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Chapter 12

THE ROLE OF LIGAMENT REPAIR IN ANTERIOR CRUCIATE LIGAMENT SURGERY

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INTRODUCTION

In 1903 Mayo Robson described the first case of treatment of ACL deficiency [1]. In a 41-year old man he found that “both cruciate ligaments were found completely ruptured, being torn from their upper attachments” and he stitched both ligaments onto the femoral wall using catgut ligatures. At six-year follow-up, he reported that the patient had a stable knee and resolution of pain symptoms.

Over the ensuing decades of the twentieth century, open primary ACL repair was further popularized by Ivar Palmer in the 30s and 40s [2] and Don O’Donoghue in the 50s and 60s [3, 4]. The technique was frequently used throughout the second part of the twentieth century. Although the initial results of open primary repair were satisfying, several authors reported inconsistent midterm results [5-8]. In a frequently quoted ACL repair paper, Feagin and Curl reported an instability rate of 94% and a re-rupture rate of 53% [8, 9] of 32 patients at five-year follow-up. Years later, in a long-term follow-up study, Kaplan et al. stated that, “although … primary repair of the anterior cruciate may work in some patients, it is an unpredictable operative procedure” [7]. The unpredictable and inconsistent results led to the abandonment of the repair approach to ACL injuries, and the worldwide attention of surgeons shifted towards ACL reconstruction in the 80s and 90s.

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It is ironic that what was widely considered the landmark paper on ACL repair, and one that provided a possible explanation for these unpredictable results, was also one of the last papers to be written on the subject because the procedure was abandoned. In 1991, Sherman et al., reported their midterm results of open primary repair in 50 patients and uniquely performed an extensive subgroup analysis [9]. In this analysis they found that some groups showed better results, and suggested that primary ACL repair might be more effective in certain subsets of patients. They noted that better outcomes were correlated with proximal (or type 1) tears and good to excellent tissue quality. Several other studies also reported that better results might be found in proximal tears [10-13]. It seemed that Sherman’s group was onto something, because another paper was published a few years later, in 1993, by Genelin et al., reporting their outcomes of open primary repair in 49 patients with only proximal ACL tears [14]. They reported significantly better results, at five- to seven-year follow-up, when compared to the aforementioned studies. However, despite better results noted in proximal tears, the ACL repair technique was largely abandoned, while ACL reconstruction became the gold standard for all patients.

By reviewing the historical studies through a modern day lens, several factors can be identified that likely contributed to the inconsistent results of primary repair. First, as noted by Sherman et al., performing ACL repair in all types of tears (e.g., mid-substance tears, poor tissue quality) likely leads to deterioration of outcomes. Second, performing open primary repair via arthrotomy was a terribly morbid procedure when compared to modern day arthroscopic surgical approaches. It is very likely that the invasive nature of the surgery also significantly contributed to suboptimal results [15]. This was also noted by Strand et al., in his long-term follow-up ACL repair paper, who opined, “…if the same results could be accomplished by a smaller, arthroscopic procedure, primary repair might reduce the number of patients needing later reconstructions with small ‘costs’ in the way of risk and inconvenience for the patients” [16]. Third, and finally, the historic postoperative treatment regimens generally consisted of post-operative casting for six weeks [17]. It is well known that immobilizing the knee joint for a prolonged period is associated with less optimal outcomes [18]. Genelin et al., noted in their study, “we believe that, even with the same operational technique, the results can be improved still further by early postoperative treatment with a continuous passive motion (CPM) machine, combined with a brace providing limited knee joint motion” [14].

Bearing these factors in mind, it is not surprising that a recent case series of arthroscopic repair of proximal ACL lesions with early postoperative range of motion (ROM) resulted in excellent results [19]. With a focus of improving on history, and not repeating it, the rest of this chapter will look at the application of the reinvigorated concept of ACL repair. First, we will discuss patient selection for arthroscopic ACL repair, which we have learned is critical for successful outcomes. Next, the surgical technique will be presented, along with the clinical results of arthroscopic ACL repair to date. Two illustrative case examples from the clinic of the senior author will then be presented. Finally, we will discuss the application of this technique, and the future directions of ACL repair.
The Role of Ligament Repair in Anterior Cruciate Ligament Surgery

PATIENT SELECTION

As discussed above, several historical articles and experiences have taught us that patient selection is critical for primary arthroscopic ACL repair to be successful. These criteria include the location of the tear, the tissue quality and timing of surgery.

ACL Tear Type and Tissue Quality

ACL tears are frequently divided into proximal bony avulsions, proximal tears, midsubstance tears, distal tears and tibial bony avulsions [9, 10]. Bony avulsion type lesions remain out of the scope of this chapter, but these avulsion lesions can either occur at the femoral side or at the tibial side, which is more common in children, and can be treated by suture fixation [20, 21], among other methods. Of all soft tissue lesions, midsubstance tears are reportedly the most common [22, 23]. Since resection of the ACL remnant, and reconstruction of the ACL is the worldwide standard these days, and the location of the tears is not relevant to the success of reconstruction, tear type is currently not reported much in the recent literature. However, using the experience of the senior author, and historical literature, potentially reparable proximal soft tissue ACL tears are estimated to occur in approximately 10 to 20% of all ACL tears depending on practice mix [5, 24, 25].

MRI is an excellent tool to assess ACL tears (Figure 1) with 93% to 100% sensitivity and 93% to 97% specificity for ACL lesions [26-28]. Although a fairly accurate estimation of the tear location can be made on MRI, direct visualization and probing of the remnant during arthroscopy is critical in making the final assessment on the location of the tear. In the senior authors experience, arthroscopy is invaluable in assessing the ACL remnant because there are times when the tissues look better than the MRI suggests, and there are times when the tissues look worse. The ACL remnant is often scarred to the posterior cruciate ligament (PCL) and what appears to be too short for repair at first examination, will oftentimes be of sufficient length for repair after the ligament remnant is dissected of the PCL.

As already identified by Sherman et al. [9], tissue quality is critically important to the success of primary ACL repair. MRI can, similarly to tear location, give a rough estimation of the tissue quality, but arthroscopy is definitely needed to make a final assessment on tissue quality. Assessment should include the entirety of the ligament remnant since there can be multiple tears, differential tearing of individual bundles and tissue quality can have complex patterns depending on the injury [10].

Timing

Traditionally, primary ACL repair is performed in the acute setting. It is believed that performing surgery in the acute setting is correlated with better tissue quality and prevents retraction of the ligament [3, 4, 29, 30]. O'Donoghue stated in his studies that, “I am convinced that early repair is a sine qua non for consistently good results” and that, “All of
the patients might well have been divided into two groups only, early repair and late repair – a 
division which would show even more dramatically the advantage of early repair” [4].

In the case series of arthroscopic proximal ACL tear repair by DiFelice et al., surgeries 
were performed after a mean of 39 days from injury, with a range of 10 to 93 days [19]. The 
results in this series show that good results also can be expected in the subacute phase and 
indicate that proximal tear location and tissue quality could potentially be more important 
than time since injury. It should be noted that, in those patients from that series with longer 
delays, the ACL remnant was uniformly scarred to the PCL that appeared to provide blood 
supply and prevent retraction [31-33]. Further, in the senior authors overall series, that now 
numbers 55 patients, delay to surgery ranged from four days to 11 years post injury. 
Nonetheless, it is intuitive that a correlation between the time to repair and tissue quality 
exists, and it is therefore generally advised to perform ACL repair within the first three weeks 
if possible [3, 30].

**Patient Demographics**

In the experience of the senior author, patients of all ages and activity level can be treated 
with arthroscopic primary repair. Initially, arthroscopic primary ACL repair was performed in 
patients who were not motivated to undergo ACL reconstruction, or did not have high 
postoperative demands. However, after early successes the procedure was performed on 
multiple younger athletes with astonishing results (see Case 1), and thus, the indications for 
patient age and activity level have been broadened significantly. The series of the senior 
author now includes patients ranging in age from six years to 57 years old, with excellent 
results in all demographics. In fact, with continued success using the arthroscopic repair 
procedure, the indications currently rely more heavily on the MRI appearance of the tear, than 
on the acuity of repair.

![Sagittal MRI cut showing proximal, avulsion type ACL tear.](image)
Interestingly, several studies have shown that the incidence of a proximal lesion is higher among skiers when compared to pivoting sports such as basketball and soccer, and that the injury is more often reported to be an isolated injury with a skiing mechanism of injury [9, 10, 34-36]. These findings have been attributed to a different injury mechanism during skiing (i.e., hyperflexion injury or hyperextension in combination with external tibial rotation and valgus load), and the fact that the lower leg is fixed in a boot [37, 38]. This higher prevalence of a proximal, isolated tear among skiers is important to keep in mind since there seems to be an increased likelihood for a successful ACL repair when the injury occurred during skiing [39].

Pediatric Patients

A special group of patients that could benefit from primary ACL repair is the skeletally immature patient (i.e., with open physes). In this population conservative treatment of ACL tears is associated with a 12-times higher risk of meniscal tears [40], while ACL reconstruction can cause premature closure of the epiphysis [41, 42]. A recent meta-analysis of ACL treatment in skeletally immature patients showed that premature closure occurred in 0 of 69 (0%) of patients treated with primary repair and in 18 of 706 (2.5%) of patients with autologous ACL reconstruction, while re-rupture following primary repair occurred in 2 of 69 (2.9%) patients and following autologous reconstruction in 26 of 706 (3.7%) patients [42]. Furthermore, preclinical studies have shown that repairing the ACL in skeletally immature animals showed better results than in adult animals with regard to structural properties, including better restoration of kinematics [43] and also histological advantages, including a greater number of capillaries in the ACL and more fibroblast activity [44, 45]. These studies indicate that ACL repair might be a good treatment option in skeletally immature patients, but further research is needed in this population. Certainly, arthroscopic ACL primary repair has all of the proper attributes of a procedure that should be applicable to children, that is: it is minimally morbid, it is a tissue sparing approach, it is effective, and it is a conservative approach that does not burn any surgical bridges and has a straightforward reconstructive solution if it happens to fail.

Figure 2. Arthroscopic view of a left knee is shown, with the scope in the lateral portal and the knee at 90° flexion, of a malleable Passport cannula in the medial working portal.
### Surgical Steps for Primary ACL Repair

#### Preparation
- Standard supine position in knee arthroscopy
- Assess location of tear with a probe

#### Suturing
- Alternating, interlocking Bunnel-type sutures
- From distal to proximal
- First anteromedial bundle, then posterolateral
- End with final pass towards femoral wall
- Induce bleeding of femoral footprint

#### Suture Anchors
- Knee in 90° flexion
- Create 4.5 x 20 mm hole in AM bundle origin
- Deploy suture anchor while tensioning remnant
- Repeat for PL bundle
- Cut sutures to be flush with the wall

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Figure 3A. Arthroscopic view of a left knee is shown, with the scope in the lateral portal and the knee at 90° flexion, of a suspected proximal avulsion type ACL tear. Note the normal appearance of the ligament.

Figure 3B. Arthroscopic view of a left knee is shown, with the scope in the lateral portal and the knee at 90° flexion, of probing the ACL fibres to confirm the proximal detachment.
**SURGICAL TECHNIQUE**

**Preparation**

The patient is placed in supine position with the operative leg prepped and draped as for standard knee arthroscopy. Equipment and implants from both standard knee arthroscopy and shoulder arthroscopy set are utilized. Anteromedial and anterolateral portals are created and a general inspection of the knee joint is performed. The ligamentum mucosum and small amount of the fat pad are excised to improve visualization. A malleable Passport cannula (Arthrex, Naples, FL, USA) is placed in the anteromedial portal to facilitate suture passage, management and repair of the ACL (Figure 2). The ligament is initially visualized to evaluate the tear type (Figure 3A). Then, using a probe, the ligament is closely inspected for location of the tear and quality of the remnant tissue (Figure 3B). A decision on the possibility of repair is now made.

**Suturing the Ligament**

When the ligament is deemed suitable for repair, the anteromedial and posterolateral bundles of ACL are identified. The sutures are first passed through the anteromedial bundle using the Scorpion Suture Passer (Arthrex, Naples, FL, USA) with a #2 FiberWire suture (Arthrex, Naples, FL, USA, USA) (Figure 4). Suturing is started at the intact distal end of the anteromedial bundle and is advanced in an alternating, interlocking Bunnell-type pattern, towards the avulsed proximal end. In general, three to four passes can be made before the final pass exits out of the avulsed end of the ligament towards the femur. A stab incision is then made just above the medial portal and the anteromedial repair stitches are retrieved to keep them out of harms’ way. Traction on these sutures can control the remnant somewhat and facilitate passage of the next set of repair stitches. The same process is repeated for the posterolateral bundle of the ACL remnant with a #2 TigerWire suture (Arthrex, Naples, FL, USA) (Figure 5). Great care should be taken to not transect the previously passed suture. When greater resistance is experienced on an attempted pass, the suture-passing device should be repositioned. The TigerWire sutures are then also retrieved out the parking portal, which ensures good visibility of the femoral footprint. By placing traction on both sets of repair stitches, the ACL remnant can be retracted medially (Figure 5). At this point, a small opening anterior notchplasty is now performed with a shaver to improve visualization and provide some extra bleeding to maximize the postoperative healing environment.
Figure 4. Arthroscopic view of a left knee is shown, with the scope in the lateral portal and the knee at 90° flexion, of the first passage of the FiberWire suture through the anteromedial bundle fibres using the Scorpion Suture Passer.

Figure 5. Arthroscopic view of a left knee is shown, with the scope in the lateral portal and the knee at 90° flexion, of the ACL with both repair stitches in place in the respective bundles. Note that the ACL can be retracted medially with traction on the repair stitches, to allow work, on the femur if necessary.

Suture Fixation

With the knee flexed at 90°, an accessory inferomedial portal is made using a spinal needle for localization, followed by a stab incision and dilation with a blunt trocar. The angle of attack of this portal should allow easy access to the femoral footprint of the ACL origin. Then, with the knee in 90° flexion, a 4.5 x 20 mm hole is drilled, punched or tapped (in case of high bone density), into the origin of the anteromedial bundle within the femoral footprint. The FiberWire sutures are then retrieved through the accessory inferomedial portal and passed through the eyelet of a 4.75 mm Vented BioComposite SwiveLock suture anchor (Arthrex, Naples, FL, USA). The first suture anchor is then deployed into the femur towards the anteromedial origin while tensioning the ACL remnant to the wall with a visual gap of <1 mm (Figure 6). This procedure is then repeated for the posterolateral bundle with the TigerWire repair stitches with the knee at 110 to 115° of flexion (Figure 7). This ensures an optimal angle of approach and avoids perforation of the posterior condyle with the anchor. The drill hole and anchor are placed into the origin of the posterolateral bundle fibres within the femoral footprint.
The Role of Ligament Repair in Anterior Cruciate Ligament Surgery

Figure 6. Arthroscopic view of a left knee is shown, with the scope in the lateral portal and the knee at 90° flexion, of the passage of the first BioComposite 4.75mm vented SwiveLock suture anchor.

Figure 7. Arthroscopic view of a left knee is shown, with the scope in the lateral portal and the knee at 90° flexion, of passage of the second suture anchor.

Once the anchors are fully deployed and flush with the femoral footprint, the handle is removed, the core stitches are unloaded and the free ends of the repair sutures are cut with an Open Ended Suture Cutter (Arthrex, Naples, FL, USA) so that they are flush with the wall. Now the repair is complete (Figure 8). The ACL remnant is tested for tension and stiffness using a probe. Finally, range of motion (ROM) is assessed and anatomic positioning should be visualized without graft impingement. Intraoperative manual laxity testing should reveal minimal anteroposterior translation with a firm endpoint using Lachman examination.

Figure 8. Arthroscopic view of a left knee is shown, with the scope in the lateral portal and the knee at 90° flexion, of the ACL after having undergone arthroscopic primary suture anchor ACL repair.
It should be noted that an Internal Brace modification to this procedure has been in use by the senior author for several years. In the modified version of this procedure, the anteromedial anchor is loaded with a Fibertape, or Tigertape, in addition to the repair stitches. After both anchors are placed, an ACL guide is used to drill a drill pin up through the tibia from the anteromedial cortex and into the anterior half of the ACL tibial insertion (Figure 9). This is then switched for a Straight Microsuture Lasso (Arthrex, Naples, FL, USA) (Figure 10), and the nitinol wire is retrieved out the anteromedial portal with the two ends of the tape. The tape is then shuttled along the ACL substance and down through the tibia where it fixed with a vented 4.75 BioComposite SwiveLock after cycling the knee and tensioning the Internal Brace near full extension (Figure 11). A reinforcement stitch like this one, used in the anterior half of the repaired ligament, has been shown in several studies to improve both biomechanics and histology of the healing ligament [46, 47].
The Role of Ligament Repair in Anterior Cruciate Ligament Surgery

Rehabilitation Protocol

The main goals of rehabilitation are controlling edema and obtaining early ROM. A brace is worn for the first four weeks along with weight bearing as tolerated. Initially, the brace is locked in extension until volitional quadriceps control returned and then the brace is unlocked for ambulation. ROM exercises are initiated in the first few days after surgery in a controlled fashion but formal physical therapy does not necessarily commence until after one month. Four to six weeks postoperatively, the patient is advanced to gentle strengthening and a standard ACL rehabilitation protocol is begun. Recovery in primary ACL repair patients is often dramatically quicker than with reconstruction and it is not uncommon for patients to take narcotic pain medications for only a few days postoperatively, if at all.

CASE EXAMPLES

Case 1: A 17-year old male rugby player was a junior playing for his high school team, when he suffered a lateral hit to the knee resulting in an ACL injury with a medial collateral ligament (MCL) injury. Twenty days after the injury he presented for a second opinion. He was scheduled for ACL reconstruction a few days later with another surgeon. He had been locked in extension in a brace until that point. On examination, the knee was stiff and sore with only 80° ROM. Stability examination was limited due to splinting. MRI revealed a proximal ACL tear, and a proximal MCL injury (Figure 12A). He was subsequently allowed to range the knee in therapy and within two weeks he had regained his ROM and was scheduled for examination under anesthesia, with possible ACL repair versus reconstruction, depending on the intraoperative findings. Stability examination under anesthesia one week later (six weeks post-injury) revealed full ROM with a grade 2 Lachman, 1+ pivot shift, and 1+ opening to valgus stress at 30° flexion. He underwent arthroscopic suture anchor ACL repair, as described above, without complications (Figures 12B-D)). After the repair, the intraoperative Lachman test was negative, and he was placed in a brace locked in extension.
Figure 12A. Sagittal MRI image showing proximal ACL tear.

Figure 12B. Arthroscopic view of a right knee is shown, with the scope in the lateral portal and the knee at 90° flexion, of the first TigerWire repair stitch in place in the anteromedial bundle.

Figure 12C. Arthroscopic view of a right knee is shown, with the scope in the lateral portal and the knee at 90° flexion, of the initial suture anchor placement.
At 3 day follow-up, the patient was off narcotic pain medications, had 80° ROM, and a stable ligamentous examination. At 1 month follow-up, the patient had full ROM and continued to have stable ligamentous examination. At 2 months follow-up the patient was running and lifting, on his own volition, to prepare for his upcoming American Football season. He was to be a senior and had been elected captain of the team the year prior. At 3 months follow-up, the patient continued to have a benign examination, isokinetic testing revealed that the operative leg was stronger than the non-operative leg, and single-leg hop testing was normal. After a careful discussion with him and his parents, they elected to accept the risk of reinjury and play the football season at the positions of fullback and linebacker. He was fitted for a functional knee brace and practices began that week.

He played the entire season without reinjury and the team won the City Championships that year. He continued to compete, and also played in his senior year Rugby season without incident. Two years post-operatively, he was re-evaluated for inclusion in the recently published case series [19]. At that time, the Lysholm, modified Cincinnati and Single Assessment Numeric Evaluation (SANE) scores were all 100/100, the IKDC objective score was A, and KT-1000 side to side difference on maximum manual pull was 1 mm. At 3 years post-operatively, while playing Rugby, he suffered another lateral blow to the knee and presented for evaluation. At this time, he was noted to have a grade 1-2 MCL injury while the repaired ACL was still intact. Conservative treatment returned to him to full activities and he continues to do well to this day over 4 years post-operatively.

**Senior Author’s Comment**

Many surgeons express to me that ACL repair may be appropriate for older, lower demand athletes, but not young contact athletes. This case is one, of many, that seem to argue differently. Tear pattern and tissue quality found at surgery made it possible, and appropriate, to perform a primary repair, and this was the only option that could have gotten him back to play his senior year football season 3 months later. Although playing so soon after surgery was somewhat risky, I let the patient and his parents make the call. I did everything I could to ensure that his knee was both strong and stable, but ultimately he decided to take the risk and play. It is intriguing to remember that if he had reinjured his repaired ligament, the salvage
surgery would have been the primary reconstruction that he would have undergone in the first place. Although some time may be lost, and a second surgery must be endured if failure of a repair were to occur, no surgical bridges are burned by performing ACL primary repair and this may change the risk to benefit analysis of what type of surgery to perform on in-season athletes who have a proximal ACL tear.

In addition, this case brings up another interesting discussion point. All historical data suggests that any attempt at primary repair should be done acutely, within the first several weeks after injury in optimum circumstances [3, 4, 29, 30]. This patient underwent ACL repair six weeks after injury and did very well. I have many examples of primary repair patients that were successfully repaired in the subacute and even chronic settings. This has led me to the belief that it is not the acuity, but the tear type and tissue quality that ultimately dictate whether someone can undergo a successful primary ACL repair.

**Case 2:** A 42-year old male snowboarder presented for a second opinion three weeks post-injury. He was an avid, extreme snowboarder and felt a pop after crashing a 20-foot cliff jump. He was unable to continue snowboarding, and eventual work-up revealed an ACL tear. He was seen by an outside physician who ordered physical therapy, of which he had completed three sessions, and scheduled him for ACL reconstruction. He had no prior history of issues or injuries with this knee. At initial evaluation, most of the swelling was resolved and physical examination revealed full ROM with a grade 2 Lachman test, and 1+ pivot shift test, in an otherwise stable knee. Radiographs were negative for fracture and the MRI showed a proximal ACL tear (Figure 13A). He was felt to be a good candidate for repair and was set up for expedient surgery. At four weeks post-injury, he underwent an arthroscopic suture anchor ACL primary repair as described above without complications (Figures 13B-D). After the procedure, intraoperative Lachman examination was negative. He was placed in a post-operative brace locked in extension.

![Figure 13A. Sagittal MRI image showing proximal ACL tear.](image)
Figure 13B. Arthroscopic view of a right knee is shown, with the scope in the lateral portal and the knee at 90° flexion, of the proximal fibres of the ACL being retracted away from the femur with an elevator, to confirm the proximal avulsion type tear.

Figure 13C. Arthroscopic view of a right knee is shown, with the scope in the lateral portal and the knee at 90° flexion, of the first TigerWire repair stitch in place in the anteromedial bundle.

Figure 13D. Arthroscopic view of a right knee is shown, with the scope in the lateral portal and the knee at 90° flexion, of the final view of the repaired ACL.
At 3 day follow-up, the patient was off of all narcotic pain medications, ROM was 0 to 90° flexion and Lachman test was negative. He did not show up for another visit until 2 ½ months post-operatively because the knee felt so good. At that time, full ROM and a completely stable knee were seen, and the patient was back to working out in the gym on his own without complaints. He presented again for a 5 month follow-up visit and reported he had a great summer biking and working out, and that he had not thought about his knee once. He was back to full activities for several months and rated his knee a 100/100 SANE score. In fact, he had just completed a 50 mile bike tour the previous weekend, through hilly terrain, with absolutely no swelling or pain.

At 1 year post-operatively, the patient returned for follow-up and continued to do well. He stated that he had a great snowboarding season and was at the same level as the year prior without thinking about his knee at all. In fact, he stated that the operative leg felt better than the other side. Examination showed full ROM with negative Lachman and pivot shift examinations. Lysholm, modified Cincinnati, SANE, and IKDC subjective and objective scores were all perfect.

Senior Author’s Comment

This patient is pretty much the perfect candidate to undergo this procedure: he had an alpine injury mechanism which has been shown to be associated with proximal ACL tears; he presented fairly expeditiously after his injury for evaluation; and he was an extremely active individual, who had a complicated life to get back to such that he could ill afford to have the extended recuperation and rehabilitation that reconstruction often necessitates. A good percentage of my patients with skiing and snowboarding injuries have proximal type tears and present reasonably acutely after their injuries, thus making them good candidates for repair. His expeditious recovery is also more of the norm, than the exception, when it comes to recovering from arthroscopic ACL primary repair. The surgical insult to the patient is more along the lines of an arthroscopy, than a reconstruction, and thus patients recuperate far more quickly than with the bigger, more morbid procedure. In addition, anecdotally, given the preservation of the native ACL biology, it seems to me that the knees of these patients feel much more normal than reconstructions when they describe how they are feeling.

RESULTS

Clinical Studies

As mentioned in the introduction, better results of primary repair of proximal ACL tears were seen in the literature when compared to midsubstance tears [14]. However, primary ACL repair in the 1990s was still an invasive procedure with arthrotomy and postoperative management consisted of lower leg casting for six weeks. Due to the preference of ACL reconstruction for the treatment of ACL injuries, ACL repair was not regularly reported in the literature. To our knowledge, only one study has reported the outcomes of arthroscopic primary ACL repair of proximal tears. DiFelice et al., reported a case series of 11 patients in
which patients with proximal tears were treated arthroscopically and rehabilitation consisted of early ROM [19]. They reported at 3.5-year follow-up excellent outcomes with one failure (9%), mean Lysholm scores of 93, mean modified Cincinnati scores of 91.5 and mean SANE scores of 91.5. Furthermore, mean subjective IKDC scores of 86.4, an objective IKDC A score in nine patients and IKDC B and C score in one patient each were reported. Tegner activity scores were maintained postoperatively in 8 of 10 patients, and KT-1000 testing showed <3 mm side-to-side differences in the 7 out of the 8 patients in whom tests were obtainable (>6 mm for the failed patient). Although the sample size was relatively small, the authors showed that excellent results could be achieved in patients with proximal tears using a modern arthroscopic approach to ACL repair.

Preclinical Studies

Although to our knowledge no other clinical results have been reported, many preclinical studies in animals have been published by the research group of Martha Murray [43, 48-51]. It was previously understood that the ACL had no healing capacity while the medial collateral ligament (MCL) did, and the group of Murray attributed this to the fact that the clot needed for ligament healing cannot remain attached to the ACL in the hostile environment of synovial fluid like it does in the extra-articular location of the MCL [52]. Based on this assumption, they performed extensive research in porcine ACL transection models, looking at both primary ACL repair and the role of a biological scaffold placed on an ACL tear to create a bioenhanced ACL repair. Some, but not all, of their findings could potentially be translated to our practice of ACL repair.

First of all, they showed that delaying time to repair has a negative effect on functional performance [30]. The authors repaired proximal ACL tears in 16 Yorkshire pigs in both legs, of which the ACL was immediately repaired in one leg and the repair was delayed with two or six weeks in the other leg. They found that in the immediate repair group the yield loads, maximum load, linear stiffness and anteroposterior laxity were superior to the delayed groups. As discussed in the section of patient selection, the benefit of early timing of ACL repair was also found in several historical studies, and this preclinical study also shows that early repair might be beneficial [3, 4, 29, 30].

Another interesting finding reported by this research group was the progression to osteoarthritis in ACL repair and ACL reconstruction. Systematic reviews and meta-analyses have shown that ACL reconstruction does not prevent the development of osteoarthritis in ACL-deficient knees [53-55]. Murray and Fleming assessed the development of osteoarthritis in different treatment options in 64 Yucatan pigs with ACL deficiency [51]. Following ACL transection at the proximal one-third they treated the pigs conservatively, with ACL reconstruction, with ACL reconstruction with biological scaffold and with ACL repair with biological scaffold. They found, at 12 months follow-up, that there was less macroscopic cartilage damage in patients treated with ACL repair with a scaffold, when compared to ACL reconstruction with a scaffold, and concluded that ACL repair might be a new, less invasive treatment option that reduces cartilage damage. This could be explained by the fact that ACL repair could potentially restore native kinematics [56] while it is known that ACL reconstruction changes the stress on the cartilage and does not restore the native kinematics [57-59].
The historical studies by Sherman et al. [9] and Genelin et al. [14], along with the recent study by DiFelice et al. [19], suggest that there might be a place for ACL repair in the treatment algorithm of ACL treatment. Arthroscopic primary ACL repair might be a good treatment option in patients with proximal ACL tears and sufficient tissue quality, while there is also an obvious potential role in the treatment of skeletally immature patients. Several potential advantages of primary ACL repair exist when compared to ACL reconstruction. First, it has been shown in preclinical studies by Murray et al. that ACL reconstruction does not restore native kinematics [57-59] and does not prevent osteoarthritis in the long-term [53, 55]. The study by Fleming et al. showed, however, that primary ACL repair restored native kinematics in animal models [56], which could explain the findings that progression of osteoarthritis did not occur following ACL repair, while this did occur in the knees following ACL reconstruction [51]. However, these findings are reported in preclinical studies and have not yet been shown in human in vivo studies.

Another potential advantage is that proprioception is preserved when the ACL is repaired, while proprioception is decreased following ACL reconstruction [60]. A recent systematic review concluded that the ACL remnant plays a role in proprioception although there was not enough hard evidence to conclude that this resulted in improved clinical outcomes [61]. Future studies are necessary to compare the role of proprioception in both ACL repair and ACL reconstruction. Furthermore, primary repair is, compared to ACL reconstruction, a minimally invasive procedure with significantly less morbidity for the patient. Arthroscopic primary ACL repair is a relatively straightforward arthroscopic procedure, whereas in ACL reconstruction requires the harvest of either the patellar tendon or hamstring tendon. These procedures can create graft harvesting complications [62]. Furthermore, ACL repair does not burn any bridges for a possible ACL reconstruction, in the case that failure of the ACL repair occurs.

**CONCLUSION**

Historically, the results of open primary ACL repair were mixed and unpredictable, which could partially be attributed to inappropriate patient selection, relatively invasive surgery and joint immobilization during rehabilitation [3, 7-9, 14]. These days, however, better results of primary ACL repair have been reported due to better patient selection (i.e., MRI), less invasive surgery (i.e., arthroscopy) and early ROM during rehabilitation. Arthroscopic primary ACL repair is an effective, minimally invasive treatment option for patients with proximal ACL tears and good tissue quality. There is considerable advantage with the decreased morbidity of the procedure, and significant potential advantages in preservation of native tissues, kinematics and joint proprioception. Finally, the procedure does not burn any bridges for a future ACL reconstruction, if necessary. Although more investigation is needed, it is certainly intuitive that there might be a potential role for ACL repair in the treatment of ACL injured, skeletally immature patients.
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The Role of Ligament Repair in Anterior Cruciate Ligament Surgery


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