SMGroup

Current Trends in ACL Reconstruction and Rehabilitation

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INTRODUCTION

Anterior Cruciate Ligament **(ACL)** tears are among the most common orthopaedic injuries with an incidence of approximately 250,000 per year in the United States. The majority of these injuries occur in young athletes, ages 15-25, involved in sports that require planting, cutting, and pivoting [1-4]. Arthroscopic reconstruction of the ACL has become the standard of care in athletes, and patients who place a high demand on their knee. It is estimated that 175,000-200,000 ACL reconstructions are performed annually [5,6]. The goals of ACL reconstruction are to restore knee biomechanics and minimize the risk of subsequent meniscal and cartilage damage while allowing patients to return to their desired activities.

ANATOMY AND BIOMECHANICS

The ACL functions to provide stability to the knee joint. The average ACL has a length of 33mm and a diameter of 11mm [7]. The ACL originates on the posteromedial aspect of the lateral femoral condyle in the intercondylar notch and inserts on the tibial plateau medial to the anterior horn of the lateral meniscus.The ACL is composed of two functional bundles named for the location of their respective tibial insertions, Anteromedial **(AM)** and Postero lateral **(PL)** **[**8-11**]**. The lateral intercondylar ridge (resident's ridge) marks the anterior border of the femoral insertion and the lateral bifurcate ridge divides the origin of the two respective bundles [12]. The AM bundle is tight in flexion and provides the majority of restraint to anterior translation; while the PM bundle is tight in extension and provides restraint to axial rotation. In addition, the ACL helps prevent knee hyperextension, tibial rotation and protects the menisci from shear forces [13,14].

RISK FACTORS

Both intrinsic and extrinsic risk factors contributing to ACL tears have been identified. Extrinsic risk factors are typically related to increased torsional resistance and an increased playing surface friction coefficient, such as cleat design and playing surfaces [15]. Intrinsic risk factors may be related to anatomy, gender, or biochemical properties. Anatomic factors include decreased intercondylar femoral notch size [16], depth of concavity of the medial tibial plateau, and increased posterior tibialslope [16,17].

Gender plays a complex role in the risk of ACL injury. ACL injuries are more common in males, due to the greater absolute number of males participating in athletic activities, however, when collegiate sports with both male and female participation are compared, females have a 2-8 times greater likelihood of experiencing an ACL injury than males [18]. Women have a larger Q angle, which increases the biomechanical stresses on the ACL [19]. The female ACL has a smaller cross sectional area, 8% lower tensile load to failure, and 22% lower modulus of elasticity. These factors, in combination with the increased knee valgus moments in omen during leg landings, have all been associated with a greater rate of injury [20-22]. Hormonal receptors on ACL fibroblasts and variations in knee laxity during the menstrual cycle have been demonstrated; however, there is no clear statement regarding the effects of the menstrual cycle on the rate of ACL injury [22-26]. In addition, a genetic predisposition may exist; 23.4% of individuals with an ACL tear report having a first-degree relative with ACL injury as well, compared to 11.7% in control group [27].

PRESENTATION AND DIAGNOSIS

Injuries to the ACL are often immediately disabling. Diagnosis of ACL injury is best accomplished with the combination of a thorough history, physical examination, and imaging. Suspicion for ACL injury should be elevated when the patient describes a noncontact injury that occurred while changing direction or landing from a jump. Injury is often associated with a popping sensation, followed by swelling, pain, an acute hemarthrosis, and difficulty with weight bearing [28].

In order to obtain an accurate physical exam, it is essential that the patient be relaxed and comfortable. The injured knee should always be compared to the contralateral knee. Many times the on-field physical exam can be done prior to the development of a large effusion, allowing for the most accurate exam. The Lachman test is performed by placing the knee in approximately 20-30 degrees of flexion with the femur stabilized; an anteriorly directed force is applied to the proximal tibia. The displacement and endpoint (firm, marginal, or soft) should be compared to the contralateral side with a noticeable difference considered a positive result. The anterior drawer test is performed by applying an anteriorly directed force to the proximal tibia with the knee at 90 degrees of flexion and the foot stabilized under the examiner. The amount of displacement and the feel of the end point (ie soft, firm) should be compared to the contralateral side with a noticeable difference considered a positive result. In addition, a grading system has been developed: grade 1 = 5 mm, grade 2 = 5 to 10 mm, grade 3 > 10 mm [29]. The pivot shift test is performed by applying a valgus stress and an axial load while internally rotating the tibia as the knee is moved from full extension into flexion. A positive test is indicated by subluxation of the tibia while the femur rotates externally followed by a reduction of the tibia at 30-40 degrees of knee flexion. This test is most often reserved for the examination under anesthesia, as patients are rarely able to tolerate this in the office. The Lachman test has shown to be the most accurate with a sensitivity of 81% and specificity of 81% while awake, and sensitivity of 91% when under anesthesia. The pivot shift test carries a sensitivity of 28% and specificity of 81% while awake, and a sensitivity of 73% and a specificity of 98% when under anesthesia [30]. The anterior drawer test is only 49% sensitive and 58% specific in acute conditions [31].

Upon initial examination, plain radiographic X-rays should be obtained. A segond fracture, avulsion of the posterior lateral capsule off of the proximal tibia, can sometimes be seen and is considered pathognomonic for ACL tears. If there is suspicion for an ACL tear based on history and physical exam, a Magnetic Resonance Image **(MRI)** is then ordered to evaluate for soft tissue injury. ACL tears and associated bone bruising are best visualized on sagittal T2 imaging (Figure 1). MRI has 100% sensitivity and 77.8% specificity in diagnosing ACL injury in adults, with similar values in pediatric patients [32-34]. Additionally, MRI provides comparable sensitivity and specificity for other knee structures such as the medial meniscus, lateral meniscus, and PCL [32]. Diagnostic arthroscopy should be considered when MRI findings do not correlate with clinical findings.

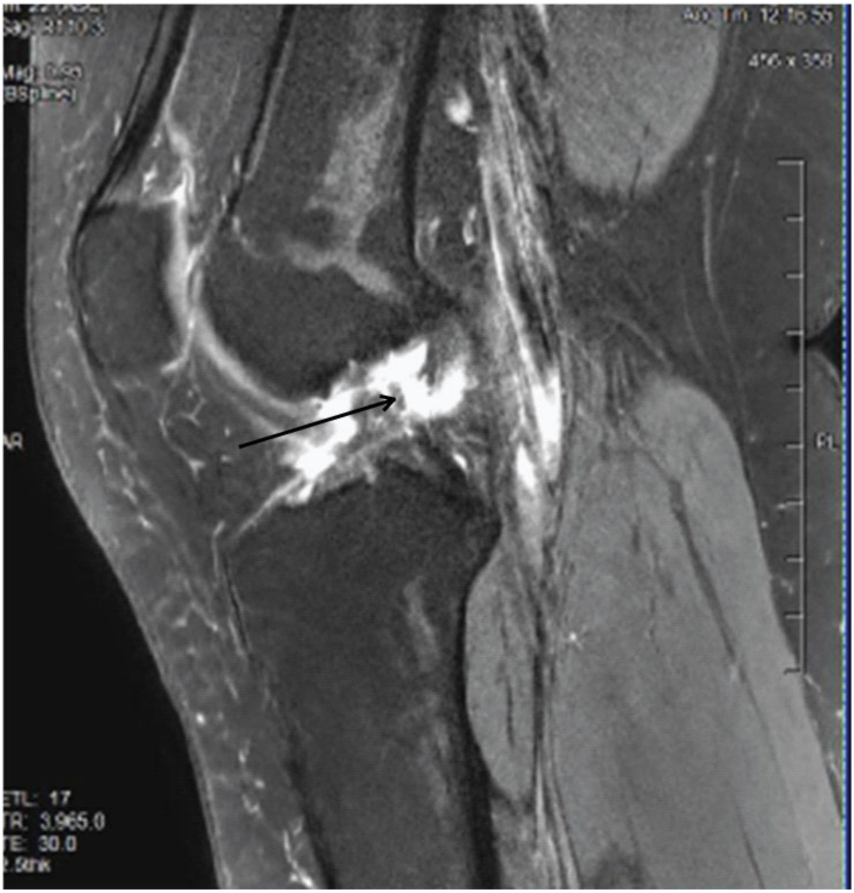

Figure 1: Sagittal STIR MRI image of the right knee demonstrating a complete tear of the ACL (arrow).

TREATMENT

The decision between non-operative and operative treatment is based on many variables including age, activity level, concomitant injuries, and overall goals of care. Non-operative management has been shown to lead to an increased risk of developing meniscal and chondral abnormalities in ACL deficient knees [35-38]. In addition, delaying ACL reconstruction (greater than 6 months) has been shown to increase the rate and complexity of meniscal tears [39-41].

Controversy exists regarding the long-term clinical effects of ACL deficient knees. Frobell et al. [42,43] conducted a randomized controlled trial with 121 young adults with complete ACL tears, all of which underwent rehabilitation with either early or optional delayed reconstruction. The study reported no statistically significant differences between the groups after 2 and 5 years with regard to pain, function in sports or recreation, radiographic Osteoarthritis **(OA)**, or meniscus surgery [42,43]. Similarly, Grindemet al. [44] conducted a prospective cohort study with 143 patients with complete ACL tears that were divided into an operative verses non-operative management. Biomechanical testing, International Knee Documentation Comittee **(IKDC)** scores, and sports participation via an online survey were collected at baseline, six weeks, and two years. They concluded that there are few differences in the clinical outcomes between operatively and non-operatively treated patientsc [44].

A study by Mihelicet al. [45] in 2011 compared 51 patients, 33 who underwent ACL reconstruction and 18 who were treated conservatively, to determine clinical and radiologic outcomes 17-20 years after treatment [45]. Outcomes consisting of physical exams, functional knee scores, and radiographic evaluation demonstrated that 83% of surgical patients had stable knees with normal or nearly normal IKDC scores. However, all of the patients with non-operative treatment had unstable knees, 84% of whom had had abnormal or severe laxity [45]. The group also reported that although reconstructive surgery does not prevent the development of osteoarthritis, it significantly lowers the risk when compared to conservative methods [45]. Similarly, Ventura et al. [46] reported that ACL reconstructions were better than non-operative treatment when examining functional knee scores, biomechanical testing, patient satisfaction, return to sport, and risk of subsequent meniscal injury in a cohort of 100 patients. They concluded that surgery should be the treatment of choice for young patients wanting to return to sports [46]. Chronic instability leads to an increased probability of developing early degenerative knee osteoarthritis [47], with accelerated chondral wear, and greater incidence of meniscal tears [48,49]. According to Lohmander et al. [50], regardless of treatment type, athletes with ACL injuries are 10 times more likely to develop early OA, with an overall incidence of greater than 50% 10-20 years after injury.

Given the conflicting reports in the literature, the decision of whether to proceed with ACL reconstruction or conservative treatment lies in the hands of the physician and patient. The American Academy of Orthopaedic Surgeons **(AAOS)** currently recommends early ACL reconstruction in young active patients (less than 35 years old) to improve knee instability and decrease the risk of subsequent meniscal damage [51]. In older patients, multiple factors including activity level, concomitant injuries, and goals of care should be taken into account when discussing operative verses non-operative management.

OPERATIVE RECONSTRUCTION

ACL reconstruction is routinely performed arthroscopically using either autograft or cadaveric allograft. Graft selection for ACL reconstruction remains controversial. The optimal graft should mimic the anatomy of the native ACL, provide sufficient strength, and allow for revascularization of the tendon. According to Lynch et al. and the Multicenter Orthopaedic Outcomes Network **(MOON)** prospective longitudinal cohort research study [52], ACL graft choice and age were the most influential predictors of graft failure [53]. The most common autografts include four-strand hamstrings, Bone-Patellar Tendon-Bone **(BPTB)**, and quadriceps tendon [54]. Allograft options include tibialis anterior tendon, tibialis posterior tendon, and Achilles tendon.

Numerous studies demonstrated no clinical difference between the various autografts [55]; however, some differences have been debated. BPTB grafts are associated with higher IKDC scores [56,57], lower failure rates [55], and superior Tegner scores, which also demonstrates higher overall knee function and activity level [58]. Hamstring autografts have been shown to produce better knee extension and lower risk of long-term osteoarthritic degenerative joint disease [59].

The main downside to autograft usage is the higher risk of donor site morbidity. BPTB autografts may lead to an increased incidence of anterior knee pain [55,59], difficulty kneeling [60,61], anterior knee numbness [62], patellar fracture [65], and patellar tendon rupture [65] when compared to quadriceps and hamstring autografts. Use of hamstring autografts can produce weakness of terminal knee flexion [66], damage to neurovascular structures, numbness over the donor site, and increased graft laxity in female patients [67,68]. Quadriceps tendon autografts have been shown to lead to hematoma formation and compartment syndrome if the graft harvest causes a significant degree of damage [69].

The use of allografts has been extensively studied and compared to autograft use for ACL reconstruction. The most attractive aspect of allograft usage is the lack of donor site morbidity, in addition to minor advantages, like shorter operative time and better cosmesis [70]. The major risk of allograft usage includes possible disease transmission, with an estimated risk of HIV transmission of 1 in 1,600,00 [71]. Although numerous studies have compared allograft versus autografts, a recent prospective, randomized clinical study by Bottoniet al.[72] evaluated the use of hamstring autograft versus tibial is posterior allograft after a minimum of 10 years post-op in young athletic patients. Although 80% of the grafts were stable and remained viable after 10 years, allografts had a failure rate of greater than 3 times that of hamstring autografts [72]. The authors reported a re-tear rate of 26.5% in allograft-reconstructed knees compared to 8.3% in the hamstring autograft knees [72]. Furthermore, in the MOON cohort, Kaedinget al. [53] prospectively demonstrated in 1000 ACL reconstructions a four times higher rate of failure in allograft versus autograft. Patients aged 10-19 years had the highest risk and for each 10-year decrease in age, the odds of allograft failure increased 2.3 times [53].

In recent years there has been increased interest in reconstructing both the anteromedial and posterolateral bundles anatomically with a "double bundle reconstruction". A recent Cochrane database systemic review consisting of 17 clinical trials demonstrated no significant difference in terms of clinical outcomes and functional knee scores between single verses double bundle reconstruction. The report suggests that double bundle reconstruction may be biomechanically superior; however, it has not shown clinical superiority [73]. Similarly, the AAOS guidelines report similar outcomes between the two techniques [51].

Studies investigating double-bundle ACL reconstruction have improved our understanding of the anatomy of the ACL, especially with regard to its origin on the medial wall of the lateral femoral condyle. Historically, it was thought that the femoral tunnel had to be placed high and posterior in the notch at the 11 or 1 o'clock position in order to provide the most isometric position for the graft [74,75]; however, recent biomechanical and clinical studies have shown that an anatomic ACL reconstruction closer to 10 or 2 o'clock (Figure 2), improves rotational stability compared to that obtained with the more vertical tunnel position. Lohet al. [76] biomechanically stressed 10 cadaveric knees with femoral tunnels at 10 and 11 o'clock position. The authors concluded that while both the tunnel positions were equally effective under an anterior tibial load, the 10-o'clock position more effectively resisted rotatory loads [77-80]. The femoral tunnel is commonly drilled using either a transtibial or accessory anteromedial portal (Figures 3,4). Two large meta-analysis and reviews suggests the anteromedial portal allows for creation a more anatomic femoral tunnel; however, there has been no clinically significant difference in knee scores, failure rates, or patient satisfaction between the two techniques [81,82]. Therefore, regardless of surgical technique, meticulous femoral tunnel position has been shown to improve outcomes after ACL reconstruction.

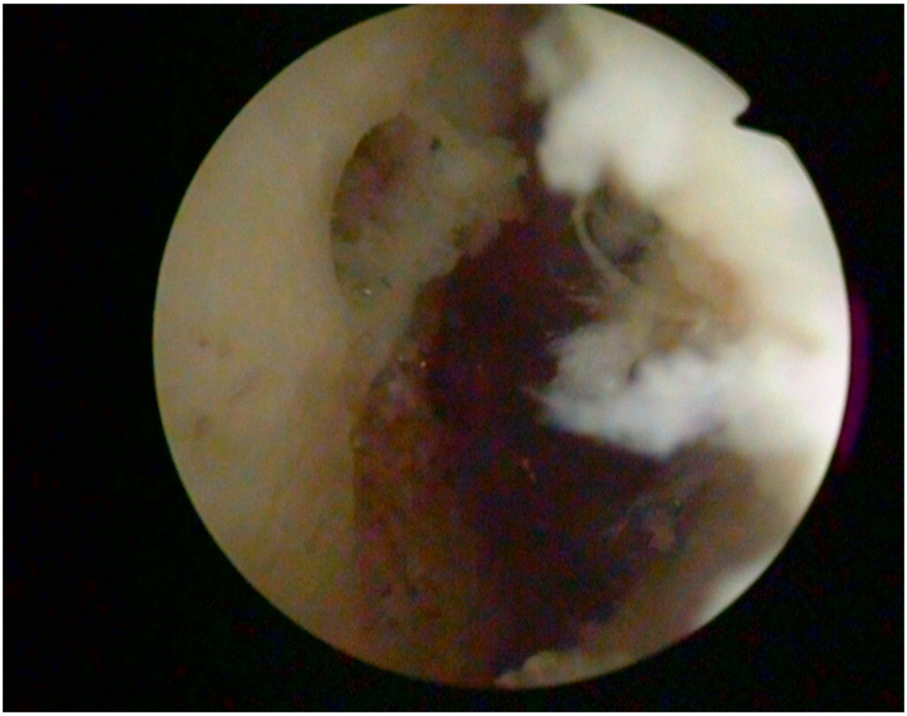

Figure 2: Arthroscopic view from the anterolateral portal of the medial wall of the lateral femoral condyle of a right knee demonstrating appropriate positioning of the femoral tunnel position. The tunnel was drilled through an accessory anteromedial portal.

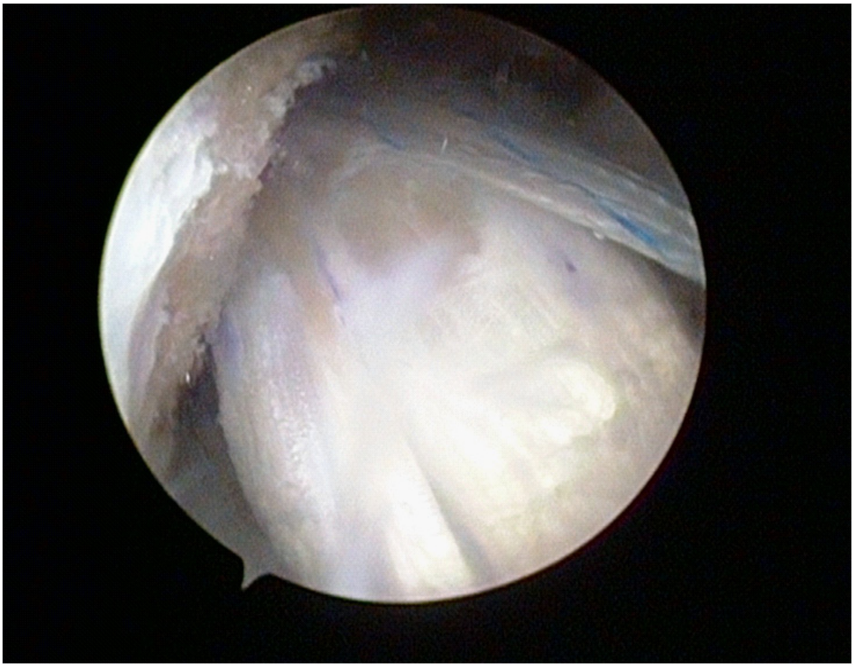

Figure 3: Arthroscopic view from the anterolateral portal of the ACL graft passing into femoral tunnel.

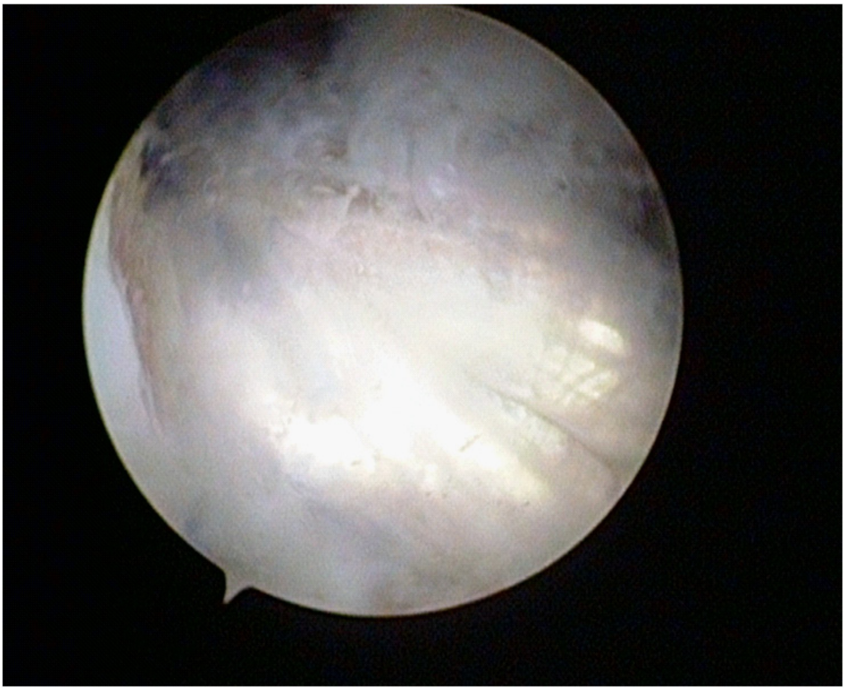

Figure 4: Arthroscopic view from the anterolateral portal demonstrating completed ACL reconstruction.

REHABILITATION

ACL rehabilitation begins prior to surgery. Preoperative swelling and decreased range of motion has been associated with the development of arthrofibrosis post operatively [83]. In addition, preoperative quadriceps weakness has been shown to affect functional outcomes two years after surgery [84,85]. Therefore, preoperative rehabilitation (pre-hab) should focus on reducing swelling, improving range of motion, and increasing quadriceps strength.

Many ACL rehabilitation protocols exist in the literature. It is important to recognize that the goal of rehabilitation after ACL reconstruction is to restore normal joint motion and strength while protecting the graft in order to allow for healing. An accelerated rehab protocol is the most current recommendation [51]. Typically, rehab protocols are broken up into several phases. The first phase (0-2 weeks), focuses on decreasing pain and inflammation while improving range of motion from full extension to 90 degrees of flexion. Cryotherapy, elevation, and electrical stimulation are all modalities used to help restore patella mobility, regain quadriceps control, and restore normal ambulation. The intermediate phases (weeks 2-16) aim to obtain full range of motion (0 to 130 degrees of flexion) while improving muscle strength and proprioception. Closed chain weight bearing exercises are gradually increased to allow for increased strength and mobility. Neuromuscular training focuses on improving static stability while progressing to dynamic stability. Jogging and light plyometrics are encouraged after week 8. The final phase (4-6 months), prior to return to play, aims to maximize muscle endurance and strength with particular emphasis on neuromuscular control. Jumping, agility training, and sports specific activity are gradually allowed while maintaining strength and range of motion [86,87]. It is essential to recognize that these protocols can differ based on surgeon preference, graft choice, and concomitant pathology such as meniscal repairs and should only be used as a guideline.

Return to Play **(RTP)** criteria continues to be a topic of significant debate. Adern et al [88] reported on 6,000 patient's post-ACL reconstruction, 90% of which had normal or nearly normal function, but only 44% of which were able to return to a competitive sport [88]. The term "return to play" itself is ambiguous. Athletes are often permitted to RTP after 6-12 months following ACL reconstruction, even though weakness and leg muscle imbalance is still present up to 2 years after surgery [89,90]. As a result, identifying objective criteria to allow patients to RTP continues to be an area of significant research.

Quadriceps and hamstring strength greater than 85% compared to the contralateral side has commonly been as a measure of readiness to RTP [86].The hop test has been used to simulate functional recovery prior to RTP. The hoptest has further been subdivided into the single-leg hop for distance, single-leg triple hop for distance, single-leg timed hop, single-leg crossover hop for distance, and vertical jump [91]. These measurements should be greater than 85% compared to the contralateral side [87]. Most physicians use a combination of functional and strength testing to determine when an athlete is ready to RTP. Bach and Cole et al. recommend the use of the hop test along with single leg squats, lateral agility and pivoting, drop to jump testing, and deceleration testing as part of an overall "Functional Sports Assessment as an Aid for Determining Return to play" [87]. Further studies should be conducted to verify and validate these tools in order to develop guidelines to better define RTP criteria.

ADVERSE PSYCHOLOGICAL AFFECTS ASSOCIATED WITH ACL TEARS

Although the majority of literature focuses on the outcomes of ACL reconstruction and conservative management, the psychological aspects of rehabilitation and their effects on the patient have recently been recognized. Since the majority of athletes who undergo ACL reconstruction are able to return to sports, those that do not return are often overlooked. Tjong et al. [92] conducted interviews of 31 patients following primary ACLR with good knee function and found that 64% had not returned to their pre-injury level of sports after a minimum of 2-yearfollow-up. Among those who chose not to return, factors such as fear, priority changes, and a cautious personality were the most influential in making their decision [92]. Similarly, Adern et al. [88] reported that fear of re-injury was the most common reason for not returning to sport. As a result, physicians must stress the importance of psychological rehabilitation (ie. coping, adaptation) along with the physical rehabilitation in order to maximize the ability of athletes to have a successful outcome.

COMPLICATIONS

Complications following ACL reconstruction are relatively rare and include graft failure (4.6 %) [94], infection (0.14% to 1.7%) [94] and knee stiffness (1.8% to 35%) [95]. The Multi-center ACL Revision Study **(MARS)**, a multi-center, multi-surgeon, prospective longitudinal cohort study has provided valuable data regarding modes of graft failure. The most common cause of failure has been identified as traumatic re-injury (32%) followed by technical error (24%) where femoral tunnel position was the most common cause [96], further emphasizing the importance of proper anatomic femoral tunnel position. Non-anatomic femoral or tibial tunnel placement can lead to joint instability. A graft placed too anterior on the tibia can cause the knee to be tight in flexion and may lead to graft impingement. Likewise, a graft placed too posterior on the tibia can impinge on the Posterior Cruciate Ligament **(PCL)** [97]. Post-operative joint stiffness should be treated first by prevention. Prior to surgery, rehabilitation should focus on maintaining range of motion and quadriceps strength, while decreasing joint effusions. If post-operative stiffness develops, aggressive physical therapy, anti-inflammatory medications, and patella mobilization should be the first line of treatment. If 90 degrees of knee flexion is not obtained by 6 weeks, arthroscopic lysis of adhesions and manipulation under anesthesia should be considered. Following this procedure, use of a Continuous Passive Motion **(CPM)** machine or dynamic splinting may be appropriate [98].

SOCIETAL AND ECONOMIC IMPACT

The estimated annual cost of ACL reconstruction is approximately $3 billion in the United States [99]. Mather et al. [100] used the MOON cohort to investigate the cost and effectiveness of patients undergoing ACL reconstruction, based on the societal perspective and included the effects of the ACL tear on work status, earnings, and disability. Effectiveness was expressed as Quality-Adjusted Life Years **(QALYs)** gained. In the short term, ACL reconstruction cost $4,503 less and was more effective (a QALY gain of 0.18) compared to rehabilitation alone. In the long term, the mean lifetime cost to society for a typical patient undergoing ACL reconstruction was $38,121 compared with $88,538 for rehabilitation [100]. A recent large meta-analysis evaluating 24 studies sought to provide a cost analysis on various topics related to ACL injuries. The authors concluded that early single bundle ACL reconstruction with a BPTB or hamstring autograft in an outpatient setting provides the most value to society compared to non-operative or delayed treatment, use of allograft, or inpatient surgery [101].

CONCLUSION

The anterior cruciate ligament is an important component of anatomic stability to the knee joint. Injuries to the ACL are common, and the risk factors associated with injury can be separated into intrinsic and extrinsic factors. While males generally sustain more overall injuries, the rate of ACL tears in female athletes is higher than in males largely due to anatomic and biomechanical differences. Diagnosis of ACL tears is based on a combination of history and physical exam findings, along with appropriate imaging studies. When an injury is identified, both operative and non-operative treatment should be considered on the basis of multiple patient factors including age, activity level, concomitant injuries, and goals of care. Excellent outcome can be obtained through either transtibial or anteromedial portal techniques of arthroscopic ACL reconstruction. Graft choice, number and placement of tunnels, and portal use can impact outcomes and should be considered when tailoring optimal treatment to meet the needs of an individual patient. Post-operative rehabilitation is separated into phases to achieve sequential goals, which focus on range of motion, strength, and stability. The timing and readiness for return to play depends on the individual patient as well as their rehabilitation success. ACL tears represent a significant economic burden, with operative treatment representing a lower overall cost than rehabilitation alone. The decision to operate on a patient with an ACL tear, operative technique used, and postoperative rehabilitation should be tailored to the individual patient to maximize the chance of obtaining a good outcome.

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