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REVIEW

Tissue Augmentation Techniques in the Management of Ligamentous Knee Injuries

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Abstract: Despite early reports of high failure rates in knee ligament repair techniques resulting in favor of reconstruction, newer advances in surgical technology have shifted the attention back to repair with the addition of various tissue augmentation techniques. Ligament repair preserves proprioceptors in the native ligament and avoids autograft tendon harvest, minimizing the complications associated with donor site ruptures in reconstruction techniques. Tissue augmentation has been successfully used in knee ligamentous and tendon repair procedures, as well as in some upper extremity procedures. This study provides a clinical update on the surgical techniques, biomechanics, and outcomes with the application of various tissue augmentation techniques in the ligaments surrounding the knee joint.

Keywords: knee, tissue augmentation, ligament repair, suture augmentation, ligament reconstruction, internal brace

Introduction

Soft tissue injuries to the knee are particularly common in physically active individuals with an estimated annual incidence of 720 injuries per 100,000 persons.[1,2] The anterior cruciate ligament (ACL), posterior cruciate ligament (PCL), medial collateral ligament (MCL), lateral collateral ligament (LCL), posterolateral corner (PLC), posteromedial corner (PMC), and medial patellofemoral ligament (MPFL) play a significant role in the stability of the knee joint, so injury to one or more of these ligaments can detrimentally affect the biomechanical function and stability of the joint.[3,4] Improper treatment can lead to instability of the knee joint, which may increase the risk of subsequent osteoarthritis.[4–6] The potential functional deficits coupled with the high cost of these injuries make it imperative to identify the optimal form of treatment for patients.

Traditionally, ruptures of the knee ligaments have been treated with reconstruction using an autograft or an allograft due to earlier reports of high failure rates in repair techniques.[7–9] However, attention has shifted to repair as a potentially effective intervention with the recent addition of tissue augmentation techniques. Ligament repair preserves proprioceptors in the native ligament and avoids autograft tendon harvest, minimizing the complications associated with donor site ruptures in reconstruction techniques.[10,11] Some of the proposed augmentation techniques involve the use of suture tape as a secondary stabilizer to the native ligament repair to aid the healing process.[12] Augmentation with internal brace has been successfully used in knee ligamentous and tendon repair procedures, as well as in some upper extremity procedures including, but not limited to, acromioclavicular joint augmentation and repair of the ulnar collateral ligament of the elbow.[12] This study provides a clinical update on the surgical techniques, biomechanics, and outcomes with the application of various tissue augmentation techniques in the ligaments surrounding the knee joint.

Anterior Cruciate Ligament

ACL injuries are highly prevalent in the sports culture, so proper treatment is imperative to maximize return to sport outcomes and avoid potential complications. Choosing the appropriate treatment of an ACL tear requires careful

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consideration between the patient and physician, as there are multiple surgical techniques with various indications. Reconstruction has typically been the favored method of treatment due to earlier studies demonstrating high complication and failure rates with primary repair.[9,13–15] However, recent advances in surgical technology and techniques have renewed interest in ACL repair as a viable treatment option.[16–18]

A meta-analysis by Vermeijden et al found that primary repair with static suture augmentation is a reliable treatment option for proximal ACL tears with only an 8% overall failure rate.[19] Of note, the failure rate was significantly higher in patients less than 18 years of age with a failure rate of 17% versus 6% in adults. While this study found a clear advantage to this repair technique, there has been significant heterogeneity in the literature when considering factors such as location of the ACL tear as well as type of suture augmentation.

Another technique being utilized to augment the ACL is internal bracing. Wilson et al published a meta-analysis analyzing ACL repair with internal bracing and found that among 347 total patients there was a 10.4% failure rate.[20] However, the results come with a warning that the data may not be very strong due to most of the evidence stemming from case series.

Dynamic intraligamentary stabilization (DIS) replaces a rigid form of suture fixation by using a braided polyethylene wire with an internal dynamic screw-spring mechanism, providing dynamic stability continuously in every degree of motion.[21–24] Kosters et al performed a randomized control trial between ACL repair with DIS compared to anatomic single bundle ACL repair with a four stranded semitendinosus autograft.[25] All patients in this study were confirmed to have an ACL that was repairable. They found similar failure rates, revision rates, and functional outcomes in the two groups; however, there was significantly more anterior tibial translation in the DIS group postoperatively. Evangelopoulos et al looked at midsubstance repairs fixed with a DIS system called "Ligamys" along with application of a collagen I/III membrane on the surface of the ACL.[26] While the Ligamys system alone did not prove to be an effective treatment for ACL tears with an 78.8% complication rate, the addition of the collagen membrane decreased the complication rate to 8.7%. Bieri et al looked at return to work rates with DIS vs reconstruction and noted a 1-month earlier return to work with the DIS group.[27] They also reported that outside of return to work there were no other clinically significant differences, including revision rates and treatment costs.

Current literature demonstrates that tissue augmentation techniques in treatment of the ACL can achieve clinical success with satisfactory functional outcomes and low failure rates.

While literature on ACL ligament augmentation techniques is certainly one of the most robust compared to other knee ligaments, further research in the form of high-quality comparative studies is necessary to fully understand the efficacy of these techniques.

Posterior Cruciate Ligament

The posterior cruciate ligament (PCL), composed of both a larger anterolateral bundle and a smaller posteromedial bundle, serves as the primary restraint to posterior tibial translation.[4,11] It has been reported that the PCL has the ability to self-heal, which historically has favored a non-operative management of low-grade (Grade I and II) isolated injuries, though this approach has been associated with decreased functional outcomes and radiographic evidence of arthritic changes. [4,10] For symptomatic Grade III or multi-ligament injuries, surgical reconstruction–most commonly with either a single or double-bundle technique–can be considered.[28–31]

The utilization of suture augmentation or internal bracing in the repair or reconstruction of ligamentous injuries has become increasingly prevalent in the literature. Recent cadaveric studies have helped develop a biomechanical argument for the utilization of these techniques. Grotting et al illustrated that the addition of suture augmentation to an all-inside PCL reconstruction reduced the posterior tibial translation to levels comparable to an intact knee.[32] Levy et al advanced the rationale for suture augmentation by demonstrating that the utilization of suture tape resulted in reduced graft elongation with increased strength in both an all-inside and interference screw reconstruction.[33]

It is perhaps even more promising that clinical studies have shown satisfactory patient-reported outcomes with suture augmentation. Hopper et al recently investigated 2-year outcomes for PCL repair with suture augmentation and demonstrated that postoperative outcomes were comparable to those of a more conventional PCL reconstruction.[34] These results were further supported by another clinical investigation that found satisfactory clinical outcomes at 2-year

follow-ups, demonstrating a high return to normal daily exercise (93.55%) and high return to competitive sports (74.19%) for patients who underwent single-bundle PCL reconstruction with internal bracing.[35]

There is a paucity of comparative studies in the current literature, owing to the fact that PCL injuries are often not isolated and concomitant with other ligamentous injuries, otherwise known as multi-ligament knee injuries.[36,37] The comparison of these multi-ligament injuries is complicated by their rarity, variations in both the specific structures affected (often denoted by the Schenck classification) and mechanism of injury, and differences in patient population. Even in studies such as Therrien et al that demonstrated similar clinical outcomes in the all-inside single-bundle PCL reconstruction with and without suture tape reinforcement acknowledge that the severity of injuries varied between cohorts being compared.[38] Still, individual case reports have demonstrated the viability of suture augmentation in severe multi-ligament knee injuries, illustrating a clear need for high-quality prospective trials comparing traditional reconstruction with and without suture augmentation.[37,39]

Medial Collateral Ligament

Rupture of the medial collateral ligament (MCL) can be a challenging problem to treat, especially in the context of multi-ligament knee injuries. Tissue augmentation techniques for knee MCL repair have been described, but there is a paucity of literature reporting functional outcomes of these techniques. This is perhaps in part because MCL injuries can often be managed non-surgically. However, surgical intervention may be needed in the setting of severe multi-ligament knee injuries or grade III injuries, and given the rarity of these injuries, limited evidence is available regarding the patient outcomes following isolated MCL repair with tissue augmentation.[40]

Semitendinosus autograft can be used to reinforce the MCL by drilling holes at the attachment sites proximally on the medial epicondyle and distally on the tibial metaphysis.[41] LaPrade et al[42] performed a clinical trial in patients with grade III MCL injuries who underwent MCL repair with semitendinosus autograft augmentation versus MCL reconstruction with semitendinosus autograft. The patients had similar objective outcomes (radiographic side-to-side opening in the medial knee under valgus stress) at 1 year postoperatively, but the patient reported outcomes favored the reconstruction procedure.[42]

Hirahara et al[43] described the use of a percutaneous technique under ultrasound guidance for MCL stabilization. The authors used ultrasound to identify the proximal and distal attachment sites of MCL to place the sockets, and the injured ligament was reinformed percutaneously with a 2 mm wide suture tape.[43] The main advantage of the percutaneous augmentation of MCL with suture tape was that the native ligament was allowed to heal, while the suture tape was providing stability to the medial knee joint by acting as a "backstop".[43] This last technique has not been supported by patient outcomes in the literature and therefore its clinical value remains unclear.

LeVasseur et al described a surgical technique with the use of Biobrace (Biorez, New Heaver, CT) to augment the MCL repair or reconstruction.[44] The BioBrace is a bio inductive scaffold that consists of type I collagen as well as bioresorbable L lactide microfilaments that aids in the biologic healing of MCL while also providing mechanical support. Similar to the percutaneous MCL augmentation technique described above, the clinical efficacy of Biobrace in MCL surgery has not been supported by patient outcomes.[44]

Augmentation of MCL repair with suture tape has also been reported. In a combined ACL reconstruction-MCL repair model, MCL repair with suture tape augmentation resulted in superior biomechanical properties (reduced valgus and external rotation laxity) compared to MCL suture repair alone.[45] Various techniques have been reported with the use of suture tape to reinforce MCL repair during the last decade;[45–47] however, clinical outcome studies focusing on the functional outcomes following isolated MCL augmentation with suture tape are missing.

Lateral Collateral Ligament

The lateral collateral ligament (LCL) is not often ruptured in isolation, but instead occurs most commonly in the context of a multi-ligament injury. For Grade 3 (complete tear) isolated LCL injuries, the traditional surgical approach is reconstruction using a semitendinosus autograft surgical treatment.[48] However, various suture augmentation techniques have been explored to protect the repaired ligament during the healing process while also allowing for earlier mobilization.

Trasolini et al[49] presented the cases of two active individuals who suffered multi-ligamentous knee injuries in which the LCL was repaired with internal bracing. By nine months postoperatively, both patients achieved a full range of motion and returned to their sports successfully.

Vermeijden et al[50] described a technique for primary distal LCL repair using suture tape augmentation to retain the native ligament. Suture tape was used on the fibular head, lateral epicondyle, and proximal LCL to augment the repair. While potential advantages of ligament preservation, protection of the repair, and early postoperative mobilization were suggested, no clinical data was reported to support these claims. Hecker et al[51] performed a similar technique in one patient among a cohort of LCL repairs but did not differentiate clinical outcomes based on the presence of augmentation, so no definitive conclusions could be made. Schoell et al[52] described the use of suture tape in one patient with a distal rupture of the LCL, distal biceps tendon avulsion, and ruptured anterolateral capsular complex. In the final follow-up, the patient demonstrated excellent strength and stability measures.

With the majority of the evidence stemming from technical notes and case reports, more substantial evidence through larger clinical studies is imperative to make any definitive conclusions about tissue augmentation techniques for the LCL.

Posterolateral Corner

The PLC is comprised of three major structures: the LCL, popliteofibular ligament, and popliteus tendon.[53] Isolated PLC injuries are rare, as they are more likely to occur in combination with a rupture of the ACL or PCL.[54] Historically, rupture of the PLC was treated with primary repair,[55] but reports of high failure rates in repairs have shifted the direction in favor of reconstruction.[8,56] However, advances in technology have renewed the interest in repair in hopes of minimizing graft-site morbidity and maintaining the proprioceptive properties of the native tissue.[57,58]

Hopper et al described a PLC repair technique with suture tape augmentation, citing early rehabilitation, preservation of donor tissue, and simplicity of the procedure as advantages. The same authors followed up with a case series of this technique in 16 patients, 5 of whom sustained a PLC injury in the context of a multiligament knee injury and 11 of whom had an isolated PLC rupture. At two-year follow-up, all subsections of the KOOS, WOMAC, and VR-12 increased significantly from pre- to postoperative time periods, and the overall satisfaction rate was high (86%). Two patients (12.5%) with isolated PLC repairs underwent further surgery on the same knee.[59] Vermeijden et al expanded on this technique, adding the fixation of the LCL primary repair portion of the case to the far cortex of the fibula, citing tissue preservation, early postoperative mobilization, and minimal invasiveness as potential benefits of the procedure.[50] Jildeh et al described similar benefits in a suture augmentation technique for patients with acute knee dislocation and injury to the biceps femoris, LCL, iliotibial band, popliteofibular ligament, and meniscocapsular attachment of the lateral meniscus. Notably, the authors all cited timing as a potential limitation, as repair of the PLC with suture augmentation is only plausible in the (sub)acute setting in order to maintain tissue quality.[60]

There is a paucity of literature on the subject, with most of the information being derived from technical papers and case series. Further clinical studies are necessary to attain any meaningful conclusions about the clinical application of this technique.

Posteromedial Corner

The PMC consists of a distinct set of structures contributing to anteromedial rotatory knee stability.[61] There is a paucity of literature on the optimal management of PMC injuries, which most commonly occur in the setting of other ligamentous injuries. Isolated grade I and II injuries have traditionally been managed non-operatively with bracing and physical therapy. Isolated grade III injuries are rare and typically occur in the setting of a multi-ligamentous knee injury.

A variety of techniques exist for both repair and reconstruction. In the setting of a multi-ligamentous knee injury, PMC reconstruction can be complicated by the limited remaining autograft available for harvest and bone tunnel convergence.[62] Newer techniques and biomechanical studies have focused on augmentation with an internal brace to reinforce the PMC repair. Lubowitz et al[63] described a technique for PMC repair with internal brace augmentation to reinforce the repair. This technique is supported biomechanically in a study from Mehl et al which demonstrated that at time zero, PMC repair with suture tape augmentation is restored close to native valgus and rotatory laxity.[64] Furthermore, Gilmer et al[65] found that the load-to-failure PMC repair with suture tape augmentation was superior to repair only and

equivalent to reconstruction of the MCL. Currently, the literature on PMC repair and reconstruction with augmentation is limited to biomechanical studies. Further clinical studies are necessary to determine outcomes, complications, and cost-effectiveness.

Medial Patellofemoral Ligament

Given the high failure and poor satisfaction rate of conservative treatment after patellar dislocation, surgical intervention is often warranted to improve treatment of these injuries.[66–68]

Traditional reconstruction of the medial patellofemoral ligament (MPFL) has been utilized most frequently, although some recent literature has demonstrated a renewed interest in MPFL repair.[12,69] Despite its ability to achieve adequate patellar stability and functional outcomes,[70,71] these procedures are associated with a relatively high complication rate,[72,73] prompting exploration into alternative techniques in the form of tissue augmentation.

To resolve the problem of laxity in post-MPFL reconstructed patellae, Xie et al conducted a randomized controlled trial to examine the effect of polyester suture augmentation in MPFL reconstruction compared to non-augmented reconstruction using a semitendinosus graft. Both groups improved from preoperative values in functional evaluations, but the augmented group had statistically significant superior results in IKDC, Tegner, Kujala, and Lysholm scores at 2 and 5-year follow-up. CT examination revealed that the corrected position of the patella deteriorated over time in the nonaugmented group but not in the augmented group. The failure rate in the augmented group was only 2.4%, which was significantly lower than the nonaugmented group (23.39%) ($p=0.004$).[74] Using a similar technique, Hobson et al compared augmented and non-augmented MPFL reconstructions in 49 adolescent patients under the age of 18 with recurrent patellar instability. At 4-year follow-up for the augmentation group and 6-year follow-up for the non-augmentation group, mean IKDC, Marx activity scale, and VAS scores all improved, but the difference was not significant between groups. However, significantly fewer patients in augmentation group experienced further injury to ipsilateral knee than in the non-augmentation group.[75]

To avoid complications associated with autografts, Hopper et al reported five-year outcomes of 17 patients who received suture tape augmentation for MPFL repair. Significant improvement was observed in all KOOS subscales, WOMAC, VR-12, and VAS scores, and there were no complications or further instability episodes.[76]

An initial cadaver study by Tsushima et al demonstrated that suture tape with knotless anchors had a mean ultimate load of 178.4 ± 4.4 compared to 102.8 ± 21.5 N for reconstruction using a semitendinosus autograft, demonstrating stronger biomechanical properties and resistance to elongation.[77] Findings from Mehl et al confirmed that primary contact pressure and joint kinematics were similar in suture tape augmentation and reconstruction with a graft.[78] Use of synthetic materials avoids complications associated with autograft harvest but may result in an overly constrained patella due to the fixation angle of the synthetic ligament.[79]

In a retrospective analysis of 17 patients, Xu et al demonstrated a 94.1% success rate using high-strength polyester suture tape for patients with recurrent patellar dislocation. While significant improvement was observed in knee functional outcome scores and radiographic values, three patients experienced complications (17.6%). Of note, the study was limited by a short-term follow-up of 14 months and therefore could not make any conclusions about long-term outcomes.[80] Findings from Sasaki et al corroborated these results in a prospective cohort study of 43 patients, demonstrating a significant increase in all KOOS subscales and improvement in radiographic findings. The study cohort included 21 athletes from different sports, all of whom returned to play within one year of the operation.[81]

Milinkovic corroborated these findings in a comparison of high-strength suture tape reconstruction to reconstruction with a quadriceps tendon autograft in 57 patients with lateral patellar instability. Participants were matched 2:1 for age, sex, anatomic risk factors, and concomitant bony correction, and both groups demonstrated significant improvement in the Banff Patella Instability Instrument 2.0, pain levels, and subjective knee joint function, but there was no significant difference between groups. Of note, the follow-up period was significantly longer in the non-augmented group (24.6 ± 1.3 vs 35.8 ± 9.9 months).

Relative to other knee ligaments, literature on MPFL tissue augmentation techniques is of higher-quality evidence and appears to be more promising. Further research is warranted to better understand the clinical implications of these techniques, but the current literature demonstrates good functional outcomes and a low risk of complications.

Conclusion

Different methodologies of tissue augmentation for knee ligament repair offer varying levels of success. Tears in the ACL have the most literature supporting outcomes of a variety of tissue augmentation techniques. Preliminary evidence suggests that suture tape augmentation and internal bracing can achieve good clinical outcomes and a low failure rate, but higher quality clinical trials are necessary to analyze the long-term effects of tissue augmentation techniques and compare to that of more traditional methods.

Ethics Approval

No ethics approval was required.

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