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Comparison of Anterior Cruciate Ligament Graft Materials and Risk of Rupture/Reinjury in Young Athletes

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by

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Abstract

The anterior cruciate ligament tear is a standard surgical injury seen with young athletes competing at elite, amateur, and recreational capacities. The purpose of this literature review is to determine the rehabilitation guidelines and risks associated with anterior cruciate ligament reconstruction, as well as determining the role of rehabilitation in graft rupture. This literature review also serves to determine if graft choice for surgical repair plays a role in an increased risk of rupture or reinjury. This literature review used various online databases, including Dynamed, Cochran, and Pubmed, with the utilization of MeSH terms listed below in "keywords" in order to identify applicable data. A systematic review of the literature was then completed. Data showed that athletes near or younger than the age of 25 were at a higher risk of graft rupture. The patellar tendon graft shows a decreased risk of rupture and instability when compared to hamstring grafts. Allografts were found to have an increased risk of rupture in young athletes when compared to hamstring grafts and should not be considered for young athletes. Failure to complete a rehabilitation program was also determined to play a role in graft rupture.

Keywords: *Anterior Cruciate Ligament, ACL, graft, allograft, hamstring, patellar tendon, bridge enhanced ACL repair, athletes, rupture, reinjury, young.*

Introduction

Anterior cruciate ligament (ACL) tears are a standard surgical injury to the knee, especially seen in younger athletes performing at both elite and amateur levels. Although this injury can be debilitating and require surgical intervention, therapy, and significant rehab, many athletes can return to sport and have little to no deficits. The surgical graft material for repairing an ACL tear can vary significantly. Surgical technique, angle of the ligament, and compliance with therapy all play a role in possible reinjury; however, the basis of this paper is to determine if the graft material used can leave an athlete more prone to re-injury and if graft selection plays a role in rehabilitation. An assessment of recent advances regarding new techniques for reconstruction and the risk reduction associated with this procedure was also completed.

Statement of the Problem

An ACL reconstruction is a procedure that follows a rupture of the ACL. Rupture is often due to the increased amount of force and stress put on the knee. Although ACL reconstruction is a relatively standard surgical procedure, there is a wide variety of the type of graft material used. The concern regarding this approach is that based on the graft material type used, the patient may be more prone to reinjury.

Research Question

In young athletes who have undergone ACL repair, do different ACL graft materials increase the chance of reinjury/relapse, and does graft selection impact rehabilitation?

Research Methods

A literature review was performed using electronic search databases; CINAHL, PubMed, Clinical Key, Cochrane Library, and Dynamed Plus. Both keyword and MeSH terms were used to define a set of the literature discussing anterior cruciate ligament repair with allograft, patellar tendon, and hamstring tendon graft materials and failure occurrence rates. The literature was searched for safety and rehab techniques post-ACL repair and how graft selection can impact rehabilitation. Bridge-enhanced ACL repair (BEAR) was assessed as well due to the promising outcomes in clinical trials regarding risk reduction. Several studies were excluded as they did not solely look at ACL repair in athletes and failure rates. Multiple other studies were excluded as they focused on various surgical techniques, angles of the ligament, and longevity studies based on various suture material. The search was narrowed to focus on the last ten years. Longevity studies were also given preference if several studies were looking at similar variables.

Literature Review

Rehabilitation and Risks of an ACL Repair

An essential aspect of ACL repair is the criteria for rehabilitation that was researched by Kyritis, Bahr, Landreau, Miladi, and Witvrouw (2016). One hundred fifty-eight professional athletes met the exclusion criteria. The athletes were all professional athletes in Qatar, and all the athletes were male. The study defined return to sport (RTS) as the athletes returning to regular team training and functioning. All athletes were treated at Aspetar Orthopedic and Sports Medicine Hospital and underwent a primary ACL reconstruction (ACLR). The study utilized a time frame between January 1st, 2008, and September 21st, 2015, to identify the participants in the study. All athletes that were part of the study were required to report any injury to the hospital.

Therefore, Kyritis et al. identified ACLR and subsequent rupture after reconstruction. Follow-up for participants was conducted at six months post-ACLR, unless a rupture occurred, then follow up was discontinued for that participant. Following the surgery, participants that only had ACLR bore weight as tolerated immediately after the surgery without assistance from a brace. However, those that underwent simultaneous meniscus repair wore a knee range of motion (ROM) brace that limited knee flexion to 90 degrees. All athletes completed a rehabilitation program at Aspetar that was supervised by specialized physical therapists, treating only ACL injuries. Kyritis et al. used three phases for rehabilitation for the participants. Those phases were early, intermediate, and advanced, respectively. The early phase focused on controlling the swelling from the surgery, restoring ROM, and activating the quadriceps and hamstring muscles. The intermediate phase focused on further muscle strengthening as well as neuromuscular control. Following the first two phases, the advanced phase focused on completing more sports-specific movements and position-specific drills. Six criteria were utilized to determine if the patient met the criteria for discharge. The six criteria were an isokinetic test at 60, 180, and 300°/s, single hop, triple hop, triple crossover hop, on-field sports-specific rehabilitation (OFSSR), and a running T-test. The criteria needed to be considered for discharge were quadriceps deficit <10% at 60°/s, limb symmetry index >90% for all hopping tests, OFSSR must be fully complete, and the running T-test completed in less than 11 seconds.

Of the 158 study participants in the study conducted by Kyritis et al. (2016), 26 experienced an ACL graft rupture within or before the follow up at six months. Of the 158 participants, 116 met the criteria for discharge. The other 42 did not meet that criterion. Of the 116, 12 participants (10.3% of discharged participants) suffered graft rupture. However, of the 42 participants that did not meet the criteria for discharge, 14 (33.3%) suffered graft rupture

($p<0.001$). A comparative regression model compared the different groups with discharge criteria. What the model identifies was that those athletes with a lower hamstring/quadriceps ratio at the 60 °per second were at higher risk for graft rupture and those that did not complete discharge criteria with a decreased hamstring/quadriceps ratio were at a four times higher risk for rupture ($p<0.001$) (Kyritis et al. 2016).

There are limitations to the study conducted by Kyritis et al. (2016). All of the study participants were male. There is an anatomical difference regarding strength in the lower extremity when it comes to males and females, according to experts in the field of rehabilitation, especially concerning the rehabilitation of an ACLR. All of the study participants are of Arab ethnicity being from Qatar. One ethnicity makes it more challenging to apply these results to a larger, more diverse population. Another limitation is the number of participants. Although there are over 150 participants in the study, the population already narrows the participant pool, and the number creates another statistical bias.

In the study conducted by Malempati, Jurjans, Noehren, Ireland, and Johnson (2015), the purpose was to outline the current rehabilitation techniques when it comes to athletes and apply them to clinical practice. In the 1980s, patients were non-weight-bearing for up to 6-8 weeks on the affected knee. Guidelines regarding this have changed significantly in terms of rehabilitation and returning to activity. The current recommendations introduced by Malempati et al. were broke down into four phases; preoperative phase, early postoperative phase, strengthening phase, and return to activity phase. Malempati et al. reviewed several sources and various recommendations and reviewed the results. They then compiled a consensus guideline for ACLR.

When reviewing the preoperative phase of rehabilitation, Malempati et al. (2015) recommended establishing an emphasis both on standard gait patterns and preservation of ROM. Regarding ROM, the emphasis was to retain at least zero to 90°. ROM is accomplished at one to three physical therapy visits. Patients then transitioned to a home therapy program at that point. If gait was reasonable, the participant could complete full weight-bearing with a locking brace. However, if the patient demonstrates a stable gait with the brace unlocked with activities of daily living (ADLs), a brace may not necessarily need to be used. One of the most critical exercises identified by Malempati et al. during this phase of the rehabilitation was a straight leg raise for quadriceps strengthening. However, they only recommend this without a lag sign. Another significant aspect of this phase is decreasing the amount of swelling and effusion into the joint capsule. The recommendations for this continue to be the rest, ice, compression, and elevation (RICE) therapy to decrease the inflammation and swelling to the area. In recent years, Malempati et al. identified that cryotherapy has also shown some results with this aspect of the rehabilitation. Following the preoperative phase is the early postoperative phase. This phase typically consists of the first four weeks following ACLR. The goals of this phase are very similar to the preoperative phase. Decreasing swelling and pain following the surgery, establish a typical gait pattern, gain ROM with 90° of flexion, and eventually discontinue the use of crutches are the main goals. Continued quadriceps strengthening also continues to be important during this phase. Incision care should also be a part of this phase, as well. Incisions should be clean, dry, intact, and free from signs of infection. Cryotherapy can also be recommended during this phase within the first 24 hours postoperatively. Following cryotherapy, ice utilization every 15 minutes for every hour to continue decreasing inflammation. Once inflammation is controlled, ice should be utilized three times daily for 15 minutes based on the recommendations by Malempati et al. When it comes to weight-bearing, patients should be up weight-bearing as tolerated on the day of surgery. A brace should be initially applied and locked at zero degrees for weight-bearing. Loading of the knee should gradually increase as tolerated as well during this phase. At the four-week mark, the patient uses a shorter brace, and it may be unlocked as well if the patient can demonstrate a typical gait pattern and perform the straight leg raise without lag. The discontinuation of crutches follows this after the patient can demonstrate a typical gait pattern as well. Crutches are excellent for gait stability in the interim during this phase. Patellar mobility added to the preoperative exercises. A critical consideration of this phase is the type of graft material used in the surgery. Malempati et al. identified that patients with patellar tendon autograft ACLR would be more prone to patellar hypomobility. Because of this, wound health and prolonged patellar immobility is essential.

In contrast, patients with hamstring tendon autograft will limited hamstring strength for the first month. These are essential concepts to know as it changes the format of physical therapy based on the graft material. The third phase is the strengthening phase. This phase takes place from four weeks postoperatively to six months. During this phase, the short brace is unlocked, and strengthening exercises should be advanced as the patient tolerates. There should not be any advancement in strength if the patient begins to experience swelling to the affected joint or pain that is lasting longer than 12 hours in the joint. At this phase, Malempati et al. (2015) recommend specific exercises be implemented, such as mini-squats, mini-lunges, leg press, hamstring curls, step downs, wall sits, and one-legged deadlifts. Implementation of Therabands occurs at this phase. Multidirectional movements that mimic the activity could also start during this phase; however, significant loading during pivoting and cutting should be avoided during this phase as it can put excessive stress on the graft and cause a rupture. The final phase is the return to the activity phase. The activity phase starts at three months postoperatively and continues until the patient returns to activity. The activity phase is very similar to the strengthening phase; however, this phase is more aggressive with strengthening. Exercises remain similar, but weight gradually increases as tolerated by the patient. Neuromuscular exercises start. During this phase, ROM should increase up to 135° as able for knee flexion and full extension. The patient should also begin sport-specific drills, including cutting and pivoting without pain before return to activity.

There are limitations to the comprehensive review conducted by Malempati et al. (2015). The study analyzes multiple guidelines from several sources and creates a comprehensive review and recommendations regarding ACLR rehabilitation; however, it does not include the data supporting these recommendations. Another limitation of this study is that it is a comprehensive review of several recommendations. While these recommendations are vital recommendations that will accomplish successful rehabilitation regarding ACLR, there may be information that is not presented.

Murray and Fleming (2013) analyzed the importance of anatomy and biology associated with the ACL and the safety of the of ACLR. The article also sets out to assess the different factors that impact the ACLR and subsequent recovery. This prospective paper analyzed 32 articles about ACLR and their applicability to both the biology associated with the ACL, factors impacting failure, and associated safety and complication concerns. The authors then summarize their findings and offer an opinion on the topic discussed.

Murray and Fleming (2013) discuss the clinical significance of an ACL injury. ACL injuries can have a significant impact on a patient's quality of life. ACL injuries are known as risk factors for post-traumatic osteoarthritis. Before current treatment gold standards of tendon grafts, surgeons used to attempt to repair the torn ACL. Native ligament reconstruction failed 90% of the time, and the reason for this is not fully understood. Despite tendon grafts replacing the ACL, patients continue to exhibit progressive articular cartilage and joint damage in the injured knee. A recent cohort study that was analyzed by this perspective paper showed that in up to 62% of patients that underwent ACLR showed evidence of post-traumatic arthritis 10-15 years post-surgery. Depending on the date of the initial injury, patients could begin showing signs of arthritis before age 30. Due to the risk of post-surgical osteoarthritis, researchers have been focusing on the biologic mechanism for the ACL healing process and what advancements make better long-term outcomes for patients. When comparing healing processes between ACL and MCL, both ligaments do have the collagen deposition and the ability to revascularize to facilitate healing. The embryologic observation made was that the provisional scaffold found in the wound site of the MCL. However, other extra-articular ligaments were missing in the ACL. The surrounding environment of the ACL (synovial fluid) makes it difficult for the two ends of the torn ACL to meet due to the lack of a structured scaffold. After identifying this as the primary mechanism for ACL repair failure, researchers set out to create a provisionary ACL scaffolding.

However, the scaffolding needed to stimulate the various cytokines needed to initiate the healing cascade for the ACL. Murray and Fleming (2013) discovered that platelets within plasma were excellent for stimulating the cytokines for collagen synthesis. This hypothesis was then tested in an animal model. When tested based on tensile load and strength, the yield load increased almost 100% from 200 ± 145N to 395 ± 110N (mean ± SD, $p < 0.03$), and the stiffness of the repair improved 60% from 50 ± 32 N/m to 83 ± 15 N/m (mean ± SD, $p < 0.02$), resulting in values that are nearly equivalent to that of a graft after ACLR when using a bio-enhanced scaffolding for ACLR. The thought then occurred about the changes that would likely take place in a skeletally immature animal. Murray and Fleming identified, with the data tested, was when skeletally immature animals utilized the bioenhanced ACLR, there was less long-term damage done to the joint and decreased the risk of post-surgical osteoarthritis.

A significant limitation of this study is that it is based on the opinion of the data that was already present to the researchers. Due to the data selected from the researchers, it gives the impression of author bias. Murray and Fleming (2013) lay out the paper in a very stepwise manner and illustrated the next steps; however, Murray and Fleming incorporated very little data into their opinion. Another significant drawback is that this proposal is extremely new, and the only data at the time of this paper was animal studies. While animal studies can replicate some similarities between humans, humans respond very differently to treatments than animals.

Recent data has shown that overall, patients have low rupture rates with modern ACLR (Van Der List, Jonkergouw, van Noort, Kerkhoffs, & DiFelice 2019). However, in the subset of patients with a proximal ACL tear, there may be specific criteria met that could predict whether a patient was a candidate for proximal ACLR. The goal of this retrospective control study conducted by Van Der List et al. was to assess which patients and injury characteristics are predictive of a repairable proximal tear. There were a total of 361 patients included in this study. All patients in the study were confirmed to have an ACL tear based on MRI imaging.

Intraoperatively, it was decided that they would undergo arthroscopic primary ACLR if a proximal tear was present in which the distal portion was long enough to be reattached to the femoral footprint. The tissue quality was good enough for sutures to be passed through and hold for reconstruction. If either of these conditions were not present, patients would undergo standard ACL reconstruction using bone-patellar tendon-bone, hamstring, or allograft. It was then registered if the patients underwent primary repair based on a proximal ligament or if patients underwent standard ACLR. Statistical analysis was performed using SPSS version 25.0 software.

A total of 361 patients were included in this study showing a median age of 28 years old. 59.8% of these patients were males. It identified throughout this study that the most common injury was during soccer (23% of injuries), and others spread reasonably evenly across other sports. However, 85% of the injuries that led to ACL tear were non-contact injuries. One hundred fifty-eight patients (44%) had proximal tears of the ACL that were eligible for arthroscopic reconstruction. The other 203 patients underwent traditional ACLR. Of those 203 patients, 57% underwent autograft (30% of these being hamstring tendon and 27% being patellar tendon), 42% soft tissue allograft, and 1% hybrid grafts. Of the patients that had repairable tears, most often were female patients ($p=0.023$), older (median age 35, $p<0.001$), and often underwent the repair within four weeks of the initial injury ($p<0.001$). Data showed that there was no significant difference for predictors of tear based on skiing vs. football/rugby injury and gender ($p=0.715$) (Van Der List et al. 2019).

There were limitations to the retrospective study conducted by Van Der List et al. (2019). One limitation is selection bias. The study specifically looked for patients with proximal tears and showed that those who had them were able to undergo arthroscopic repair. By selecting purely proximal tears, the impression of selection bias as though they were selecting these patients preferably as Van Der List et al. do not discuss the rate at which they were identifying proximal tears. Another limitation, as it pertains to this literature review, is that the study does not analyze outcomes based on the arthroscopy with the proximal tear vs. the typical ACLR. The distinction opens the possible participant pool to all forms of an ACL tear, not just proximal tears, and could improve the study.

Patellar Tendon Graft

The purpose of the study conducted by Erickson et al. (2015) was to determine how orthopedic surgeons approach ACLR in elite athletes in the NFL and NCAA Division I and how the approach would change based on elite, young, and middle-aged athletes. The study surveyed 267 orthopedic surgeons at the NFL and NCAA Division I level using an online survey that consisted of nine questions. The questions assessed the surgeon's experience level, graft choice, the drilling technique used to access the femoral tunnel, the graft bundle, and the rehab process following the ACLR.

Approximately 51% of the surgeons responded. The average experience of performing ACLR was 16.8 years and often performed anywhere from 10-250 ACLRs in a year. Of the responding surgeons, 99.3% chose autografts for their patients (athletes). Of the surgeons who chose the autografts, 86.1% states that they would choose the patellar tendon graft if they were operating on their starting running back. However, 49.6% of surgeons state that they would choose patellar tendon graft for 25-year-old recreational athletes, and 42.3% would use hamstring tendon for recreational athletes. Furthermore, 45.3% said they would prefer hamstring tendons in an older 35-year-old recreational athlete (Erickson et al. 2015).

There were limitations within the study conducted by Erickson et al. (2015). One is that the methods used was a survey sent to the surgeons conducting the repairs of the ACL. Using a survey limits the study to solely those that responded to the survey, leading to a potential selection bias not only with surgeon responses but the particular biases of those surgeons concerning the graft preference. Another limitation is the number of responses. Only 51% of the 267 responded to the survey.

The goal of the cohort study conducted by van Yperen, Reijman, van Es, Bierma-Zeinstra, and Meuffels (2018) was to determine the long-term effects of operative vs. non-operative management for an ACL rupture. Fifty participants were identified for this study and split into two groups. One of the groups underwent nonoperative management of the ACL rupture. The other group underwent patellar graft ACLR after failing three months of nonoperative management. Both groups were then followed-up at ten and 20-year intervals and evaluated for osteoarthritis in the affected knee, functional status of the knee, meniscus status, and knee stability.

Based on the objective international knee documentation committee (IKDC) score, 84% of the operative group had an average or near-normal score. The score is a significant increase to just 20% of the nonoperative group ($p<0.001$) (van Yperen et al. 2018). The pivot-shift test finding was negative in 68% of patients in the operative group compared to 13% for the nonoperative groups ($p<0.001$). Lachman's test was negative in 48% of the operative group compared to 4% in the nonoperative group ($p=0.002$) (van Yperen et al. 2018).

There are limitations to this study (van Yperen et al. 2018). The number of participants is one limitation. With a participant pool of 50 participants, it is hard to compare the author's statistically relevant data to the general population. Another limitation of this study is selection bias. The participants in this study were selected based on having the ACL reconstruction completed at the author's clinic, as well as having the nonoperative management completed at the clinic.

Hamstring Tendon Graft

The goal of the study conducted by Gupta et al. (2017) was to compare stability, functional outcome, and the level of return to sport in athletes that underwent ACLR with a free hamstring graft versus a graph that had preserved insertions. The study was a prospective, single-blind randomized trial. One hundred and ten professional athletes were identified as participants and randomly placed in two groups of 55 participants. Group one underwent ACL are with the hamstring tendon graft that had preserved insertions, and group two underwent the same only with a free hamstring tendon graft. Participants were then followed up with at three months, six months, one year, and two year intervals and assessed with several clinical tests. The tests included the activities of daily living function scale and sports function scale, also known as the Cincinnati knee score, knee arthrometer, and the Tegner activity scale. The same surgeon completed the operation for both groups. All participants underwent the same postoperative rehabilitation protocol that typically lasted around six months.

A total of 650 underwent ACLR during the timeframe studied, 110 met inclusion criteria. Groups were split, first being ACLR with hamstring tendon autograft with preserved insertion, group two was ACLR with free hamstring tendon autograft. Regarding Arthrometric (KT-1000) testing, tibial translation was significantly lower in group one patients at 24 months compared to group 2 ($p<0.0001$, 95% CI 0.51-1.23 mm). When using the Cincinnati knee score for activities of daily living (ADL) between the two groups, group one had significantly higher scores ($p<0.0001$, 95% CI, -17.32 to -6.08) (Gupta et al. 2017). Another metric that used was the Tegner activity scale. Group 1 had a statistically higher score both preoperatively and at 24 months follow up ($p=0.008$, 95% CI, -2.08 to -0.16) (Gupta et al. 2017).

There are limitations in this study (Gupta et al. 2017). One limitation is the number of participants included in the study. One hundred ten participants broken into two groups of 55 is challenging to apply the data to the general population. Another limitation of this study is that one surgeon completed all operations. The level of experience of this surgeon nor comfort level with either of these operations is discussed. There also could be perceived selection bias based on how comfortable the surgeon feels about the operation he has to perform on each patient.

Comparison of Hamstring vs. Patellar Tendon Graft

The goal of Heijne and Werner (2010) was to give preliminary evidence on the long-term outcomes as it relates to ACLR and patellar and hamstring graft materials. Between the years 1999 and 2005, 80 ACL injuries were identified that met this study's inclusion criteria. The inclusion criteria were patients whose age was between 16 and 50 years and a symptom-free contra-lateral knee. Patients with a medial or lateral meniscus tear or a medial collateral ligament injury where the surgical repair was not indicated, were also included. Twenty different surgeons performed the repairs for the participants. At the first post-rehabilitation session, patients were randomized into two groups using closed envelopes in order to create random blind groups without knowledge of graft type. All patients completed a standardized postoperative rehabilitation program before returning to sport. They were reevaluated at intervals of three, five, seven, nine months, one year, and two years. At these intervals, several different criteria were assessed. The criteria were anterior knee laxity, pivot shift, thigh muscle torques, one-leg hop, postural sway, anterior knee pain, knee injury osteoarthritis outcome score (KOOS), and Tegner activity scale.

When evaluating the results (Heijne & Werner 2010), there is a treatment effect when comparing graft choice of ACLR and laxity of affected joint ($p=0.04$). For the three, five, seven, nine-month follow-up, there was no statistical difference found when comparing the laxity of the joint and graft choice (hamstring vs. patellar). However, at the one year follow up, Heijne and Werner found laxity when comparing the unaffected knee and the affected knee. The patellar tendon showed an additional 1.3 mm of laxity (SD 0.4), and the hamstring graft showed an additional 2.4 mm (SD 0.3) of laxity (p=0.03). At the two years follow up 1.5 mm (SD 0.3), and 2.5 mm (SD 0.4) of laxity were noted respectively with the grafts noted (p=0.05).

Regarding the pivot shift, a statistically significant difference was noted between the patellar and hamstring tendon grafts in favor of the patellar tendon at all intervals except the nine months follow up. Concerning anterior knee pain, there was a statistical difference noted when it came to the two years follow up between the two grafts. It shows that, though the number of participants experiencing knee pain was the same (n=30), the degree of pain decreased with the patellar graft (p=0.04). There was no significant difference when it came to the risk of osteoarthritis and graft choice (p=n.s.), however, using the Tegner activity scale, there was an improvement in activity noted with the patellar tendon compared to the hamstring at the 1-year follow-up (p=0.01) (Heijne & Werner 2010).

One of the limitations of the study (Heijne & Werner 2010) was the number of participants. The study did an excellent job removing bias by creating randomized groups. However, the groups are small and may not be able to be applied to a larger population. Another limitation is the rehab process. Individualization of every rehab process is going to be applied to each athlete based on the anatomical weaknesses that could have contributed to the tear of the ligament.

One of the few large-scale studies conducted comparing graft failure rates was conducted by Laboute, James-Belin, Puig, and Verhaeghe (2018). The goal of this large cohort study was to determine the risk of graft failure in ACLR between a hamstring and patellar tendon autograft. Participants in this study were identified at the European Center for Sports Rehabilitation (ECSR) to have undergone either the patellar tendon or hamstring tendon autograft for their ACLR. In order to meet the eligibility criteria for this study, participants must have had a simple hamstring or patellar tendon autograft surgical technique performed for the surgical procedure. After participants were identified based on eligibility criteria, participants were then contacted by phone for a two-year follow-up. If participants were unable to be reached, they were "lost to follow-up." Four data sets were evaluated when participants were contacted. These data sets included repeat or contralateral ruptures, return to sport, and the timing of both of these.

There were a total number of 4,076 athletes screened at the European Center for Sports Rehabilitation. One thousand six hundred and fifty-two were removed due to inclusion criteria, and 2,424 remained eligible. Of these patients, 1,831 (75%) underwent hamstring autograft ACLR with the other 593 (25%) receiving patellar tendon graft. After removing the patients that did not respond to a follow-up phone call, researchers had 955 participants (713 hamstrings (75%); 242 patellar (25%)) (Laboute et al. 2018). Although there was a significant percentage of participants lost to follow-up, the ratio of patellar and hamstring tendons was maintained. Furthermore, there was a significant number of participants that were not lost to follow-up. Because of the substantial data still able to be collected, this translated to statistically significant data by the authors.

At baseline, there was no statistical difference between the analyzed and non-analyzed group. In terms of sex-based on surgery types, the distribution of participants was the same. Between the two groups, 51 graft failures were noted in total. Of those 51, 46 of the failures came from the hamstring group and five from the patellar group. The logistic regression completed showed that the hamstring group was significantly at more risk for graft failure than the patellar tendon group (OR =3.64, 95% CI(1.55;10.67) with p=0.007) (Laboute 2018). When the data was adjusted to include surgery type, age, sex into the regression model, they noted that there was a statistical significance when it came to type of surgery ($p=0.007$) showing that those with hamstring graft were at increased risk of rupture, and age of the patient ($p<0.001$). Concerning age, the authors identified that those that were under the age of 25 were at an increased risk for rupture ($p<0.001$) (Laboute et al. 2018).

There are limitations of the study that could have an impact on the data. One limitation is that participants were followed-up on with a phone call, and if the participants did not answer that first phone call, they were lost to follow-up (Laboute et al. 2018). Participants were limited to those who answered the phone call. Those that did not answer could impact the data. The second limitation was that Laboute et al. (2018) only evaluated athletes that underwent rehab at ECSR. Selection bias limits other athletes included in the study.

The goal of Mascarenhas, Tranovich, Kropf, Fu, and Harner (2012) was to assess the patient-reported outcomes concerning return to sports in athletes that are younger than the age of 25 following an ACLR with either patellar or hamstring tendon autographs. Participants in this study had a primary ACLR completed by one of two surgeons and had self-reported strenuous athletic activity were eligible for this study. Thirty-six patients with patellar tendon ACLR and 47 patients with hamstring ACLR met inclusion criteria. The researchers were utilizing a variety of questionnaires, including the international knee documentation committee (IKDC) subjective knee form, activities of daily living, and sport activity scales. Utilization of these questionnaires assessed the functional aspect postoperatively of the knee, and whether they were able to return to the high level of the sporting activity, they were before the injury. Researchers completed assessments of x-ray images in the patients for evaluation of the severity of post-operative osteoarthritis. Post-operative rehabilitation was identical for both groups and typically return to sport was achieved at around six months.

For this study, 36 patients with patellar tendon ACLR and 47 with hamstring tendons met clinical criteria. Patients that underwent hamstring ACLR reported significantly higher activities of daily living and sports activity scale scores ($p<0.01$) (Mascarenhas et al. 2012) when compared to patellar tendon ACLR. However, there were no statistical differences between groups of IKDC or SF-36 summary scores (p=n.s.). There were also no differences noted between groups in the number of patients that reported recurrent instability post-surgically. Furthermore, 74% of patellar tendon patients were able to return to strenuous sport activity, while only 70% of hamstring patients were able to do the same; however, p values were not statistically significant. On physical exam, hamstring ACLR was able to have more passive and active ROM with extension postoperatively compared to patellar ($P<0.05$).

There are limitations to the study conducted by Mascarenhas et al. (2012). One limitation is the nature of how the data was collected. Participants in this study self-reported the associated data that the study was collecting. While Mascarenhas et al. used questionnaires to attempt to make the data objective, there is subjective bias in participant's answers. Questionnaires should be associated clinically and not necessarily utilized without other data. Patients who were happy with their surgery could have given higher scores compared to those who were neutral or had poor feelings regarding their surgical outcomes. A second limitation of this study was the number of surgeons that were performing the operations. There is subconscious patient selection bias and preference when it comes to graph types as well as a bias regarding the level of experience with the surgeons, and how comfortable they feel with the procedure. A third limitation of this study is the number of participants studied. While statistically significant data was able to be obtained, due to the number of participants in the study, there may be some difficulty applying it to a larger population.

Allograft

The goal of this randomized control trial conducted by Bottoni et al. (2015) is to evaluate the long-term results of ACLR using allograft or hamstring autograft. There has been some controversy with the utilization of allographs for ACLR in young athletes, but there is little long-term evidence to support this. Between June of 2002 and August of 2003, patients with an ACL tear that was confirmed by MRI imaging were randomized to receive either a hamstring autograft or an allograft. The graph fixation technique was identical in all knees, and all participants in the study underwent the same postoperative rehabilitation, which was blinded by the physical therapists that were administering the protocol. Preoperative and postoperative assessments were completed via direct physical examination or telephone and internet-based questionnaires. Preoperative assessments were completed immediately before the surgical procedure. They were then assessed at 3, 14, and 30 days postoperatively and then monthly after that. The questionnaires assessed the functional and subjective status using various knee metrics. The measurements identified were graft integrity, subjective knee stability, and the functional status of the participant.

In this study, 100 knees underwent ACLR split evenly between allograft and autograft. The further assessment showed that concerning graft failure, there were 17 out of 100, 13 of which came from the allograft group (p=0.03). However, concerning overall stability, there was no statistically significant difference between graft types.

There are limitations to the study conducted by Bottoni et al. (2015). One limitation is that, although the patients were young and athletic, this was a military-based study. The majority of the participants were male as a result. Follow-up regarding their ACL reconstruction was difficult due to the frequency of participants transfer to a different military base or being discharged from the military. Another limitation was the number of participants in the study. There were only one hundred knees assessed in this study.

Following Bottoni et al. (2015), the goal of the retrospective case review study conducted by Lenehan, Payne, Askam, Grana, and Farrow (2015) was to determine whether the high reports of surgical revision or graft failure regarding allograft were truly as high as reported. The authors also set out to evaluate the long-term results in a cohort of patients. Between the years 2000 and 2008, patients that underwent allograft ACL reconstruction performed by two senior surgeons at the single institution were retrospectively reviewed. Preoperative patient demographics and additional knee sequela were also included and reviewed. Following the surgical procedure, post-operative complications following the ACL reconstruction were recorded. The complications included infection, graft rupture, and the need for repeat surgical revision. Participants were also clinically evaluated utilizing the IKDC assessment tool as well as the Tegner Lysholm activity scale.

Researchers contacted a total of 99 patients with allograft and 24 with autograft ACLR for follow-up. 17% of patients required additional surgery following the allograft ACLR. This rate was higher (by 30%) if patients were under the age of 25. However, the rate of revision of autograft was 4%. Age did not impact whether there was an increased risk with autograft (Lenehan et al. 2015).

There are limitations to the study conducted by Lenehan et al. (2015). One limitation is within the author's initial goal of the study. Lenehan et al. wanted to show that allograft was not as poor of a graft choice as is cited in other studies. Because of the study design, Lenehan et al. give the impression of selection bias. The second limitation of the study is the reporting of their results. Although Lenehan et al. did allow for long term data to be collected, they did not describe how data sets were analyzed, and P values were not recorded. While data that was collected is compelling and accurate regarding additional comparative allograft studies, we cannot accurately state whether the data is statistically significant.

Despite the limitations, the information collected by Lenehan et al. (2015) does support conclusions by Bottoni et al. (2015). Overall rates of operational revision and graft failure in allograft compared to autografts was high. Furthermore, Lenehan et al. did show that the rates of rupture and the need for revision were significantly higher in participants that were less than 25 years of age.

In conjunction with the previous two studies, Smith, Howell, and Hull (2011) add information to this literature review. The goal of the case series by Smith et al. was to determine whether the utilization of slippage resistant fixation with ACL graft would not increase anterior laxity and slippage clinically. Nineteen subjects were identified between June of 2007 and September of 2008 to meet inclusion criteria of a confirmed torn ACL, full range of motion at the time of the reconstruction, and no evidence of degenerative osteoarthritis based on x-ray images. These participants were treated for an ACL rupture with allograft fixation. All participants underwent the same surgical technique. An independent examiner, who was different from the treating surgeon, assessed the affected knees and determined whether there was an increase in laxity and slippage between the day of surgery and at monthly follow-up intervals with a max interval follow-up at 12 months and whether this determined the recovery of function in motion.

The total number of participants in this study was 19. There was anterior laxity noted in all subjects. However, laxity did not increase between the day of surgery and one year follow up. Total slippage was increased between the day of surgery and at one month ($p<0.05$). However, after four months, there was no increase in anterior slippage (Smith et al. 2011).

There are limitations to the study conducted by Smith et al. (2011). One limitation is that this study is a case series and is considered level 4 evidence. Another limitation is the number of participants included in the case series. Furthermore, follow up was discontinued at the 12-month interval. Based on current guidelines for rehab protocols for ACL reconstruction, patients were likely not eligible to return to sport until the six-month interval. While the study did find an increase in laxity with the allograft in long-term outcomes, as well as graft rupture, the need for revision was never followed up or recorded. While the primary goal of the study was to assess surgical technique with the allograft, it cannot be discounted that the graft choice itself may be the cause for increased laxity as researchers never compared allograft to other graft selections.

Bridge Enhanced ACL Repair (BEAR) Procedure and What Role This Could Play

Bridge-enhanced ACL repair is a new procedure currently in clinical trials. The first study discussed is Kiapour, Fleming, and Murray (2015). The goal of the study conducted by Kiapour et al. was twofold. The first was the determine whether sex affects the biomechanical outcomes of the BEAR procedure and if the suture type used in the ACL reconstruction can decrease the difference is in outcomes based on the gender of the subject. This particular study is a large animal preclinical study. The BEAR procedure is currently undergoing clinical trials and is not a standard of practice at any level.

Seventeen Yorkshire pigs, eight of which were male and nine of which being female, underwent bilateral ACL transection utilizing the BEAR procedure. One side of the ACL reconstruction used a nonabsorbable suture and the other being an absorbable suture. Each leg was randomized with each animal to remove a selection bias based on right or left ACL. Anterior-posterior knee laxity for each knee was measured after 15 weeks of healing. Mixed linear models were then used to compare the biomechanical outcomes with the two groups. Surgical procedures were the same for each group. The only notable difference was suture material. Once at 15 weeks, post-operative, anterior-posterior knee laxity values were measured at 30 degrees, 60 degrees, and 90 degrees of flexion. The knees were subjected to 12 sinusoidal cycles of anterior-posterior loads at each degree of knee flexion. Laxity was defined as the total femoral translation in the sagittal plane with respect to the tibia. Data was consolidated, and P values that were less than or equal to 0.05 were considered statistically significant. The results identified by the researchers are shown in figures one and two.

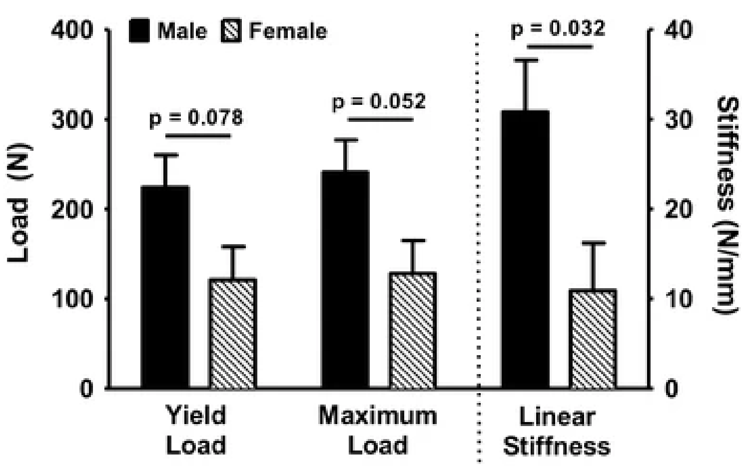

Figure 1. ACL structural properties for knees treated with bridge-enhanced ACL repair using absorbable suture compared between sexes after 15 weeks of healing.

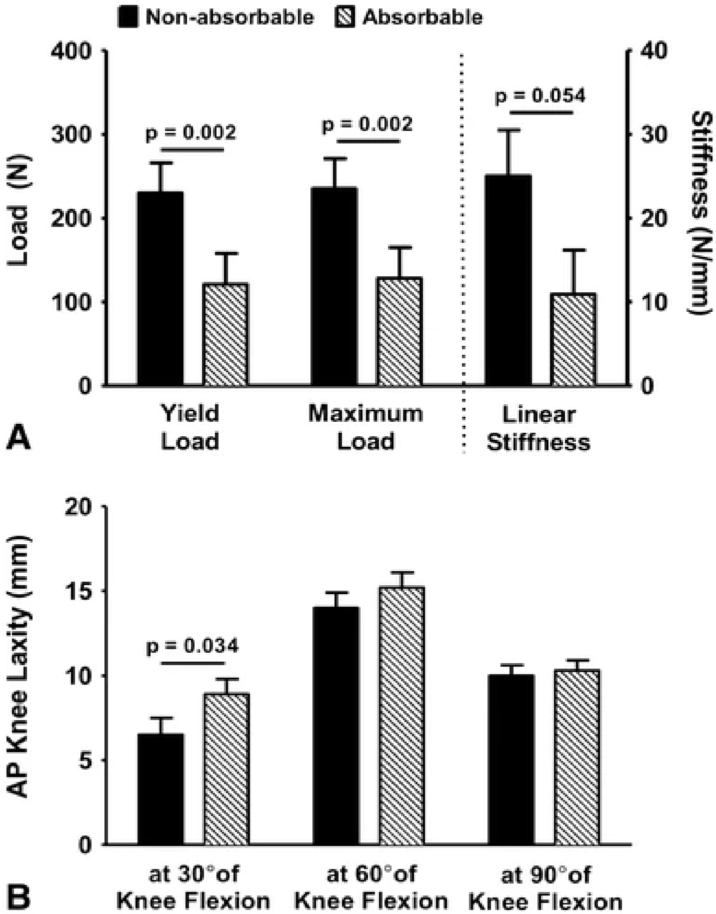

Figure 2. Biomechanical outcomes in female pig knees using absorbable suture compared with those treated with nonabsorbable suture concerning (A) ACL structural properties and (B) AP knee laxity after 15 weeks of healing.

The figures above illustrate that when treated with absorbable suture, females have a lower ACL linear stiffness and maximum load than males after 15 weeks of healing. Data illustrates that female knees treated with an absorbable suture compared to a nonabsorbable suture have a lower linear stiffness, ACL yield, and maximum load. A greater anterior-posterior knee laxity can be seen with both absorbable and nonabsorbable sutures (Kiapour et al. 2015). When repaired with a nonabsorbable suture, data illustrates no statistical difference between male and female knees.

The study conducted by Kiapour et al. (2015) is a preclinical animal control trial. A limitation of the study is the applicability to the human condition. Kiapour et al. did use pigs, which creates concern about its applicability to a human knee. The applicability is especially evident due to the rupture of ACL is typically secondary to weakness of the hamstring muscles, which cause an increase in anterior translation of the knee. The anterior translation may not be able to be seen within pigs. Another limitation was the number of pigs used in the study; however, there are limitations regarding resources concerning non-human studies.

Following Kiapour et al. (2015), the goal of the cohort study completed by Murray et al. (2016) was to assess the newly developed BEAR procedure. This study was used and designed to determine whether there was significant data to show a decreased rate of adverse reactions to the implantation of the scaffolding.

Murray et al. (2016) completed this study as the first in-human study completed with the BEAR procedure. A total of 20 patients enrolled in this study. The study was nonrandomized. Of the 20 patients, ten patients received the BEAR procedure, and the other ten received a hamstring autograft ACLR. The BEAR procedure was performed by placing the BEAR scaffold between the two torn ends of the ACL and sutured together. At this time, the BEAR scaffold is the only device that fills the gap and attaches the two torn ends of an ACL. Following suturing of the BEAR scaffolding, ten milliliters of the patient's whole blood was injected into the scaffolding before wound closure. Patients from both groups followed up on at an interval of three months postoperatively. At that time, participants were measured based on several data sets. These data sets included postoperative pain, muscle atrophy, loss of range of motion, and implant failure.

Twenty patients enrolled in this first-in-human study; ten received the BEAR procedure, and ten received hamstring autograft. When comparing the two groups, there were no joint infections or signs of significant inflammation with either group. There were no differences regarding knee effusion or pain of either group. Lachman tests were negative in both groups. MRI imaging modality from BEAR and ACLR both demonstrated an intact ACL or graft. However, hamstring strength at three months showed to be significantly higher in the group that underwent BEAR than the hamstring group ($p<0.001$) (Murray et al. 2016).

A limitation of Murray et al. (2016) is the number of participants in the study. Another limitation is that they compared it to a hamstring autograft. The data might change, especially regarding hamstring weakness if a patellar graft was used. However, the data provided was found to be statistically significant. The concern with suturing the two ends of an ACL together is the lack of healing capability of the ACL itself. The BEAR procedure allows the two ends of the ACL to heal while removing the risk of post-operative osteoarthritis

Discussion

All of the studies discussed offer tremendous value to this overall literature review. Regarding the rehabilitation of ACLR, Kyritis et al. (2016) were able to provide statistically relevant data. Kyritis et al. also illustrates the importance of proper rehabilitation and the effect it can have on the graft and rate of rupture. The data from Kyritis et al. can also be applied to the findings of Malempati et al. (2015). Malempati et al. were able to illustrate a comprehensive recommendation concerning the rehabilitation of an ACLR. Malempati et al. also note the differences in rehabilitation techniques based on graft material used. The study conducted by Murray and Fleming (2013) adds findings showing associated with risks when it comes to ACLR. Murray and Fleming identify that post-surgical osteoarthritis is associated with ACLR and is a significant drawback of surgery. Murray and Fleming also give reasonable background on ACLR. In conjunction with findings by Kyritis et al. and Malempati et al., Van Der List et al. (2019) assists with identifying patients that are eligible for ACLR and what patient populations may be more at risk. With information proposed regarding rehabilitation and risk, clinicians can assess both the biologic implications of an ACLR, as well as the role of rehabilitation from ACLR. Van Der List et al. also illustrate that the most commonly used autograft reconstruction was conducted with the hamstring tendon.

Concerning the patellar tendon graft, Erickson et al. (2015) illustrate that in high-level athletes that are near the age of 25, surgeons prefer to utilize patellar tendon. In conjunction with Erickson et al. and their findings, van Yperen et al. (2018) identifies that there was no significant increase in the risks of osteoarthritis when comparing nonoperative management to operative management. The study also shows that compared to nonoperative management, operative management with patellar tendon ACLR did show increase stability in the knee long term.

Hamstring tendons are also a viable autograft option for athletes. Gupta et al. (2017) add additional findings to this literature review. Gupta et al. findings are considered level one evidence due to the evidence being found with the utilization of a randomized control trial. Gupta et al. also illustrates that, despite producing statistically relevant data, authors identify that the data does not translate into clinically significant differences. Without clinical significance, this may show that different ACL tears are not clinically different in their repair and return to sport.

When comparing both hamstring and patellar tendon grafts, Heijne and Werner (2010) were able to produce statistically significant data. Heijne and Werner illustrated that the patellar tendon overall had more stability with follow-up, both concerning anterior laxity and pivot shift when compared to the hamstring tendon. In conjunction with their findings, Laboute et al. (2018)

were also to contribute extensively to this literature review. Laboute et al. is one of the few extensive studies that directly applies only graft type when looking at athletes and directly compares hamstring and patellar tendon graft types. While Mascarenhas et al. (2012) is level three evidence based on their study being a therapeutic case-control study, Mascarenhas et al. do contribute to this literature review. Seemingly counter to findings by Heijne and Werner, Mascarenhas et al. identify that patients reported less range of motion stiffness and greater preservation of extension. Mascarenhas et al. also were able to illustrate that hamstring tendon grafts show less radiographic evidence of osteoarthritis.

Bottoni et al. (2015) contribute extensively to this literature review regarding allograft ACLR. Bottoni et al. identify significant data illustrating that athletes or young athletic individuals who underwent allograft ACLR are three times more likely to suffer rupture or reinjury that ultimately requires a surgical revision of the graft. Bottoni et al. state that, based on this data, allograft should not be considered as a surgical option for young athletes. The findings by Smith et al. (2011) illustrate the allograft being a poor surgical option by identifying increased anterior slippage in laxity with the allograft. However, Smith et al. attribute this to the surgical technique.

The BEAR procedure does show some promise. Kiapour et al. (2015) conducted the first non-human study that does contribute extensively to this literature review. Kiapour et al. highlight the role of gender when it comes to the biomechanical outcomes of BEAR and identifies some of the mechanisms that are responsible for the discrepancy between male and female knees. This discrepancy could lead to a more specialized and individualized rehabilitation strategy when it comes to male versus female to increase better outcomes in women. In the first human clinical trial of BEAR conducted by Murray et al. (2016), the authors illustrate that overall there were no significant differences between a hamstring autograft and the new BEAR procedure. However, Murray et al. do show that the BEAR procedure preserved hamstring strength. Furthermore, Murray et al. illustrate that if the two ends of an ACL could be scaffolded together and prompt spontaneous healing, it would remove the risk for post-operative osteoarthritis at the 10-year mark. The BEAR procedure had similar early outcomes but also decreased the risk for post-operative osteoarthritis.

Through the course of this literature review, the choice of graft material is shown to be a highly individualized process, and several variables must be considered. Along with the decisions that aid in graft choice, clinicians must consider the variables that could lead to rupture. In reviewing rehabilitation techniques, Kyritis et al. (2016) show the importance of completing a comprehensive rehabilitation regimen following the surgical repair of the ACL. Kyritis et al. found that those who did not complete their physical therapy regimen and discharged from treatment were at four times greater risk of rupture.

Furthermore, Malempati et al. (2015) illustrated that graft selection does have an impact on the rehabilitation process. For example, a patient who undergoes hamstring tendon graft repair would expect to show increased hamstring weakness post-surgery. Murray and Fleming (2013) illustrated that those who undergo an ACLR with a graft are at an increased risk for post-traumatic osteoarthritis after about 10-15 years. However, the BEAR procedure shows that with the creation of scaffolding for ACLR, the risk of arthritis could be eliminated. Murray et al. (2016) illustrated that the strength outcomes were similar to that of the hamstring tendon. This strength retention shows that scaffolding utilization could eliminate the risk of arthritis with similar structural outcomes as current grafts.

When it comes to comparing various grafts, one of the few extensive cohorts studies conducted was by Laboute et al. (2018). The authors found that participants who underwent hamstring tendon graft were at an increased for rupture when compared to the patellar tendon. Furthermore, Laboute et al. also found that patients who were under the age of 25 were at an increased risk for rupture regardless of graft. Heijne et al. (2010), although a smaller study, also complements Laboute et al., showing more stability of the patellar tendon graft compared to the hamstring graft one-year post-surgically. Decreased stability could place the knee at an increased risk for re-injury to the ACL, but this is speculation and not confirmed by data in this literature review. In the study conducted by Erickson et al. (2015), a survey of orthopedic surgeons seems to confirm this practice as they stated that they would likely utilize a patellar tendon in elite NFL and NCAA athletes and a patellar tendon graft in recreational athletes near the age of 25. This selection could be due to the increased risk of rupture below the age of 25, shown by Laboute et al., but again this is speculation. When assessing the risk of rupture in young athletes with allograft, Bottoni et al. illustrated that athletes who underwent ACLR with allograft were three times more likely to suffer rupture or reinjury needing surgical revision when compared with the hamstring autograft. Because of this, Bottoni et al. (2015) recommended that allografts not be considered a surgical graft option for young athletes. This recommendation is supported by Lenehan et al. (2015). These authors showed in a retrospective case review that the overall rates of revision and graft failure were higher with allografts compared to autografts.

When assessing the core question of what graft increases the risk of rupture or reinjury in young athletes, the literature shows that athletes near the age of 25 or younger are at an increased risk for rupture. Literature also shows that the hamstring tendon graft does have a higher rate of rupture compared to the patellar tendon graft, as well as a slight decrease in stability. Based on the literature, allografts should not be considered in young athletes as they have a higher rate of rupture and reinjury than hamstring grafts. Along with graft choice, rehabilitation is a critical component to the overall risk of rupture, and rehabilitation does need to be tailored based on graft choice. Failure to complete a rehabilitation program leads to an increased risk of rupture. However, with the recent clinical trials of the BEAR procedure, post-traumatic arthritis at 10-15 years could be eliminated through the use of a scaffolding and the surgical procedure itself.

Applicability to Clinical Practice

Rural primary care providers frequently serve as the initial provider assessing knee pain and making the diagnosis of an ACL injury. While orthopedic specialists handle the surgical intervention for this injury, rural primary care providers (PCPs) assess the patient pre and post-operatively along with the surgical team. A significant component of primary care is patient education. Clinicians in primary care who have an in-depth understanding of not only the procedure for ACL repair but the knowledge regarding potential graft materials can assist with both patient education of the procedure as well as setting realistic goals and the timeline for return to sport. A risk assessment by a PCP can also be made with the knowledge of graft failure rates and the age of the patient. After completing this risk stratification, proper referral for surgical intervention can be made that would be in the best interest of the patient. Risks, including long-term arthritis, can also be discussed with the patient before surgical intervention. Having this knowledge would allow a primary care provider to serve a patient population better and integrate it into practice, especially in the rural setting.

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