Future Prospects for Bridge Enhanced ACL Repair in ACL Injury Treatment

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Abstract. Anterior cruciate ligament (ACL) is one of the four most important ligaments in human knee, and ACL tears are one of the most commonly seen injuries among common ligamentous knee injuries. Severe ACL tears usually require surgical treatment for complete recovery. In the past decades, ACL reconstruction (ACLR) has been the gold standard by its high success rate and easiness on surgical application. However, ACLR sacrifices native ligament tissue and may lead to donor-site morbidity and delayed neuromuscular recovery. The new Bridge-Enhanced ACL Repair (BEAR) technique introduces a biologically augmented approach that keeps the patient's native ligament tissue and proprioceptive fibers while restoring ligament integrity. Histological analyses have proven ligament function regeneration sign on BEAR treated patients. In randomized controlled and prospective cohort studies, BEAR treated patients show better IKDC and KOOS improvements compared to patients treated with traditional ACLR. Clinical reports further validate BEAR's potential to reduce postoperative complications and enhance neuromuscular function. This review aims to synthesize the biological rationale, operative evolution, clinical effectiveness, and remaining challenges of BEAR in contemporary ACL care.

Keywords: BEAR; anterior cruciate ligament; collagen scaffold; ligamentization.

1. Introduction

Anterior cruciate ligament (ACL) is one of the four major ligaments in knee joint function during its movement. The ACL plays an important role in stabilizing the knee structure and maintaining the stable movement of the anterior tibial from unexpected translation and rotational instability. Due to the importance of ACL ligament in supporting the movement of knee function, and the high frequency of its role in exercising, among most of the knee injury cases, ACL tear is most likely to happen, especially among athletes playing basketball, football, or skiing, which requires strong confrontation and spinning body movements [1, 2]. Besides athletes, ACL tears are also common in recreational or nonprofessional exercisers, especially those who train without proper guidance or maintain poor movement habits. Untreated or improperly treated ACL ruptures could lead to chronic instability, secondary meniscal damage, and the early development of osteoarthritis.

There are two commonly accepted approaches to managing ACL tears. For mild or partial tears that do not significantly compromise knee joint stability, conservative management with structured rehabilitation is usually preferred. In contrast, more severe injuries, especially complete ruptures that lead to clear instability, generally require surgical intervention. Over the past decades, two main surgical strategies have dominated ACL treatment, reconstruction and repair. ACL reconstruction is the process to replace the torn ligament with a graft, which may be autograft, allograft, or synthetic tissue, with the primary goal of restoring mechanical stability, joint mobility, and allowing the patient to return to physical activity at a level close to their preinjury level [3, 4]. In contrast, ACL repair aims to preserve the native ligament tissue by reattaching the torn ends and promoting biological healing across the rupture site. From the perspective of recovery, the repair approach maintains the intrinsic vascularity, proprioceptive fibers, and local tissue environment of the original ligament, which is, theoretically, more beneficial for healing and potentially improve the restoration of proprioceptive function.

Since 1970s, numerous attempts were made by the medical community to repair the ACL ligament. However, most of those attempts were not successful. The intrinsic poor vascularity of the ACL, combined with the fibrinolytic activity of the synovial fluid, prevented the formation of a stable fibrin clot, and thus prevents the torn site bridging successfully. Due to the lack of protective biological environment to facilitate cellular migration and collagen synthesis, the repaired ligament often failed to regain adequate tensile strength, resulting in persistent instability, and causes a higher risk of re-rupture. Thus, ACL repair techniques gradually became marginalized over the following decades, being replaced by the more mechanically reliable method of ACL reconstruction. Although reconstruction procedures are generally less technically demanding, have a lower failure rate, and achieve consistent short-term success, this process does have a significant defect: reconstruction sacrifices the native ligament tissue and its proprioceptive neural fibers, which may impair postoperative neuromuscular control of the knee. Moreover, the graft remodeling process is relatively slow, and the biomechanical strength of the artificial graft is often weaker than the native ligament, unable to provide enough strength between the tendon and the bone, making it hard for the patient to restore full movement capability. Besides, ACL reconstruction often involves the use of artificial fixation devices or synthetic materials, which can lead to donor-site morbidities such as anterior knee pain or hamstring weakness, causing a higher risk of degeneration of the joint.

As the development of biotechnology and material science, in recent years, ACL repair has once again gained renewed attention by the clinical view. Among the emerging approaches, Bridge-Enhanced Anterior Cruciate Ligament Repair (BEAR) is one of the most important approaches and has a great hope for ACL injuries [1, 5]. The BEAR procedure utilizes a resorbable type I collagen scaffold that is saturated with the patient's autologous blood and placed between the torn ends of the ligament. This scaffold acts as a biological bridge, provides a microenvironment favorable environment for healing by recruiting platelets, growth factors, and fibroblasts to the injury site. By preserving the native ACL stump and stimulating the intrinsic repair response, BEAR aims not only to restore ligament continuity but also to reestablish proprioceptive function of the knee without placing an artificial graft. This review aims to evaluate the current evidence regarding the BEAR technique, summarizing its biological mechanism, surgical practice, clinical efficacy, and existing limitations.

2. Biomechanical Basis of the BEAR Technique

As an innovative approach to ACL repair, the BEAR technique relies on biologically augmented scaffold to support ligament regeneration and promote biological integration. This concept relies on the application of a type I collagen scaffold, which is a structure made of the same material that forms the ligament and tendon, saturated with autologous whole blood to form a bioactive matrix which then further promotes the restoration of the torn ligament. Type I collagen fibers, which have an excellent biocompatibility, allowing essential nutrients and oxygen to be delivered to the regenerating site by promoting blood supply through angiogenesis [5]. This process further helps cell migration, proliferation, and extracellular matrix deposition during the healing process.

In the study conducted by McMillan et al., tissue specimens were collected and analyzed from patients who had undergone BEAR procedures. After 12 to 20 months of the implantation treatment, biopsies show a structure of densely organized type I collagen fibers, well-developed neovascularization, and uniform fibroblast alignment. These are all positive signs of biomechanically functional healing for the patient's joint function. More importantly, no sign of acute inflammation, infection, or scar tissue formation was observed at the biopsy sites [6]. These results indicated that the repaired BEAR-treated patient's ACL develops normal fibroblast and vascular architecture, showing robust neovascular remodeling consistent with healthy ligament regeneration. In conclusion, these studies provide direct histological evidence that the BEAR technique creates a supportive biological microenvironment for the ACL and enables anatomic and functional regeneration.

3. Surgical Technique Development and Standardization

Arthroscopic workflows and rehabilitation protocols for BEAR have been detailed and validated, enabling reproducible implementation in clinical practice. A representative technical report described a stepwise procedure that includes whipstitch fixation with number 2 Vicryl sutures, creation of femoral and tibial tunnels at native footprints, implantation of a resorbable bovine derived type I collagen scaffold, hydration of the scaffold with autologous whole blood, and fixation with Endobutton devices. Throughout the procedure, anatomic landmarks are confirmed under arthroscopic visualization to ensure precise tunnel placement and scaffold position. Autologous blood hydration establishes a bioactive microenvironment that promotes platelet and growth factor aggregation, supporting tissue healing and early integration. Attention to portal placement, tunnel orientation, and the sequence of scaffold hydration helps maintain construct stability and favors durable biological incorporation [7].

Despite growing standardization, practical challenges remain in routine use. Accurate scaffold positioning and control of injected blood volume are critical variables that influence postoperative recovery and long-term outcomes. Image guided intraoperative techniques and structured rehabilitation pathways can mitigate these risks by improving placement accuracy and supporting graded loading during healing. Current indications prioritize skeletally mature patients with preserved tibial remnants and minimal scar formation, most often treated within an acute window of approximately fifty days after injury, which aligns surgical feasibility with the biological milieu favorable for repair.

4. Clinical Outcomes and Functional Performance

In short-term clinical follow ups, BEAR technique has shown a compatible outcome compared to the rehabilitation result to conventional ACL reconstruction method [8, 9]. In some specific aspects, including the postoperative complications, BEAR technique is even more superior. In a retrospective cohort of 58 skeletally mature patients, Shah et al. reported significant gains in International Knee Documentation Committee and Knee Injury and Osteoarthritis Outcome Score at nine months, with mean IKDC increasing from 48.6 preoperatively to 71.9 postoperatively ($p < 0.001$). The average flexion testing result for the patient at nine months is reaching 135 degrees, with full extension capabilities. No patients reported retears or conversion to reconstruction, and only 9% of all the investigated patients have reported complications.

Another mid to long-term prospective randomized controlled trial study conducted by Murray et al. has shown a similar positive result on the outcomes of BEAR technique treated patients. Patients who experienced BEAR surgery showed significant improvement in the International Knee Documentation Committee (IKDC) evaluations at the two-year postoperative mark. The mean IKDC score improved from approximately 47 preoperatively to 89 postoperatively, indicating significant functional recovery. More importantly, patients in the BEAR group exhibited better hamstring strength and less donor site morbidity, which is a common issue in traditional ACL reconstruction process. At 24 months after the surgery, the repaired ligament exhibited low signal intensity comparable to native ACL tissue, meaning a progressive collagen maturation and scaffold resorption is taking place, and the rebuilt ligament is showing normal function as a native ligament [10].

Longer term observations indicated no increase in failure rates with BEAR compared with reconstruction, addressing a historical concern. Patients also reported reduced anterior knee pain and improved quadriceps strength recovery, suggesting a potential neuromuscular benefit through preservation of native tissue and proprioceptive fibers. A clinical case report by Khan et al. documented full knee range of motion at twelve months after BEAR, supporting restoration of ACL integrity and joint stability [11]. Taken together, current evidence indicates favorable clinical outcomes, strong biological integration, and reduced postoperative morbidity with BEAR, findings echoed in subsequent summaries [12].

5. Conclusion

Overall, the BEAR technique has demonstrated very good postoperative outcomes and a better success rate compared to traditional ACL repair methods, and a much better rehabilitation outcome and better knee function restoration compared to ACL reconstruction approach. BEAR method provides significant biological and clinical advantages, as it promotes ligament regeneration through biological integration, avoids donor-site morbidity commonly seen in graft harvesting, and supports faster and more natural functional recovery. The BEAR technique is particularly suitable for young, skeletally mature patients with acute ACL tears and preserved tibial remnants, offering a lower complication alternative for ligament repair. Together, these findings indicate that BEAR may serve as a more superior treatment than traditional reconstruction and provides a direction for future biologically enhanced ligament restoration techniques.

Despite the encouraging results, there are still some further studies to be done. The long-term clinical outcomes of BEAR technique are still limited by small clinical sample sizes, and further long-term studies are required to confirm its applicability across different patient populations, ages and ethics. In addition, the role of BEAR in complex or chronic ACL injuries has yet to be fully established. Future research should focus on expanding its use to broader clinical indications, improving surgical precision and scaffold design to further improve healing quality and long-term durability.

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