Primary Anterior Cruciate Ligament Repair: Current Concepts

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Abstract:
The renewed interest in ACL repair over the last two decades stems from advances in modern arthroscopic techniques and clinical studies that have provided evidence that the ACL can reliably heal, and patients can return to sport (RTS) at a comparable rate to ACL reconstruction (ACLR) patients. The ability to maintain and utilize native ACL tissue, with proprioceptive capabilities, and the smaller drill tunnels needed to repair an ACL leads to an overall less invasive procedure and improved early rehabilitation. Additionally, repair avoids the variety of comorbidities associated with autograft harvest. This current concept review details modern techniques of ACL repair and their current studies, a review on the use of biologic enhancement in ACL repair, and other considerations to appropriately integrate ACL repair into the sports medicine orthopedic surgeon’s practice.

Current Concepts:
- Modern ACL repair is less invasive than ACL reconstruction and avoids the comorbidities associated with autograft harvest. This leads to improved early rehabilitation and improved forgotten knee scores.
- Modern arthroscopic surgical techniques for ACL repair include the use of anchors or buttons for femoral and tibial fixation with adjustable tensioning cinch loops augmented with suture tape or DIS.
- Sherman Type 1 and 2 tears are the most heavily researched regarding ACL repair as they have been found to have a higher intrinsic ability to heal. Re-rupture rates can be expected between 7-20% when utilizing suture tape modification or DIS for these tears.
- The use of collagen-based scaffolds, such as the BEAR implant, may improve the ligamentization and healing capacity of the ACL.

Future Perspectives:
- Level 1 and 2 trials involving modern arthroscopic techniques for ACL repair of Sherman 1 and 2 tears are needed. As well as studies comparing ACL repair with and without the use of the BEAR implant.
- Further studies on the incorporation of biologics for ACL repair, especially the role of collagen-based scaffolds, are needed.
- The role of ACL repair for adolescents and in those with Sherman 3 tear patterns is still unclear.

Keywords: ACL reconstruction; ACL repair; anterior cruciate ligament; bridge-enhanced ACL repair; dynamic intraligamentary stabilization; suture tape augmentation

Introduction

Over the last two decades, modern advances in arthroscopic techniques and protocols aimed at repairing the ACL have flourished. Promising studies focused on debunking the previously accepted notion that the ACL lacks the intrinsic ability to heal seem to be published on a weekly basis. The continued interest in ACL repair stems from clinical and animal-based studies that
have provided evidence that the ACL can not only heal, but patients can return to sport (RTS) at a nearly comparable rate to ACL reconstruction (ACLR) patients [1–4] and they can also feel better more quickly [5–8]. The ability to maintain and utilize native ACL tissue, with proprioceptive capabilities, and the smaller drill tunnels needed to repair an ACL leads to an overall less invasive procedure. Additionally, repair avoids the variety of comorbidities associated with autograft harvest, including hamstring or quadriceps weakness, increased risk of remaining native tendon rupture, anterior knee pain, and cramping. This may be the biggest advantage to ACL repair. This leads to faster return of ROM, improved early PROMs, and a more natural feeling knee as demonstrated by improved forgotten knee scores [5,8].

Additionally, revision of failed ACL repair to reconstruction has been found to be equivalent to a primary ACLR [2]. Despite this, there is a plethora of evidence that has reported significantly higher or even unacceptable re-rupture rates for those undergoing repair [9]. Feagin and Curl, in 1976, were the first to provide data illustrating high failure rates of ACL repair (~50%) at 5 year follow up [10]. Although interestingly, the roughly 50% that were subjectively doing well at 5 years continued to do well at 30-year follow up [9]. Unavailable or immature arthroscopic techniques, prolonged postoperative immobilization, and poor patient selection have contributed to these unacceptably high failure rates. In 1991, Sherman et al, identified that patients with proximal avulsions of the ACL and those with remaining good tissue quality performed significantly better following ACL repair [11]. This research led to the Sherman classification for ACL ruptures (MRI and corresponding arthroscopic images provided below in Figures 1-10). Steadman et. al further contributed to ACL repair literature, showing that elite skiers with proximal avulsions can perform well and return to competitive sports following open repair, although they still found a 18.5% re-rupture rate [12]. Steadman et. al continued to develop novel techniques for ACL repair, introducing the concept of the healing response, consisting of only microfracture of the femoral footprint in those with proximal ACL avulsions [13,14]. They found skeletally immature patients with type 1 ACL tears treated with the healing response had a reinjury rate of roughly 23% [14], while an older patient cohort (average age of 51) with the same pathology and treatment protocol had an improved re-rupture rate of only 8.9% (follow up minimum of 2 years, average 7.6 years) [13]. Although, for both patient populations, those that did not go on to failure demonstrated improved PROMs without pain or subjective instability [13,14]. The healing response was later refuted by Wasmaier et al, showing contrary results with poor clinical outcomes and revision rates as high as those treated conservatively [15].

These early studies illustrate that the patients that go on to heal following ACL repair continue to have lasting improved outcomes. Due to early clinical findings by Sherman and Steadman, as well as histological data by authors such as Nguyen et. al, who has demonstrated that the proximal one-third ACL has an “intrinsic healing response” similar to the MCL [16], has led to a shifted focus towards research predominantly exploring patients with Sherman 1 and 2 ACL tears. The purpose of this study is to describe and elucidate preliminary outcomes regarding novel ACL repair techniques including suture augmentation, dynamic intraligamentary stability, and those focused on biologic enhancement of the repaired ACL. Additionally, this study provides information on other factors to consider when incorporating ACL repair into an orthopedic surgeon’s practice.
No ethics approval or informed consent was required for this current concepts review.

**Sherman Classification (Figures 1-10)**
T2 sagittal MRI slices and their corresponding arthroscopic images from the anterolateral viewing portal, consistent with their specific ACL tear pattern.

**Modern Techniques for ACL repair and their outcomes**

*Suture Repair with or without Suture Tape Augmentation*

There are a variety of novel arthroscopic suturing techniques for ACL repair. They generally involve penetrating and self-retrieving cinched/looped suture around the remaining ACL fibers with an arthroscopic suture passer and approximating/tensioning these fibers to the ACL femoral footprint through either biocomposite suture anchor(s) (Image 1) or through suspensory cortical fixation using a metallic button. Initial Level III/IV studies with small patient cohorts using these techniques published by DiFelice [17] and Achtnich et. al. [18] illustrated promising results at short term follow-up with high PROMs and failure rates of 9% and 15%, respectively. Despite these initial promising findings, cadaveric biomechanical studies by DiFelice and Van Der List demonstrated that the addition of an adjustable tensioning cinch loop as well as suture tape augmentation (Image 2) improved gap formation and load to failure after preconditioning cycles of the knee when compared to a single or double static cinch loop with or without tape augmentation [19,20]. Massey et al further added to this evidence, comparing a locking Krackow suture repair to the same repair supplemented with an adjustable loop femoral cortical button fixation and suture tape augment, concluding that suture tape augmentation provides a vital addition in strength and resilience to the ACL repair construct during physiologic loads and protects the repair from cyclic displacement and load failure during early rehabilitation [21]. These studies have further led to a paradigm shift in suturing technique and common practice incorporation of tape augmentation in ACL repair. Since then, continued advancements in suture repair constructs have led to the advent of new generation suture devices (Image 3), improving the utility and ease of adjustable loop application.

Similarly, suture tape augmentation has increased in popularity in ACLR. Studies have shown improved time zero biomechanics with diminished elongation of tissue as well as improved functional remodeling of the tissues, without stress-shielding of the graft [22]. Initial animal and clinical trials indicate that suture tape augmentation appears to be a safe adjunctive treatment to improve initial stability while providing stress-sharing properties at higher loads [22]. Long-term effects of suture tape incorporation in ACL repair or reconstruction is largely unknown.

A 2020 systematic review looking at 13 level III/IV studies with 418 patients treated with ACL repair with suture tape augmentation was followed up on average at 2 years. Average failure rate was 8%, although when stratifying for age, failure was found to be 17% for patients younger than 18, and 6% for patients older than 18. Functional outcome scores were found to be good to excellent (greater than 80% of maximum) with low complication and revision surgery rates outside of re-rupture [23].
Dynamic Intraligamentary Stabilization (DIS)

Although structural ACL repair augmentation in the United States has focused on suture tape, European ACL repair research has predominantly utilized dynamic intraligamentary stabilization (DIS) (Image 4), with PROM and re-rupture outcomes similar to those quoted above [5]. DIS utilizes a non-resorbable cord-like suture that is fixed to a spring implant at the proximal tibia. This provides dynamic stabilization of the ACL with a posterior drawer type force applied throughout range of motion, aiming to protect the repaired ACL and distribute load across the knee joint during early healing and rehabilitation.

There have been 2 high quality randomized control trials of level 1 evidence reporting outcomes of 85 and 48 patients, respectively, both comparing DIS to hamstring autograft. Glasbrenner et al. [3] reported results of 64/85 patients at 5 years post-op comparing ACL repair (31/34 proximal tears) versus hamstring autograft ACLR. Lysholm and IKDC scores slightly favored ACL repair, with IKDC found as significant. Recurrent instability was found to be high in both groups (35% for repair and 20% for reconstruction) with the majority of instability occurring in patients less than 25 years old and in those with preoperative Tegner activity scale greater than 7. Of note, failures by the ACL repair group were treated with single stage ACLR, while re-ruptures of the ACLR group at times needed a two-stage revision. They concluded that DIS was a viable option for older patients and those with low to moderate activity demands. Hoogeslag et al. [1,24] reported on 48 patients with the majority of ACL repair patients found to have proximal avulsions (20/24). At 2 years, they found re-rupture rates more similar to those reported in the literature for static augmented proximal avulsions with failures at 8.7% compared to 19% for ACLR [24]. At 5 years, failure rates were found to be 20.8 and 27.2%, respectively [1]. PROMs and adverse events were also found to be similar between groups. DIS has been found to be a reasonable treatment choice for proximal ACL tears, although there seems to be an increased risk of adverse events (mostly hardware irritation) when compared to ACLR, which can usually be treated with staged removal of the tibial based spring (up to 42% in the literature) [24]. Failure of ACL repair following DIS may also increase risk of two-stage revision, necessitating tibial bone grafting following removal of the monoblock implant 60% of the time [25].

Biologic enhancement and scaffolds

One of the reasons that the ACL has a diminished propensity to heal is due to its intra-articular environment, predisposing it to synovial fluid and the high concentration of degradative enzymes within it [25]. Enzymes such as matrix metallopeptidase, elastase and plasmin are responsible for breaking down collagen, elastin and fibrin, which are crucial for the normal healing process [26]. To further improve the healing capacity of the ACL, several biologics have been utilized along with novel collagen-based scaffolds to combat these degradative enzymes.

In 2000, Murray and Martin [27] noted that fibroblasts from ACL remnant tissue were able to migrate and proliferate on a collagen-glycosaminoglycan scaffold. They illustrated that growth factors such as TGFβ1, PDGF-AB, EGF, and FGF-2 could influence the migration of fibroblasts and thus could be crucial adjuncts to ACL repair healing. Guillen-Garcia at Clinica CEMTRO in
Madrid, Spain [28] further explored the role of fibroblasts in ACL repair healing in sheep. They compared ACL repair utilizing a porcine collagen membrane with and without implanted cultured autologous fibroblasts. On a macroscopic level, both ACL repair groups appeared similar, with similar expressions of COL1, MMP-13 and tenasin-C compared to control samples taken from native ACL, reaffirming the ideology that the repaired ACL may preserve its biologic properties. Although the main difference between the groups was that in tissues engineered with cultured fibroblasts, increased peripheral vascularization was found at the neo-formed structures, indicating that the fibroblasts have high mitotic potential. Proliferating fibroblasts found in remnant ACL tissue have also been found to heavily express vascular endothelial growth factor (VEGF) [29], which has been found to be a crucial factor in revascularization of the tendon in ACLR tendon grafts. Despite these promising findings, fibroblast-based collagen membranes are not approved for human clinical trials at this time.

Platelet- and fibrin-based injectables have long been studied for adjunctive use in ACLR, at times demonstrating in vivo improvement of graft incorporation and ligamentization [26]. Despite this, the myriad of techniques and applications for biologics in reconstruction and repair of the ACL, as well as their variable outcomes, have led to controversy and limited application. Platelet- and fibrin-based injections have been found to rapidly degrade in the harsh synovial fluid environment, which may contribute to the variable results found in the literature [26,27]. The advent of collagen-based scaffolds may have the potential to minimize this degradation process when mixed with other biologically active components. This concept has been most profoundly explored by Murray et al. [30]. In 2009, they found that PRP use alone did not enhance ACL healing when used in conjunction with ACL suture repair in a porcine model. Although, when combined with a collagen-platelet composite scaffold, enhanced biomechanical and histological healing of the ACL was found. Additional studies have further elucidated that the addition of an extra-cellular matrix-based collagen scaffold with PRP outperforms either group alone [31].

Current research by Murray et al. [2] has shifted towards the use of whole-blood, as they have found that physiologic platelet concentrations when injected into a collagen-based scaffold may have superior outcomes to PRP. This technique, dubbed bridge-enhanced ACL repair (BEAR) (Images 5-7), now has data following a 2-year 100 patient (average age 17 years) randomized control trial, comparing the BEAR technique to predominantly hamstring autograft ACLR. They determined that PROMs and knee AP laxity were non-inferior to ACLR and that failure rates were not significantly different (p = 0.32) between the two cohorts (14% for ACL repair versus 6% for ACLR). For this adolescent patient population, these findings are much improved compared to other primary ACL repair cohorts of similar patient demographics (49% failure rate seen by Gagliardi et al.) [32] and similar to findings in the literature for adolescent athletes undergoing ACLR (10-28%) [33,34]. Patients undergoing ACL repair also had superior hamstring strength at follow up [2]. Of note, patients requiring revision ACLR following repair failure had IKDC findings similar to those found in primary ACLR.

Stem cells have also been explored as a means of improving ACL repair viability. Marrow stimulation through microfracture at the femoral footprint, as described in the healing response technique, has been clinically shown to release multipotent cells that promote neovascularization at the ACL repair site in animal models [35,36]. When compared to bone-marrow aspirate
concentrate (BMAC) and PRP glue in the treatment of partial ACL tear repair, Gobbi et al. [37] found marrow stimulation to have no clinically significant difference.

**General Outcomes for ACL repair**

**Tear Location**

Since the exhaustive subgroup classification of ACL tears was depicted by Sherman in 1991 [11], the role of tear location and outcomes of ACL repair has been studied extensively. DeFelice and van der List [38] performed a systematic review describing historical outcomes of open ACL repair based on the Sherman classification. Of the 29 studies included, 72% of tears repaired were proximal, 23% midsubstance, and 5% distal. Overall failure rates were found to be 6.8 +/- 7.7%. When subclassifying for tear pattern, proximal tears trended towards improved anterior drawer examination, patient satisfaction, and failure rates. They also found midterm results to be improved in cohorts that only treated patients with proximal avulsions. Kaplan et al. [39] described results on open ACL repair of midsubstance tears, finding early failure in 17% of patients with only 62% RTS.

Due to these early open ACL repair studies and the trend towards improved and minimized variability of outcomes with proximal avulsions, many novel arthroscopic clinical studies have focused on cohorts involving Type 1 and 2 ACL tears. A systematic review from van der List in 2020 [23] describes outcomes of arthroscopic proximal ACL tears from 13 studies and 1101 patients. Failure rates were found to be between 7-11%, with re-rupture rates trending lower for those treated with suture tape augmentation (compared to isolated suture repair or those using DIS). There were no major complications outside of re-rupture, and PROMs were all >85% of maximum scores.

Contrarily, studies such as Murray’s BEAR procedure [2], described above, uses a mixed patient cohort, including those with Type 3 ACL tears. Although this illustrates that midsubstance tears do have the ability to heal, further research is needed to evaluate outcomes of ACL repair when isolating for midsubstance tears when using arthroscopic techniques. Currently, there are no ACL repair studies isolating and selecting patients with Type 3, 4, or 5 ACL tears.

**Partial tears**

Partial ACL tears, especially those involving greater than 50% of the ligament, are likely to progress to full tears and symptomatic instability over time [40]. Treatment may involve nonoperative management with rehabilitation, the healing response technique, ACL repair, selective bundle reconstruction, or ACLR [41]. Rapid degradation of remaining intact ACL fibers following partial ACL injury has been demonstrated in animal models [42], which may contribute to these poor outcomes. To prevent secondary instability events leading to complete rupture and the associated chondral or meniscal damage that can occur with them, treatment of symptomatic partial ACL injuries is frequently recommended [40]. MRI sensitivity in identifying ACL ruptures has been found to be roughly 87% [43]. This number may be even lower for partial ACL injuries. This means that identifying patients with partial or single bundle injuries
relies even more on careful history and physical examination findings that suggest whether a patient has either a “functional” or “nonfunctional” ACL. Literature focusing on ACL repair techniques for partial ACL tears is relatively limited. Gobbi et al. [37] performed arthroscopic side-to-side repair of partial injuries along with marrow stimulation and found patients to have excellent PROM for those who did not experience failure. Although, instability failure rates at long term outcome (10 years) were found to be 27%. A more novel repair technique, including tensionable looped suture fixated to a suture anchor in the femoral footprint in military personnel with partial proximal avulsions, has been explored by Weixiong et al. [44]. They found excellent PROMs and 0/19 failures at mean follow up of 37 months. Novel arthroscopic repair techniques applied to partial tears, especially those with partial femoral avulsions of a single bundle of the ACL (Images 8-9), along with biological enhancement appears to be a viable treatment option, although more high-level studies comparing treatment to non-operative management or ACLR need to be performed.

Multi-ligamentous Knee Injuries

With the increase in popularity of ligament repair and adjunctive suture augmentation for a variety of clinical applications, new attempts at treating knee dislocations or multi-ligamentous knee injuries without reconstruction have surfaced. Recent studies have cited satisfactory short and midterm outcomes (IKDC ~75) with isolated repair and suture augmentation for type III and IV injuries, in these high-risk cohorts. Rates of revision have been found to be relatively high (~17%) with side to side stress instability of 3-11mm [45,46].

Other Considerations

Preoperative and Intraoperative Decision-making

For surgeons interested in incorporating ACL repair into their practice, preoperative and intraoperative decision making are both paramount. For each patient, surgeons must be prepared to repair or reconstruct the ACL and appropriately counsel them preoperatively. This often involves the foresight of notifying vendors of specific repair products that may or may not be available at the surgery center or hospital they operate at.

Partial or incomplete ACL injuries may provide patients with unique exam findings separating them from complete tears. Although, more frequently, exam findings will be equivocal between varying degrees of severity of injury to the ACL and different tear patterns. Advanced imaging can give surgeons a preoperative idea of which ACL tear pattern is reparable in their hands. Examples of MRI findings and their arthroscopic counterpart compatible with each tear pattern have been included to provide surgeons cues to look for when diagnosing tear patterns preoperatively. Sometimes, MRI intrasubstance signal consistent with partial or incomplete injury to the ACL can be nonspecific and questionable regarding the severity of the ACL injury [43]. Additionally, MRI’s frequently read by radiologists to be normal may contain ACL strain, partial or complete tearing. In patients with a questionable degree of injury to the ACL, given appropriate nonoperative management and rehabilitation considerations, they may request surgical intervention due to continued instability events upon RTS. Careful questioning of the
patient will provide cues to the surgeon illustrating that the patient continues to have symptoms of a “nonfunctional” ACL. In these circumstances, KT1000 testing may further provide surgeons with additional information regarding side-to-side differences that can suggest ACL injury. Ultimately, arthroscopic evaluation with the ability to provide an ACL repair or reconstruction if a partial or complete injury is found may be necessary. During surgery, assessment of tissue quality involves arthroscopic evaluation of the ACL stump by a probe. Proximal tears may also be assessed using an arthroscopic grasper to visualize tissue mobility to the femoral footprint. Midsubstance and even proximal tears with shredded or disorganized fibers are less amenable to healing (Image 10). If the tissue quality or tear pattern is of debatable repairability, do not be afraid to bail to an ACLR.

Surgical Timing

Prolonged time from injury to surgery has been reported to negatively influence the outcomes of contemporary ACL repair techniques [1,47,48]. The longer the time from injury, the more the ACL tissue is at risk of degrading from the harsh synovial environment, diminishing the healing potential of the ACL [42] and reducing the possibility of encountering repairable tissue quality at the time of surgery [47]. Currently, the dogma of ACL repair is to treat the injury as soon as feasible. The mean time interval from injury to surgery reported in a recent meta-analysis was just 21 days, with some surgeries conducted as early as 1 day post injury and other studies illustrating average timing delayed greater than 6 weeks [49]. Despite on average earlier surgical intervention, the increased risk of extension loss, identified following acute reconstruction in early ACLR studies, has not been similarly identified in ACL repair with suture tape augmentation (less than 1%) [50]. Complications requiring surgical intervention other than failure were frequently grouped together and have been found to be near 10%, which is comparable with ACLR [4]. This may be higher in those undergoing DIS (~20%) [51]. The concept of increased risk of arthrofibrosis with early ACLR intervention has also been refuted in more recent studies [52]. In contrast, ACL repair patients are more likely to have greater than 90 degree ROM at 1 week and full ROM at 4 weeks than ACLR [50]. There is no human clinical data comparing the acuity of ACL repair and its relative healing capacity and likelihood of developing arthrofibrosis.

Patient-Related Factors

Additionally, age and activity level are of consideration. Orthopedic surgeons should be wary of treating adolescent patients with ACL repair as they continue to demonstrate significantly higher failure rates with repair than with a traditional reconstruction [32]. Further research into these patient demographics with collagen-based scaffold augmentation and the addition of LEAT or ALLR is needed prior to adoption by the general sports medicine orthopedic surgeon. Older patients involved in lower energy, pivoting injuries, leading to type 1 and 2 tears, such as those seen frequently in skiing, provide an ideal patient population for repair [13]. Patients also requesting a less invasive surgery that allows them to return to work more quickly, may opt for repair. For patients willing to trade a potentially more normal feeling knee with improved early rehabilitation for the risk of a higher failure rate, this may be the ideal operation. For the competitive athlete, the increased risk of failure may not be worth it.
Addition of Laterally Based Procedures

There has been a plethora of recent data supporting the increased use of laterally based adjunctive procedures such as lateral extra-articular tenodesis (LEAT) and anterolateral ligament reconstruction (ALLR) [53–55] for patients undergoing ACLR. Selection criteria focuses on high-risk patients. Patients who are younger than 25, competitive athletes, or have high-grade pivot-shift tests, Segond fractures or lateral femoral notch sign, ligament hyperlaxity, and concomitant meniscus repair, among others, are considered [53–55]. In patients selected for ACLR or repair, the additional rotational stability conferred by a LEAT or ALLR may ultimately lead to lower failure rates and help protect the graft/ligament during the early recovery period. A 2020 study by Hopper et al. [56] found a 5.3% failure rate when high risk patients underwent a combined ACL repair (type 1 and 2 ACL injuries) along with ALL suture tape augmentation. PROM and overall patient satisfaction scores were also excellent (~90-94%). At a failure rate of 5%, this is similar to high-risk patient populations undergoing combined ACLR and laterally based procedures. With the findings of this study as well as the additional findings found throughout ACLR literature, LEAT/ALLR should be heavily considered as an adjunctive procedure in ACL repair.

Post-operative Care

Currently, there is no evidence-based data, comparing and advocating for faster rehabilitation protocols and RTS for ACL repair versus reconstruction [57,58]. Initial data does support that the rehabilitation process is less painful and that patients regain post-operative mobility and patient confidence more quickly [5,6]. This intuitively makes sense as drill tunnels are smaller, there is no graft harvest, and patients maintain some proprioceptive fibers of the native ACL. This early recovery and increased patient confidence causes patients to be eager to return to activity at an accelerated rate compared to ACLR. Continuing to follow ACLR protocols for therapy with RTS on a more gradual basis is prudent until more expedited protocols have been fully researched and established.

MRI monitoring of ACL repair patients may also be considered during the post-operative time period. ACL maturation on MRI during repair is fundamentally different than that seen following reconstruction. In ACLR, signal intensity peaks at 4-8 months postoperatively, following the process of ligamentization [59]. In ACL repair, maturation and signal intensity have been found to frequently normalize by 3 months following surgery [59,60]. One study demonstrated isointense signal of the repair in 9/10 patients at 3 months [60].

Conclusion

Despite a lack of level 1 and 2 evidence, the current literature supports novel ACL repair techniques as a safe and effective treatment option for patients with ACL tears. Patient selection is key, as adults with Sherman Type 1 and 2 ACL injuries with remaining good tissue quality as found through arthroscopic evaluation, have been shown to perform significantly better at short- and medium-term follow up. Patients with Sherman Type 3 ACL injuries and those with poor tissue quality are likely best suited with ACLR at this time. Adjunctive biologics, especially collagen-based scaffolds and the addition of growth factors through whole blood or PRP and/or
bone marrow enhancement through microfracture of the femoral footprint, can be considered to improve healing and revascularization of the ACL, especially if considering repairing a Type 3 ACL tear. In addition, improved stability of the repair construct through use of adjustable cinch loop tensioning sutures, suture tape augmentation, and laterally based extra-articular procedures should be incorporated to protect the ACL repair from gap formation and early failure.

Further research is needed to ultimately determine the long-term outcomes of modern ACL repair. Additionally, level 1 studies directly comparing the use of scaffolds and biologics to suture augmentation alone will be helpful to determine the relative risk reduction for these costly adjunctive treatments.

Given the use of these techniques above and appropriate patient selection criteria, patients should be counseled on outcomes comparable to ACLR. Specifically, they may experience a slightly higher re-rupture rate with the benefits of improved early rehabilitation and pain, the avoidance of autograft comorbidities, and a more natural feeling or “forgotten” knee.

References


Massey P, Parker D, McClary K, Robinson J, Barton RS, Solitro GF. Biomechanical comparison of anterior cruciate ligament repair with internal brace augmentation versus


48. Magarian EM, Fleming BC, Harrison SL, Mastrangelo AN, Badger GJ, Murray MM. Delay of 2 or 6 weeks adversely affects the functional outcome of augmented primary


Figure 1. Sherman Type 1
Sagittal T2 weighted MRI image depicting a Sherman Type 1 - ACL avulsion injury from the lateral wall of the femoral condyle.

Figure 2. Sherman Type 1
Arthroscopic view from the anterolateral portal looking into the femoral notch noting an ACL avulsion from the lateral wall of femoral condyle. Sherman Type 1.

Figure 3. Sherman Type 2
Sagittal T2 weighted MRI image depicting a Sherman Type 2 tear through the proximal third substance of the ACL.

Figure 4. Sherman Type 2
Arthroscopic view from the anterolateral portal indicating a tear through the proximal third of the ACL.

Figure 5. Sherman Type 3
Sagittal T2 weighted MRI image depicting Sherman Type 3 tear through the midsubstance of the ACL.

Figure 6. Sherman Type 3
Arthroscopic view from the anterolateral portal showing a tear through the midsubstance of the ACL.

Figure 7. Sherman Type 4
Sagittal T2 weighted MRI image depicting a Sherman Type 4 tear through the distal third of the ACL.

Figure 8. Sherman Type 4
Arthroscopic view from the anterolateral portal showing a tear through the distal substance of the ligament.

Figure 9. Sherman Type 5
Sagittal T2 weighted MRI image depicting an avulsion of the ACL from the distal insertion at the tibia.

Figure 10. Sherman Type 5
Arthroscopic view from the anterolateral portal showing a distal tibial avulsion of the ACL.

Image 1: Primary ACL Repair with Suture Anchor Fixation
An arthroscopic suture passer is used to pass cinched looped suture around the remaining ACL fibers and tensioned/fixated to a biocomposite suture anchor at the ACL footprint on the lateral femoral condyle.

**Image 2: Primary Repair with Suture Tape Augmentation**
An ACL targeting guide is used to place a drill pin within the center of the ACL tibial footprint. Suture tape previously incorporated during femoral fixation of the ACL is then retrieved and passed through this tibial tunnel and secured on the tibia over a metal button or with a suture anchor.

**Image 3: Adjustable Loop Cinch Fixation**
Adjustable loop cinches allow for incremental tensioning and retensioning of the ACL stump during ACL repair.

**Image 4: Dynamic Intraligamentary Stabilization**
This technique utilizes a spring loaded monoblock implant designed to dynamically preserve the ACL by applying a posterior drawer force across the knee in a load-sharing manner.

**Image 5: BEAR Procedure**
The collagen-based scaffold is seen loaded onto a suture tape augment.

**Image 6: BEAR Procedure**
The scaffold is then saturated with roughly 5-10 mL of patient whole blood.

**Image 7: BEAR Procedure**
The saturated implant is then inserted through a medially based arthrotomy prior to tensioning the previously shuttled suture tape augment.

**Image 8: Arthroscopic view from the anterolateral portal illustrating a patient with a posterolateral bundle ACL tear.**

**Image 9: Arthroscopic view from the anterolateral portal demonstrating treatment of a partial ACL tear using adjustable loop fixation with suture tape augmentation.**

**Image 10: Sherman 2 ACL injury with shredded and disorganized ACL fibers. A BEAR implant was used to supplement repair in this case. Consideration was given to ACLR given the degree of ACL injury.**
Declaration of interests

☐ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☒ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Brian Gilmer reports a relationship with Arthrex Inc that includes: consulting or advisory, funding grants, non-financial support, speaking and lecture fees, and travel reimbursement. Brian Gilmer reports a relationship with Arthroscopy Association of North America that includes: board membership. Brian Gilmer reports a relationship with DePuy Orthopaedics Inc that includes: travel reimbursement. Brian Gilmer reports a relationship with ROM3 that includes: equity or stocks.