



# Arthroscopic Primary Repair of the Anterior Cruciate Ligament: A Narrative Review of the Current Literature

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## Abstract

Reconstruction is widely accepted as the gold standard treatment for anterior cruciate ligament [ACL] injuries. This technique has been shown to usually restore the stability of a symptomatic ACL-deficient knee, but many patients continue to have problems, including graft failure, inability to return to sporting activities and the development of arthritis. Primary ACL repair was described more than a century ago, but was abandoned based on the science of the time and perceived unsatisfactory outcomes. During the last decade there has been a resurged interest in preserving ACL in an attempt to avoid some of the consequences following ACL reconstruction. Recent studies have reported promising outcomes in a well-defined subset of patients. The primary aims of this review are to summarize the current knowledge regarding ACL preservation surgery and discuss the newer techniques of ACL repair compared with the surgeries that were performed in the past. The pursuit of novel solutions for patients with ACL injuries should consider long-term joint health as a priority. The development of biologically active factors to improve the ACL's healing capacity may help further advance ACL repair techniques. Furthermore, data reported in this review suggests that in a well defined subset of patients, ACL repair is possible with successful outcomes in the short-term and that longer term studies investigating these techniques are warranted.

**Keywords:** Anterior Cruciate Ligament; ACL; Primary repair; Arthroscopic ACL repair; Healing response; Biologically enhanced

## Introduction

Isolated anterior cruciate ligament [ACL] tears have been reported to occur at a rate of 68.8 per 100,000 people in the United States [1]. The ACL is considered the primary passive knee stabilizer for anterior tibial translation and internal rotational forces [1,2]. A complete tear of the ACL has been associated with knee joint instability and development of osteoarthritis [OA] [3-5]. Currently, the gold standard surgical treatment for patients with ACL deficiency is single-bundle, auto graft ACL reconstruction [ACLR]. ACLR is performed with the purpose of minimizing symptomatic knee instability, limit further injury to meniscus and cartilage, and allow patients to return to their activities [6-8]. Despite the popularity of ACLR, patients satisfaction and success of the procedure is not always achieved, due to high expectations and little knowledge regarding realistic outcomes in the different subset of populations suffering an ACL

tear [9,10]. In fact, some recent studies actually report a higher incidence of OA in patients undergoing ACLR than in patient who undergo conservative treatment, and inconsistent rates of return to pre-injury activity level [36-83%] have been reported [11-17]. The best surgical treatment strategy for ACL injuries may have yet to be defined based on long term success measures.

Over the last decade there has been a renewed interest in ACL repair [ACLR] to treat ACL tears in a well-defined subset of patients [18-22]. Primary ACLR has several potential advantages over ACLR, including preservation of the native ACL's nerve endings and blood supply, which are essential for knee proprioception and kinematics [23,24]. ACLR is associated with less trauma to an already injured knee and with no donor site morbidity, which may lead to decreased rehabilitation time and faster restoration of range of motion and quadriceps and hamstrings strength [24,25]. The primary aim of this review is to report on the current knowledge on ACL preservation surgery after ACL injuries and to provide background information on the currently described ACLR techniques.

## History of ACL Primary Repair

The first documented ACLR was performed by Robson in 1895 using an open technique in which he re-approximated the two ends of the ruptured ligament with sutures through an anteromedial parapatellar arthrotomy [25]. Modifications of this technique were subsequently promoted including use of non-reabsorbable sutures passed through the ligament's remaining tissue and then tied over the Iliotibial band or lateral femoral condyle cortex through drilled tunnels [26,27]. Early performers of ACLR insisted on the importance of immobilization in a cast at

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30° of knee flexion for 4-6 weeks after surgery [25,28,29]. Several studies demonstrated excellent short-term outcomes [26,27]; however, high rates of failure and abnormal knee laxity were reported after mid-term follow-up [26,30,31]. Despite mostly inconsistent and disappointing mid-term results, a percentage of patients did report good to excellent outcomes. For example, Marshall reported promising results in their 1982 case series of 70 ACL repairs [27]. After a mean follow-up of 29 months, all patients were reported to have stable knees with a firm lachman end point and an average score of 42.7 on a 50 point normal knee score sheet. No subsequent meniscal surgery was needed and 93% were active in sports. In the same way, Feagin, reported good to excellent outcomes after primary ACLR in 25 of 30 patients after a 2 years follow-up. However, these results were not maintained in further follow-ups. In 1976, Feagin and Curl published a 5 year follow-up study reviewing 32 of 64 patients who had surgical repair of "isolated tears" of the ACL. The authors reported that 22 of the 32 patients returned to full duty, 12 had impairment of ordinary activities and 24 had impaired athletic activities with 71% having pain and stiffness, 94% having knee instability and 54% reinjury [26].

In 1987, Higgins and Steadman performed 30 acute ACLR in 27 world-class skiers with an average follow-up of 57 months. Recreational skiing was resumed by 23 patients at an average of 5 months. Ski racing and pivot-requiring activities were resumed at 9 months by 21 patients, the other 2 patients did not return to competition because of psychological reasons. Only 2 patients reported giving way of the knee with strenuous activity, 78% reported no pain and 5 patients [18%] re-injured their ACL at an average time of 28 months postoperatively. The authors concluded that a primary ACLR procedure produced an adequate success rate in their professional skier population [32].

There are some important differences between these two cohorts [31,32]. Feagin's cohort included 64 male cadets injured during football or lacrosse games; however, only 32 of these patients were available at 5 years follow-up and, of these 32, only 23 had surgical repair for a complete tear of the ACL. The other 9 patients were not repaired or had a partial excision. In Steadman's study, all 27 knees were injured in ski accidents and presented with a complete ACL tear. These tears were repaired surgically. In Steadman's cohort three patients with bilateral ACL tears were lost in follow-up. Steadman's technique utilized multiple loops of sutures passed through the ligament, this configuration generated tension from several different points within the tissue. Nineteen patients had a concomitant extra articular ilio tibial band tenodesis. Conversely in Feagin's report he only performed, a figure of eight in the ACL and no concomitant iliotibial band tenodesis were performed. The postoperative protocol in Steadman's group allowed 45° degrees of protected range of motion in a brace immediately after surgery, while Feagin's group had a long leg cast fixed at 30° of flexion for 6 weeks.

In Feagin's study, thirty-four patients were reached for the 30 years follow-up. At this point, results were comparable with those obtained five years postoperative. Twenty [71%] had at least one more surgical procedure and as one might predict, these cadets

had decreased their activity level. However 53% reported their knees as normal [IKDC score] [31].

Given the mixed results, reports of limited success, and low reliability of primary suture repair of the ACL, augmentation with other tissue [iliotibial band, bone-patellar tendon- bone graft] was pursued in addition to suture to try and improve ACL surgical treatment outcomes [33]. Gradually, ACL augmentation surgery was performed without the suture repair achieving relatively good results thereby establishing ACL reconstruction as the current gold standard procedure [24,33].

### Why was ACL repair abandoned?

In the early years of ACLR surgery, the technique consisted of an invasive arthrotomy of the knee for a direct visualization of the torn ACL. Visualization was difficult and limited. Multiple sutures were then passed through the ligament's remaining tissue and tied over the iliotibial band or lateral femoral condyle cortex through drilled tunnels. The postoperative protocol consisted of immobilizing the joint in a long leg cast for 6 weeks [26-28,30]. ACLR was associated with high failure rates, postoperative complications [arthro fibrosis, persistent instability, re-ruptures] and low reliability [1,26,34]. Some of these poor outcomes may be explained by inadequate patient selection, surgical technique, and lack of postoperative rehabilitation.

### Current Surgical Treatment

The current surgical gold standard treatment for ACL tears is single-bundle auto graft ACLR [2,8]. Although this technique does restore the gross stability of a symptomatic ACL-deficient knee, is technically demanding and there may be associated complications [2,36]. These complications may include incorrect placement of the graft, over constraint of the joint, persistence quadriceps or hamstring weakness, poor joint proprioception, and continued rotational instability [37-39]. Graft failure rates of 2-12% have been reported following ACLR [10,40,41]. Disregard technical error, risk factors for ACLR failure include younger patients [< 22 years old], females and higher activity level [10,40,42,43]. Return to pre-injury level, has been reported in different populations. Young elite athletes have better reported outcomes compared to general adult population. Kay et al., reported 92% of return to sports [RTS] in children and adolescents, but only 78% returned to pre-injury level [44]. Similarly, in a systematic review of 1272 elite athletes, 83% returned to pre-injury level [18]. Cheecahrem reported only 36% of RTS in 110 patients who underwent ACLR after 10 years follow-up [16]. Webster, in a cohort of 1440 athletes, reported rates from 18-48% RTS depending on age and sex [17]. In addition, 10-25% of patients are not satisfied with the results due to complications following graft harvesting and the surgical procedure. The most common complaints are anterior knee pain [13-43%], kneeling pain [12-54%], quadriceps muscle atrophy [20-30%], and loss of range of motion [ROM] [12-23%] [11,21]. Furthermore, high rates of OA have been reported after ACLR [12-14,45]. Current literature does not support ACLR as a prophylactic treatment for preventing OA after ACL tear [10].

Despite current results, ACLR technique is being performed without taking into consideration the different populations and



their needs, creating unrealistic expectations in many of them [10].

### Why Re-Consider Repair?

During the last decade there has been a renewed interest in preserving the ACL in an attempt to avoid some of the consequences following ACLR, and there have been promising outcomes in a well-defined subset of patients (Figure 1) [35-39].

#### Basic science

The healing capacity of the ACL has been compared to the medial collateral ligament [MCL] which heals uneventfully [33]. In the extra articular environment, the tear site of the MCL is filled with a blood clot [provisional scaffold] that allows surrounding cells to invade and remodel into a fibro vascular scar restoring the ligament's function. The stump of a torn ACL has been reported to heal to surrounding tissue in the inter condylar notch such as the PCL or the medial wall of the lateral femoral condyle in the inter condylar notch [22]. This observation may imply that the ACL does have a healing potential. Interestingly, Nguyen et al., biopsied the interface ACL-PCL of 5 patients undergoing ACLR, in which the torn ACL was reattached to the PCL and reported that the histological characteristics observed were the same as in the healing process of the MCL [22].

The formation of a bridging clot is not observed in the ACL, however, likely because of premature dissolution by enzymes in the synovial fluid. Therefore, use of a provisional scaffold may ameliorate the non-healing of the wound site in the intra-articular ligament [40,41]. Fleming, et al., reported that the use of a scaffold alone to enhance suture repair of the ACL was ineffective in an animal model [42]. Murray et al enhanced the ACL suture repair with a collagen-scaffold and Platelet-Rich-Plasma [PRP] demonstrating repair tissue similar to the extra articular ligament wounds (Figure 2) [40,41].

#### Advances in Technology

Magnetic resonance imaging [MRI] now provides an accurate

preoperative diagnostic of the tear location and thus allows for the selection of patients who are more likely to benefit from a primary repair (Figure 3) [43,44]. In addition, advancements in modern technology, the use of specialized devices, bioactive scaffolds and the development of minimally invasive arthroscopic techniques may also improve outcomes after primary ACLR [18,24,45].

#### Progression to OA

The benefit of enhanced primary repair of the ACL on reducing the risk of PTOA, after an acute tear, has recently been postulated [39]. Long-term studies are required to assess the incidence of PTOA after ACL surgery. Clinical human studies with current techniques for ACLR are not enough to strongly support this theory. However, Sherman, reported better radiographic scores in patients with successful ACLR compared to ACL insufficient knees after 61 months follow-up [46]. Similarly, Drogset, reported a prevalence of 11% of OA in the injured knee after 16 years follow-up for ACL primary repair [47]. This results are encouraging when compared to >50% prevalence of OA after ACLR [9].

#### Current Techniques for Repair and Reported Outcomes

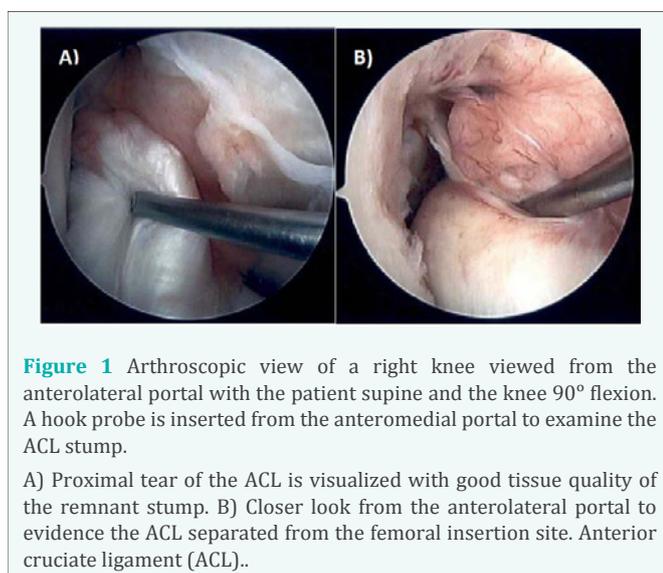
To date, 4 different operative techniques for ACLR have been described in the literature: (1) Refixation with suture anchors, (2) Internal Brace Ligament Augmentation [IBLA], (3) Dynamic Intraligamentary Stabilization [DIS] and (4) Bridge-enhanced® ACL Repair [BEAR®] [45] (Figure 4).

#### Arthroscopic Suture anchor ACL Repair

DiFelice et al., were the among first to develop and evaluate outcomes after arthroscopic primary ACLR using suture anchors [18]. This approach uses 2 sutures placed into each bundle. Suturing begins distally and create an alternating, interlocking Bunnell-type stitch that exits the proximal end, after which each suture is tensioned and fixed to the femoral wall using two 4.75mm vented Bio Composite™ Swive Locks® anchors. The remaining suture can be used as an internal brace by passing it through two drilled tunnels on the anterior tibia and fixing them with interference screws (Figure 5).

Achtnich et al. [38], modified this technique by reducing the amount of suture material pulled through the ACL thereby minimizing the risk of strangulating the ACL. The authors describe use of just one anchor and additional micro fracturing to improve healing. This technique was criticized by DiFelice's group who emphasized the importance of creating an anatomic re-approximation of both native ACL bundles, with independent sutures, as this strategy maximizes the ligament-bone contact area and creates a more anatomic and biomechanical construct. In addition, they argued that the vented nature of the suture anchors accomplished the same goal as microfracturing [48].

With these new techniques, short-term studies show better outcomes than in the past; however, ACLR still is noted

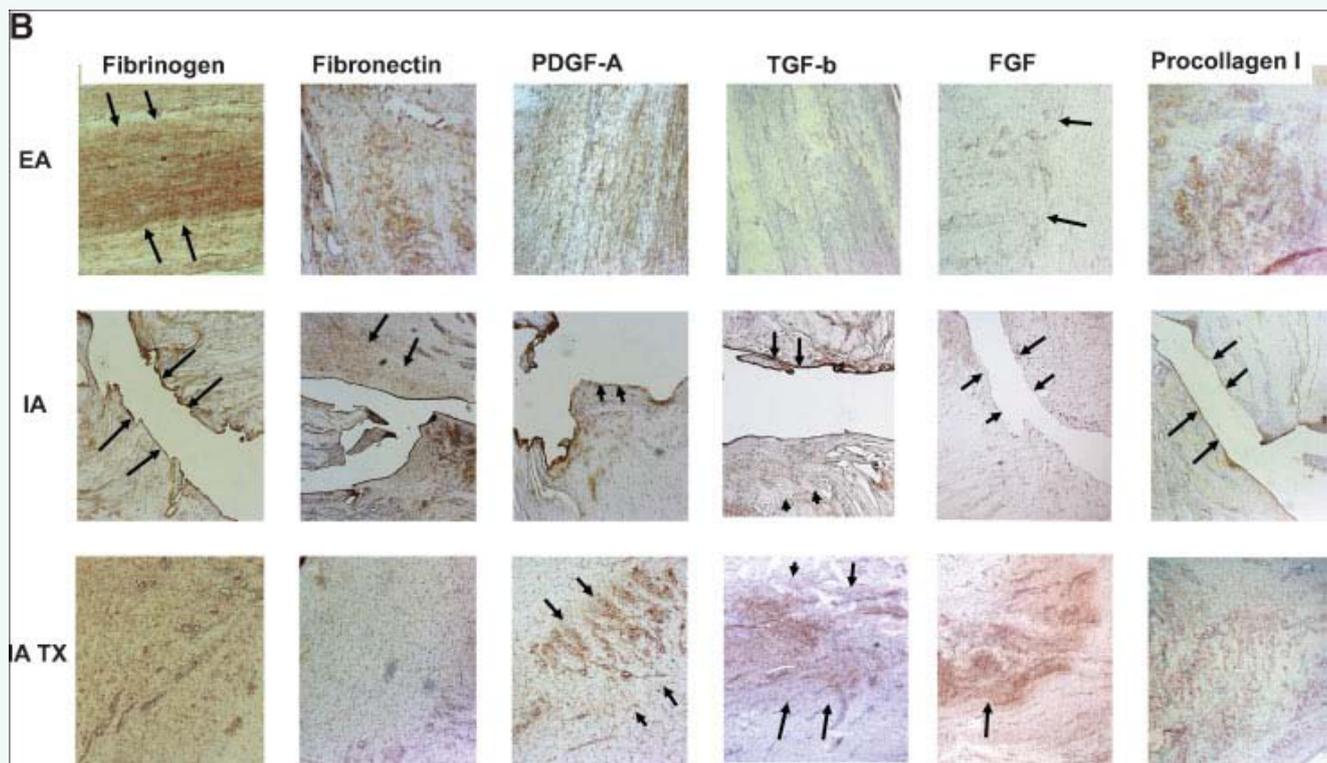


**Figure 1** Arthroscopic view of a right knee viewed from the anterolateral portal with the patient supine and the knee 90° flexion. A hook probe is inserted from the anteromedial portal to examine the ACL stump.

A) Proximal tear of the ACL is visualized with good tissue quality of the remnant stump. B) Closer look from the anterolateral portal to evidence the ACL separated from the femoral insertion site. Anterior cruciate ligament (ACL)..



**Figure 2** Histological micrographs comparing healing response after 6 weeks of wounding of the extra-articular (EA) and intra-articular (IA) ligaments treated with and without collagen-scaffold and Platelet-Rich-Plasma (PRP). EA (First row) adequate healing of the wound in a patellar tendon. IA (Second row) untreated wound remains relatively empty of any substratum. IA TX (Third row) ligament wound treated with a collagen-PRP scaffold, shows healing response comparable with EA ligament. Black arrows mark the wound edges. Similar distributions of proteins were noted in the treated IA wounds and the EA wounds. Black arrows delimitate the wounds edges. (PDGF-A: platelet-derived growth factor; TGF- $\beta$ : transforming growth factor; FGF: fibroblast growth factor) (adapted and modified with permission from Murray et al., Bone Joint Res. 2014).

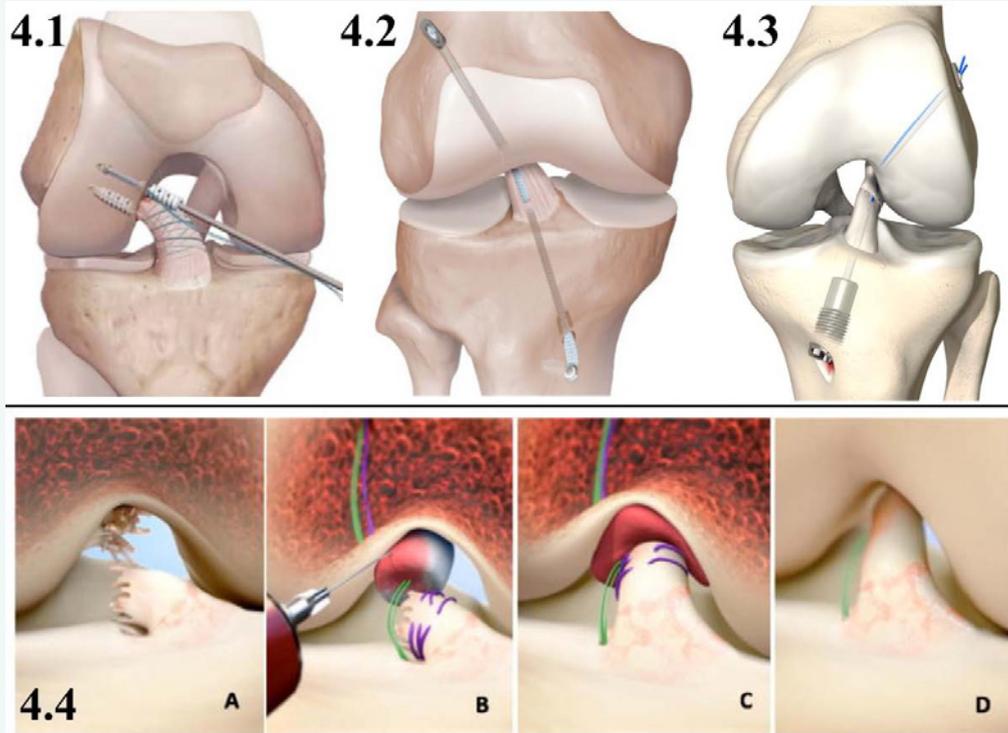


**Figure 3** 3 Tesla Magnetic Resonance Image of a right knee to diagnose a clinically suspected anterior cruciate ligament injury. A) Sagittal Proton Density Fat Saturated and B) T2 Stir Coronal sequences showing a high grade tear of the anterior cruciate ligament with proximal femoral avulsion maintaining good quality ligament tissue.

to have lower graft failure rates in the short-term [38,49,50]. Achtnich compared 20 patients with proximal ACL tears, who underwent primary arthroscopic repair with 20 similar patients who underwent single-bundle ACLR. The authors reported excellent subjective outcomes in both groups, but found a significantly higher graft failure rate [15% vs 0%] in the repair group. Moreover, MRI confirmed ACL graft presence in 100%

of reconstruction cases versus ACL native tissue in 86% of the repairs at their last follow-up [38].

Hoffmann et al. [51], reported good to excellent clinical outcomes in 75% of 12 patients treated with primary re-fixation of proximal, femoral ACL avulsion tears. After a mean follow-up of 79 months, 25% were considered failures. One patient suffered an early retear [8 weeks postoperatively], one patient with an



**Figure 4** Schematic diagram of the four different operative techniques for ACL repair that have been described in the literature: (1) Refixation with suture anchors, (2) Internal Brace Ligament Augmentation (IBLA), (3) Dynamic Intraligamentary Stabilization (DIS) and (4) Bridge-enhanced ACL repair (BEAR): (A) the torn ACL tissue is preserved; (B) ACL tibial stump is secured with #2 absorbable suture (purple), another #2 non reabsorbable suture (green) is passed through a drilled 4mm femoral tunnel, then through the collagen-scaffold and ACL and finally through the tibia (4mm tunnel). The collagen-based scaffold is then saturated with 5 mL of the patient's blood. Both sutures are fixed with an extracortical button on the tibia and femur cortex; (C) tibial stump is approximated to the saturated scaffold; (D) The ligament reunites to the femoral insertion through the collagen-based scaffold.

(Images 4.1 and 4.2 were provided with courtesy of Arthrex®, Naples, Florida 2019).

(Image 4.3 was provided with courtesy of Mathys Ltd Bettlach).

(Image 4.4 used with permission of Murray et al., *Orthop J Sports Med.* 2016).

additional patellar tendon tear and one with rheumatoid arthritis developed persistent subjective feelings of instability. Therefore, the authors concluded that in cases of additional serious damage to extensor structures or in the presence of systematic rheumatic disease, loss of function and unsatisfying clinical results occurred. A further study reported excellent clinical outcomes after arthroscopic primary proximal ACLR with no complications or need for revision surgery on any of the thirteen consecutive patients included at a mean follow-up of 31.3 months [36].

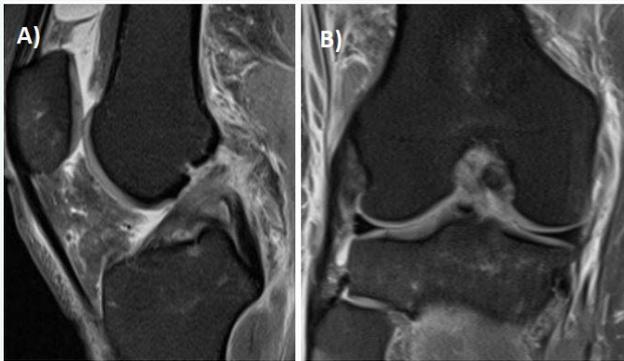
DiFelice et al., aimed to prove that good clinical outcomes could be maintained in the mid-term. In 2018, in a cohort of 11 patients, they reported excellent results with only one re-rupture after a mean follow-up of 6 years. When comparing the results of this study with the outcomes at 2 years follow-up, no deterioration or differences were noted between the 2 and 5 year assessments [52].

The first case series in skeletally immature patients [Tanner 1-2], reported no failures or leg length discrepancies at 3.6 years follow-up. All patients described their knee as normal. In MRI

obtained at last follow-up, no articular lesions or growth arrest were observed, and the reinserted ACL was recognized in every exam [53].

### Internal Brace Ligament Augmentation

IBLA describes an augmentation to suture repair of the proximally torn ACL [Internal Brace TM Ligament Augmentation Repair, Arthrex, Inc., Naples, FL]. It consists of passing a non-absorbable braided suture, placed on a fixation device, through the proximal end of the torn ACL. The construct is passed through the drilled tibial, through the ACL stump and femoral tunnel and pulled up onto the lateral surface of the femur where it is fixated to the cortex utilizing a femoral button loaded with high-strength suture tape [Retrobutton/TightRope RT and FiberTape®, Arthrex, Inc., Naples, FL]. The distal end of the internal brace is secured in the tibial metaphysis with a bioabsorbable bone knotless anchor [SwiveLock®, Arthrex Inc., Naples, FL]. The mechanical protection afforded by the internal brace may allow for improvement in ligamentous healing, by unloading the healing ligament tissue [54].



**Figure 5** Right knee arthroscopy, viewing from the anterolateral portal with the knee in 90° of flexion. Primary ACL repair performing a suture anchor repair technique with internal bracing.

A) After creating a 4.5 x 20 mm hole in the ACL's origin of the femoral wall, the sutures passed through the torn ligament are fixed into the femoral wall with a 4.75mm BioComposite™ SwiveLocks® Anchor.

B) A completed primary ACL repair is appreciated after the ligament is reattached into the femoral wall at its anatomic origin. A probe is introduced through the anteromedial portal to test the tension after the repair.

C) The remaining suture attached to the femoral wall is used as an internal brace by passing it on the lateral and medial side of the repaired ACL and through two drilled tunnels on the anterior tibia and securing them distally with a swivelock® screw.

Recently, clinical short-term outcomes have been reported with IBLA technique. Mackay et al., performed 68 acute femoral-sided avulsions with the IBLA technique demonstrating similar patient related outcome scores to traditional ACLR at one-year follow-up. Only one failure was reported at 18 weeks after return to full contact sports [55]. Similarly, Heusdens et al., reported on 42 patients after performing IBLA in acute [ $< 3$  months], proximal ACL tears with good tissue quality of the remaining stump. Clinical outcomes were reported after 2 year follow-up. Patient Reported Outcome Measures [PROM] improved significantly over time [ $p < 0.0001$ ], demonstrating the most pronounced improvement after 3 months and reaching the highest values at 1 year follow-up. At 2 years postoperatively, the PROM decreased slightly compared to the 1 year postoperatively scores. Re-ruptures were reported in two patients at 5 and 15 months post surgery during a soccer match. Both patients were treated with ACLR without complications [56]. Interestingly, IBLA use has expanded indications in the pediatric population [62]. In a case series of three children with proximal complete ACL rupture, treated with surgical repair utilizing IBLA, complete healing and knee stability was reported 3 months after surgery, when the device was removed. All patients returned to previous level of activity at 4 months, and excellent knee function without growth disturbance was found beyond 2 years [57].

The addition of an internal brace to the ACL repair technique is thought of as a means to protect the ligament during early ROM. DiFelice et al., augmented 52% of 52 patients treated with ACLR and reported that adding an internal brace to the repair did not influence ROM [23]. Recently, Jonkerougou et al., compared ACLR

in a group of 27 patients with IBLA to 28 patients without the bracing and noted that failure rates were lower in the augmented group [7.4% vs 13.8%]. However, no statistically significant or clinically relevant differences in subjective outcomes were found [58].

### Dynamic Intraligamentary Stabilization [DIS]

The essential prerequisites for ACL healing are mainly the same as for all biological tissues, stability and biologic factor supply. Egli et al., developed a technique to stabilize the knee joint during the self-healing period of the torn ACL, holding the knee in a constant posterior drawer position throughout all degrees of flexion, via a screw-spring mechanism to act as a dynamic internal fixator. The working theory behind the DIS technique is to provide stability to the repaired ACL tissue by mechanically unloading the healing ligament [59-61].

Hooges lag et al., performed a level I, randomized control trial comparing 23 patients who underwent primary ACLR with DIS versus 21 patients treated with ACLR. All patients had pre-injury Tegner scores  $> 5$  and average age was 21 years. The authors reported no statistically significant difference in PROM in between groups at 2 year follow-up [IKDC subjective score 95.4 in DIS group versus 94.3 in the ACLR group]. In the ACLR group, two ipsilateral retears and two contra lateral ACL tears were reported. In the ACLR 4 ipsilateral retears and no contra lateral tears were observed in the latest follow-up. This article provides clinical relevancy that DIS ACLR technique was not inferior to ACLR in terms of patients subjective outcomes [71].

In a clinical evaluation of 278 patients treated with primary ACLR using DIS technique, Henle et al., reported almost normal knee function, excellent satisfaction [mean Lysholm 96.2; VAS 8.8] and return to previous sports level in most patients after 2 year follow-up. Eight re-ruptures occurred at an average of 338 days after surgery, and 3 patients reported insufficient subjective stability of the knee. All failures were treated with ACLR and showed good results. There was a 24.1% rate of re-surgery for implant removal [62].

In a systematic review of 23 articles published in the literature related to the DIS technique, two year follow-up studies reported revision rates of 7.9% to 11%, which then increased to 20% at 5 year follow-up. The reported failure rates ranged from 4 -13.6%. However, the definition of "failure" in many of these articles is unclear. Furthermore, not all patients classified as failures require a revision surgery. So, in this time it is difficult to come to a conclusion about the effectiveness of the DIS technique. The authors do suggest that the key to success is the correct patient selection. Younger patients with higher Tegner scores who underwent the DIS procedure demonstrate higher failure rate. Patients with proximal tears of the ACL show better outcomes [63].

Regardless of good functional outcomes reported by some authors using DIS technique, high re-surgery rates have been described. Osti et al., reported on 57 patients with an overall complication rate during the first 12 months after surgery of 57.9%, including re-rupture or non-healing [17.5%], arthro



fibrosis [5.3%], implant interference [12.3%] or repeat arthroscopy [22.8%] as a result of meniscus tear, cyclops syndrome, or restricted ROM [64].

In order to avoid the bias from a developer's perspective, Meister et al. independently analyzed outcomes of 26 patients who underwent ACLR using DIS device. The authors reported rates of 15% retears, 35% reoperations [due to re-tear or arthrofibrosis], and 43% hardware removal in the total sample [65].

Ateschrang et al., arthroscopically evaluated the macroscopic integrity and morphology of 47 knees after ACLR utilizing the DIS technology for a period of 6-12 months postoperatively. Their results demonstrate that clinical recovery of ACL function is associated with restoration of ACL volume and scar tissue formation. Four patients [8.5%] in their cohort were noted to have deficient ACL recovery, although none required secondary reconstructive surgery [66].

### **Bridge-enhanced® ACL repair [BEAR®]**

The BEAR® procedure aims to provide a mechanical basis and biologic stimulus to augment ACL regeneration and enhance suture repair [37,40,41,67]. This technique specifically refers to placing a specific BEAR® scaffold in the gap between the torn ends of the ligament or on the femoral site for proximal ACL tears at the time of suture repair. Different materials are being tested and used as scaffolds in animal studies. Collagen sponge-type from bovine connective tissue has proven to be resistant to degradation by catabolic enzymes of synovial fluid and activates patient's own platelets to release anabolic growth factors into the wound site [68]. This surgical technique might provide an alternative treatment option to current ACLR.

Murray et al. recently published the first study performed in humans comparing a nonrandomized cohort of 10 patients who underwent ACLR with the BEAR® procedure versus 10 ACLR with hamstring autograft. After 24 months follow-up, none of the patients in either group presented a re-tear. Subjective and objective scores improved significantly from preoperative in both groups [ $P < 0.0001$ ]. However, BEAR® led to significantly better hamstrings strength in comparison with ACLR group [69].

### **When Should a Repair be considered?**

Prior to modern techniques, ACLR was performed without discrimination: in both acute and chronic injuries, in young active patients as well as elderly patients, and in both recreational or high level athletes [27,28,31]. Sherman et al., performed an extensive subgroup analysis to correlate factors that would predictably affect the outcomes of ACLR procedure. The authors classified ACL tears into four types according to the location of the tear [I= avulsion of the entire ligament off the femoral insertion; II= proximal stump of 20% III= proximal stump of 33%; IV= Midsubstance tear]. Their analysis demonstrated excellent results in 17% of the patients, good results in 37% and poor results in 46%. The most relevant factors to predict these outcomes were:

(1) Type I tears and better tissue quality, (2) Non-contact or

low energy injuries [e.g., skiers], (3) Preoperative joint laxity and (4) Increased age. Based on these findings, they recommended primary repair in patients over the age of 22 years, non-contact injuries with proximal ACL avulsion and good quality tissue, as well as, lower-grade preoperative pivot-shift [46].

Conversely, in 2017 Krismer identified negative factors likely to influence success of ACLR. The following determinants were noted after ACLR utilizing the DIS technique:

(1) pursuit of competitive sports activity with a Tegner pre-injury score  $>7$ ; and (2) mid-substance ACL rupture location [70].

In a different study, Henle et al., investigated the incidence of revision ACL surgery as well as patients' characteristics and surgery-related factors that could increase the risk of ACL revision after DIS. Young age [less than 24 years old], high level of sports activity [Tegner level  $>5$  points] and increased knee laxity [ $>2$  mm of side-to-side difference] were significantly associated with revision ACL surgery [71]. The same risk factors have been associated with higher risk of graft failure and revision surgery after ACLR [9,49,72,73].

Current literature does not clearly define proper selection of patients, however, based on the published outcomes, ideal candidates for this procedure are listed in (Table 1) [32,39,46,70,71].

### **Conclusions**

The optimal treatment for ACL injuries has to be determined. Evidence from this current review is strongly suggestive that ACLR is possible with successful outcomes in the short-term, sufficient to empower longer term studies. Incidence of PTOA may also be reduced; however long-term outcomes with the new techniques are still needed to prove this benefit. Biologic enhancement of the ACLR is an encouraging technique to obtain successful results in the long-term. Other techniques like DIS show high reoperations rates after the primary procedure.

Most recent clinical human studies, performing ACLR with the new techniques, are short-term studies and have small sample of patients. However, current literature reports better outcomes than in the past and subjective patients measurement scores following ACLR are not inferior to those undergoing ACLR.

Orthopaedic surgeons of today, when treating patients with ACL injuries, should begin to focus on long term joint health and efforts should not be solely based on graft survival. The concept of primary ACLR was abandoned more than 30 years ago based on the science of the time. Even then however, a subset of patients had well to excellent outcomes. A subset of patients with an ACL tear may not benefit by receiving ACLR surgery and could be given the opportunity of another treatment such as primary repair.

Accurate selection of patients who benefit from this procedure is the key to success. Preoperative MRI enables the surgeon to identify patients with repairable tears. Minimally invasive arthroscopic techniques represent potential solutions to the high failure rates previously associated with ACLR. By attempting to preserve the native ACL by a repair, the proprioceptive features



**Table 1:** Summary of the factors to be considered when indicating primary repair surgery on a patient with ACL tear.

Factor to Predict Outcomes	Good Prognosis	Poor Prognosis
Time from injury	< 3months	Chronic
Type of tear (Sherman classification)	I-III	IV
Tissue quality of the remaining stump	Good	Low
Level of energy when injury	Low	High
Activity level (Tegner scale)	≤7	>7
Age	>25 years	<25 years
Pivot Shift	1+ or 2+	3+

of the ACL may be maintained, thus potentially improving postoperative recovery. Finally, if the repair fails, a straight-forward primary ACLR can still be performed.

Further research aiming to preserve the native ACL and develop biological active factors to improve its healing capacity will help further advance ACLR techniques and widen indications to different types of ACL tears and levels of activity.

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