength	1. Stationary bike 2. Prone hangs for extension 3. Wall slides with opposite LE assistance for flexion 4. Quad set with active heel lift 5. Open-chain strengthening 6. Closed-chain strengthening (as able/pain-free) 7. Modalities (Interferential Current Electrical Stimulation, cold pack, Gameready, compression therapy) for pain/swelling
Phase 1 (0-4 wk)	1. Reduce pain 2. 0-90° of ROM 3. Achieve/maintain full knee extension 4. Quell postoperative swelling 5. Retard muscle atrophy 6. Protect the graft site 7. Reduce the potential for a hemiarthrosis or an infection	1. Prone hangs for extension 2. Gravity-assisted knee flexion ROM 3. Patella mobilizations 4. Scar massage 5. Quad sets with active heel lift 6. High-rep/low-resistance hip and ankle strengthening (open chain) 7. Heel cord stretching 8. NES as needed for quad/VMO strengthening 9. Modalities (Interferential Current Electrical Stimulation, cold pack, Gameready, compression therapy) for pain/swelling
Phase 2 (5-11 wk)	1. Gain full ROM 2. Minimize stress to the graft site 3. Increase gross hip, knee, and ankle strength 4. Improve balance/proprioception 5. Normalize gait	1. Continue as necessary from above 2. Aquatic therapy 3. Stationary bike (once 0-110° of flexion) 4. Open-chain strengthening (90-45°) 5. Closed-chain strengthening (30-0° initially) 6. Steps progressing (1-8) of *Functional progression after knee injury* 7. Full squats and lunges are begun at 8 weeks 8. Stairmaster and elliptical at 8 weeks 9. Quads, HS, and gastroc/soleus flexibility training 10. Balance/proprioceptive training with perturbations
Phase 3 (12 wk-6 mo)	1. Eighty-five percent strength of uninvolved side 2. Good eccentric quad control with closed chain exercise 3. Good eccentric hip abductor and external rotator control	1. Continue as necessary from above 2. Progressive Running Program 3. Steps progressing 8-28 of *Functional progression after knee injury*
Phase 4 (6 mo)	1. Goals of phase 1, 2, and 3 are met 2. Single leg hop for distance at 90%	1. Unrestricted exercises with team

Note. ACL indicates anterior cruciate ligament; NES, Neuromuscular Electrical Stimulation; ROM, range of motion.

swelling during the first postoperative week greatly impacts the progression of return to activity (DeCarlo & McDivitt, 2006). Avoiding a hemiarthrosis and subsequent quadriceps inhibition after surgery allows for early quadriceps activation and the ability to maintain full terminal knee extension (Biggs & Shelbourne, 2006).

Emphasis is placed on regaining quad strength acutely after surgery during Phase 1 of postoperative rehabilitation, and it is typically necessary to utilize neuromuscular (Neuromuscular Electrical Stimulation [NES]) and/or Russian electrical stimulation to improve quad strength and vastus medialis obliques recruitment. It has been shown that providing NES in conjunction with therapeutic exercise significantly increases quadriceps activation in patients following ACL reconstruction (Kim, Croy, Hertel, & Saliba, 2010).

Patients are issued bilateral axillary crutches and, depending on the surgeon preference, a weight-bearing

FIGURE 15. Immediate postoperative anterior cruciate ligament. A hinged knee brace and cold therapy wrap is applied.

status is issued. The research does support that at the very least the patient is allowed to put some weight through the lower extremity referred to as touch down weight bearing (TDWB) (Wilk et al., 1996). With the knee in full extension, TDWB allows for a co-contraction of the quadriceps and HTs, thus minimizing anterior and posterior sheering of the newly reconstructed ACL (Andrews, Harrelson, & Wilk, 2004). Therefore, TDWB is important in preventing quadriceps weakness and in effect improving quadriceps strength. Progressive weight bearing typically begins at 4 weeks.

During the first 4 weeks, the knee is immobilized in extension during normal activities of daily living and during ambulation. This is usually achieved by utilizing a hinged-knee brace, which is locked in extension. The purpose of the locked hinged-knee brace is to prevent unwanted knee flexion due to poor quadriceps tone, therefore preventing unwanted stress on the ACL graft. The hinged-knee brace also allows for progressive unlocking as the patient's ROM increases and ACL graft maturity occurs. Ninety degrees of flexion is desired by the end of Phase 1 or the end of the fourth postoperative week, along with maintenance of full extension.

It is also important to begin hip and ankle strengthening exercises in all planes in the first phase of rehabilitation. This is necessary secondary to the fact that the hip and knee are largely rotational joints. Mascal, Landel, and Powers (2003) acknowledged that strengthening of the hip and ankle musculature allows the patient to minimize excessive frontal plane motion and rotational stressors to the "hinged" knee joint, which is especially important when progressive weight bearing begins and in the later phases of rehabilitation (Mascal et al., 2003).

PHASE 2

After 4 weeks, the second phase begins. The goals of the second phase are to gain full ROM at a progression of 10°–15° per week until full flexion is achieved, continue minimizing stress to the graft site, continue increasing gross hip, knee, and ankle strength, improve proprioception, and achieve normalization of gait. Aquatic therapy

may be utilized to normalize gait and to improve strength in a "reduced weight" environment. It is important to remember that the weakest point of the graft is from approximately 4 to 6 weeks postoperatively (DeCarlo & McDivitt, 2006); therefore, the patient is allowed to begin progressive weight bearing at 4 weeks postoperatively, thus weaning away from the crutches, and is typically completely off crutches by 6 weeks. Full ROM is typically achieved around the sixth–seventh week as well.

Strengthening exercises for the quads to protect the graft site include multiangle (90°, 60°, and 0°) isometrics, open chain strengthening from 90° to 45°, and closed chain exercises from 0° to 30°. Research has shown that performing closed chain exercises in this manner minimizes strain on the newly reconstructed ACL, secondary to a co-contraction of the quads and HTs and compressive forces at the tibiofemoral joint (Wilk et al., 1996).

From 6 to 8 weeks postoperatively the patient is allowed to begin progressing/deepening ROM with closed chain exercises. Full squats and lunges begin at 8 weeks postoperatively. At this time, contraindications are running/jogging and jumping on land. The focus also shifts to regaining good eccentric quadriceps strength with closed chain exercises. Performing an eccentrically biased rehabilitation program leads to greater improvements in quadriceps strength and hopping ability when measured in the later phases of rehabilitation (Gerber, Marcus, Dibble, & LasStayo, 2009).

PHASE 3

At 12 weeks, the patient is able to start impact loading activities such as jogging and double-legged hopping. Once the patient is able to jog without visible deviations and to land from a double-legged hop with good eccentric quad and hip abductor and external rotator control, progressive jogging to running and jumping to plyometrics and return to activities begin.

PHASE 4

Phase 4 of postoperative rehabilitation consists of returning to preinjury activity level. Various return-to-play criteria are suggested in the literature. The athlete is ready to return to sport if he or she has met all of the goals of postoperative phases 1, 2, and 3, and when he or she is able to complete a single leg hop for distance at 90% when comparing the injured lower extremity to the uninjured lower extremity at approximately 6 months postoperatively.

One systematic review of the rehabilitation literature found that six of 10 studies defined a result of greater than 90% of the distance hopped on a single-hop test compared with opposite side as acceptable (Barber-Westin & Noyes, 2011). Another systematic review suggested that the athlete achieve full ROM, 85% or greater on quadriceps and HTs strength and single leg hop tests compared with the opposite side, less than 15% deficit on HT-quadriceps strength ratio, no pain or swelling with sport-specific activities, and a stable knee in active situations to return to athletics within 6 months (VanGrinsven, VanCingel, Holla, & VanLoon, 2010).

Conclusion

The understanding and management of ACL tears have evolved greatly in the specialty of orthopaedic surgery over the last 30 years. Future advances of research and technology in the field of orthopaedics will continue to advance and change the management of ACL tears preoperatively, perioperatively, and postoperatively. It is imperative for orthopaedic RNs and APRNs to possess a thorough understanding of the anatomy of the ACL, the various mechanisms of injury to the ACL, in addition to evidence-based treatment strategies and rehabilitation principles pertaining to ACL tears. This knowledge will allow orthopaedic RNs and APRNs to better inform patients of the treatment and management options related to ACL tears, improve patient compliance, and encourage positive patient outcomes, with the ultimate goal of returning the patient to their level of preinjury function.

REFERENCES

American Medical Association, Subcommittee on Classification of Sports Injuries and Committee on the Medical Aspects of Sports. (1968). *Standard nomenclature of athletic injuries* (pp. 99–100). Chicago, IL: Author.

Amis, A., Bull, A., & Lie, D. (2005). Biomechanics of rotational instability and anatomic anterior cruciate ligament reconstruction. *Operative Techniques in Orthopaedics*, *15*(1), 29–35.

Andrews, J., Harrelson, G., & Wilk, K. (2004). *Physical rehabilitation of the injured Athlete* (3rd ed.). Pennsylvania, PA: Saunders.

Arnoczky, S., Rubin, R., & Marshall, J. (1979). Microvasculature of the cruciate ligaments and its response to injury: An experimental study in dogs. *Journal of Bone and Joint Surgery*, *61*(8), 1221–1229.

Barber-Westin, D., & Noyes, R. (2011). Factors used to determine return to unrestricted sports activities after anterior cruciate ligament reconstruction: A systematic review with video illustration. *The Journal of Arthroscopic and Related Surgery*, *27*(12), 1967–1705.

Beynnon, B., Johnson, R., Abate, J., Fleming, B., & Nichols, C. (2005). Treatment of anterior cruciate ligament injuries. *The American Journal of Sports Medicine*, *33*(3), 1579–1602.

Biggs, A., & Shelbourne, D. (2006). Use of knee extension device during rehabilitation of a patient with type 3 arthrofibrosis after ACL reconstruction. *North American Journal of Sports Physical Therapy*, *1*(3), 124–130.

Brand, J., Weiler, A., Caborn, D., Brown, C., & Johnson, D. (2000). Graft fixation in cruciate ligament reconstruction. *The American Journal of Sports Medicine*, *28*(5), 761–774.

DeCarlo, M., & McDivitt, R. (2006). Rehabilitation of patients following autogenic bone-patellar tendon-bone ACL reconstruction: A 20-Year perspective. *North American Journal of Sports Physical Therapy*, *1*(3), 124–130.

DeFranco, M., & Bach, B. (2009). A comprehensive review of partial anterior cruciate ligament tears. *The Journal of Bone and Joint Surgery*, *91*(1), 198–208.

Ferrari, J., & Bach, B. (2001). Isolated anterior cruciate ligament injury. In:Chapman, M. W. (Ed.), *Chapman's orthopedic surgery* (pp. 2347–2359). Philadelphia, PA: Lippincott, Williams & Wilkins.

Fideler, B., Vangsness, C., Lu, B., Orlando, C., & Moore, T. (1995). Gamma irradiation: effects on biomechanical properties of human bone-patellar tendon-bone allografts. *The American Journal of Sports Medicine*, *23*(5), 643–646.

Furman, W., Marshall, J., & Girgis, F. (1976). The anterior cruciate ligament: A functional analysis based on post-mortem studies. *Journal of Bone and Joint Surgery*, *58*(2), 179–185.

Gerber, J., Marcus, R., Dibble, L., & LasStayo, C. (2009). The use of eccentrically biased resistance exercise to mitigate muscle impairments following anterior cruciate ligament reconstruction: A short review. *Sports Health: A Multidisciplinary Approach*, *1*(1), 31–37.

Kim, K., Croy, T., Hertel, J., & Saliba, S. (2010). Effects of neuromuscular electrical stimulation after anterior cruciate ligament reconstruction on quadriceps strength, function, and patient-oriented outcomes: A systematic review. *Journal of Orthopaedic & Sports Physical Therapy, 40*(7), 383–391.

Hashemi, J., Chandrashekar, N., Beynnon, B., Slauterbeck, J., & Schutt, R. (2008). The geometry of the tibial plateau and its influence on the biomechanics of the tibiofemoral joint. *Journal of Bone and Joint Surgery*, *90*(12), 2724–2734.

Heming, J., Rand, J., & Steiner, M. (2007). Anatomical limitations of transtibial drilling in anterior cruciate ligament reconstruction. *The American Journal of Sports Medicine*, *35*(7), 1708–1715.

Liu, S., Osti, L., Henry, M., & Bocchi, L. (1995). The diagnosis of acute complete tears of the anterior cruciate ligament: Comparison of MRI, arthrometry and clinical examination. *Journal of Bone and Joint Surgery*, *77*(4), 586–588.

Macaulay, A., Perfetti, D., & Levine, W. (2012). Anterior cruciate ligament graft choices. *Sports Health: A Multidisciplinary Approach*, *4*(1), 63–68.

Maekawa, K., Furukawa, H., Kanazawa, Y., Hijioka, A., Suzuki, K., & Fujimoto, S. (1996). Electron and immunoelectron microscopy on healing process of the rate anterior cruciate ligament after partial transection: The roles of multipotent fibroblasts in the synovial tissue. *Histological Histopathology*, *11*(3), 607–619.

Maletius, W., & Messner, K. (1999). Eighteen to twenty-four year follow-up after complete rupture. *The American Journal of Sports Medicine, 27*(4), 711–717.

Mascal, C., Landel, R., & Powers, C. (2003). Management of patellofemoral pain targeting hip, pelvis, and trunk muscle function: 2 case reports. *Journal of Orthopaedic & Sports Physical Therapy*, *33*(11), 647–660.

Meisterling, S., Schoderbek, R., & Andrews, J. (2009). Anterior cruciate ligament reconstruction. *Operative Techniques in Sports Medicine*, *17*(1), 3–10.

Meredick, R., Kennan, J., Appleby, D., & Lubowitz, J. (2008). Outcome of single-bundle versus double-bundle reconstruction of the anterior cruciate ligament: A meta-analysis. *The American Journal of Sports Medicine*, *36*(7), 1414–1421.

Mroz, T., Joyce, M., Steinmetz, M., Lieberman, I., & Wang, J. (2008). Musculoskeletal allograft risks and recalls in the United States. *Journal of the American Academy of Orthopaedic Surgery*, *16*(10), 559–565.

O'Donoghue, D., Rockwood, C., Frank, G., Jack, S., & Kenyon, R. (1966). Repair of the anterior cruciate ligament in dogs. *Journal of Bone and Joint Surgery*, *48*(3), 503–519.

Palmieri-Smith, R., Thomas, A., & Wojtys, E. (2008). Maximizing quadriceps strength after ACL reconstruction. *Clinical Sports Medicine*, *27*(3), 405–424.

Rappe, M., Horodyski, M., Meister, K., & Indelicato, P. (2007). Nonirradiated versus irradiated Achilles allograft. *The American Journal of Sports Medicine, 35*(10), 1653–1658.

Roe, J., Pinczewski, L., Russell, V., Salmon, L., Kawamata, T., & Chew, M. (2005). A 7-year follow-up of patellar tendon and hamstring tendon grafts for arthroscopic anterior cruciate ligament reconstruction: Differences and similarities. *The American Journal of Sports Medicine*, *33*(9), 1337–1345.

Schultz, S., Schmitz, R., Nguyen, A., Chaudhari, M., Padua, D., McLean, S., & Sigward, S. (2010). ACL research retreat V: An update on ACL risk and prevention, March 25–27, 2010, Greensboro, NC. *Journal of Athletic Training*, *45*(5), 499–508.

Shelton, W., & Fagan, B. (2011). Autografts commonly used in anterior cruciate ligament reconstruction. *Journal of the American Academy of Orthopaedic Surgeons*, *19*(5), 259–264.

Smith, H., Vacek, P., Johnson, R., Slauterbeck, J., Hashemi, J., Shultz, S., & Bruce, D. (2012). Risk factors for anterior cruciate ligament injury: A review of the literature – part I: Neuromuscular and anatomic risk. *Sports Health: A Multidisciplinary Approach, 4*(1), 69–78.

Steiner, M., Battaglia, T., Heming, J., Rand, J., Festa, A., & Baria, M. (2009). Independent drilling outperforms conventional transtibial drilling in anterior cruciate ligament reconstruction. *The American Journal of Sports Medicine, 37*(10), 1912–1919.

Torg, J., Conrad, W., & Kalen, V. (1976). Clinical diagnosis of anterior cruciate ligament instability in the athlete. *The American Journal of Sports Medicine, 4*(2), 84–93.

VanGrinsven, S., VanCingel, E., Holla, J., & VanLoon, J. (2010). Evidenced based rehabilitation following anterior cruciate ligament reconstruction. *Knee Surgery, Sports Traumatology, Arthroscopy, 18*(8), 1128–1144.

Wasilewski, S., Covall, D., & Cohen, S. (1993). Effect of surgical timing on recovery and associate injuries after anterior cruciate ligament reconstruction. *The American Journal of Sports Medicine, 21*(3), 338–342.

West, R., & Harner, C. (2005). Graft selection in anterior cruciate ligament reconstruction. *Journal of the American Academy of Orthopaedic Surgeons*, *13*(3), 197–207.

Wilk, K., Escamilla, R., Fleisig, S., Barrentine, S., Andrews, J., & Boyd, M. (1996). A comparison of the tibiofemoral joint forces and electromyographic activity during open and closed kinetic chain exercises. *American Journal of Sports Medicine, 24*(4), 518–527.