Technical Note

Anterior Cruciate Ligament Reconstruction using Bone-Tendon-Bone Allograft: Surgical Technique Using Augmentation with Bio-Composite Scaffold

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Abstract: Anterior cruciate ligament (ACL) rupture rates remain high; the incidence of isolated ACL ruptures is 68.6 per 100,000. This Technical Note introduces a technique for ACL reconstruction (ACLR) using a bone-tendon-bone (BTB) allograft augmented with BioBrace, a biocomposite scaffold. The BioBrace scaffold is sutured onto the BTB allograft to reinforce the ligament and accelerate healing. Graft preparation with BioBrace, ACLR, and graft passage is described. This technique aims to reduce re-rupture risk, enhance graft healing, and improve patient-reported outcomes. BioBrace offers advantages over other augmentation approaches and synthetic materials, providing improved remodeling, biologic integration, and increased mechanical strength. Feasibility and efficacy have been demonstrated in animal models and human applications. This technique presents a promising approach to enhance ACLR outcomes.

Anterior cruciate ligament (ACL) rupture rates remain high in the United States with the incidence of isolated ACL tears estimated to be 68.6 per 100,000 when adjusted for age and sex.[1] Traditionally, bone-patella tendon-bone (BTB or BPTB) has been recognized as the gold standard graft option for ACL reconstruction (ACLR).[2] Typically, autograft is preferred; however, subsets of the population are better candidates for allografts.[3] Recent interest has been shown in other graft types because of BTB autograft donor site morbidity; specifically, patients may experience greater incidence of anterior knee pain, decreased patellar motion, and increased complications.[2] As such, a BTB allograft may be favored in certain situations, such as for revision surgeries, multiligamentous reconstructions, and in patients older than 40 or possessing poor donor quality.[3] BTB allograft offers the benefits of BTB autograft, such as bony incorporation on both ends, without the donor site morbidity. Although it may be a favored allograft in certain situations, the tendinous cross-sectional area is thin in a BTB allograft, so augmenting with additional collagen and tensile strength could help incorporation, as well as decrease the re-rupture risk.

Our described technique aims to reduce risk of re-rupture and provide additional collagen structure via augmentation of a BTB allograft. The BioBrace (Biorez, New Haven, CT) is a biocomposite scaffold composed of bioresorbable poly (l-lactide) microfilaments and highly porous type I collagen. Its biomechanical properties promote load sharing and biologic healing while gradually reabsorbing as the tissue remodels. When sutured onto the graft, BioBrace mechanically reinforces the ligament and potentially accelerates the healing process. We describe our technique for graft preparation and ACLR using BTB allograft augmented with BioBrace.

Surgical Technique

Video 1 demonstrates the following surgical technique.

Graft Preparation

A nonirradiated preshaped BTB allograft (Musculoskeletal Tissue Foundation, Edison NJ) is prepared on

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the back table. It is first thawed in a saline bath, after which the soft tissue and bone are inspected for adequacy of preparation and implantation. The tibial and femoral bone blocks are then measured, reshaped, calibrated, and drilled in a standard fashion. High-strength sutures are then passed through the drill tunnels in the bone blocks for later graft passage.

Graft Preparation With BioBrace

The full-length 25 cm BioBrace is placed flush on the deep or underside of the prepared allograft. Approximately 3 cm of the BioBrace is left as temporary excess at the future femoral bone block, and the remainder of the BioBrace strip is left uncut at the tibial bone block until preparation is completed (Fig 1). The BioBrace and the sutures at both ends of the graft are held together using clamps (Fig 2). Beginning at the junction between the femoral bone block and the patellar tendon, using a whipstich technique, a 2-0 FiberLoop (Arthrex, Naples, FL) suture with a straight needle is passed through the patellar tendon and the BioBrace to secure the BioBrace to the graft. These sutures are continued until the tibial bone block is reached at the other end (Fig 3). The end of the suture is then cut and tied, and the knot is buried within the graft.

After it has been sutured to the graft, the excess BioBrace is cut 1 to 2 mm away from the sutures on either end, so the brace only overlaps the tendinous portion of the graft (Fig 4). The BioBrace portion of the graft-implant hybrid is then hydrated with platelet-rich plasma (PRP) to make the graft more pliable, as well as to promote accelerated healing and incorporation once inserted (Fig 5).

The graft is marked at the junction between the bone blocks and the tendon on either end for ease of arthroscopic identification of the portions that will be in the femoral and tibial tunnels. Last, the graft is then placed on the graft prep station and tensioned in a standard fashion.

ACL Reconstruction

A standard ACLR with independent medial portal femoral tunnel drilling is performed. Anterolateral and anteromedial portals are created, and a diagnostic arthroscopy is done to examine the knee joint and address any meniscal or chondral lesions before proceeding with the ACLR. The remnant ACL is removed from the femur and tibia in preparation for the allograft leaving the femoral and tibial ACL footprints to aid in proper tunnel location later (Fig 6). A small notchplasty is performed as needed.

Using the anteromedial portal, the over-the-top guide is used, the knee is hyperflexed, and the beath pin is inserted at the femoral origin of the ACL on the lateral wall of the intercondylar notch. Once the position is confirmed, low-profile reamer of the appropriate size according to the diameter of the bone plug is used to drill the femoral tunnel and then to ream the tunnel to a socket depth matching the length of the bone plug (Fig 7). A passing suture is then shuttled into the femoral tunnel and out the lateral side of the thigh. A tibial ACL guide is introduced and positioned over the tibial ACL footprint, and a full tibial tunnel is created with a barrel reamer (Fig 8). A rasp may be used on the

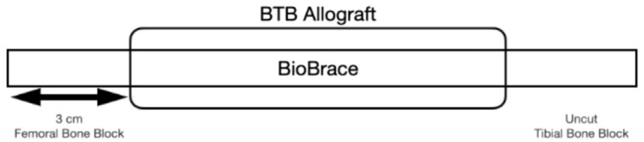

Fig 1. The BioBrace is extended 3 cm beyond the bone-tendon-bone (BTB) allograft to reserve room for the femoral bone block. The tibial end of the BioBrace remains uncut at this stage.

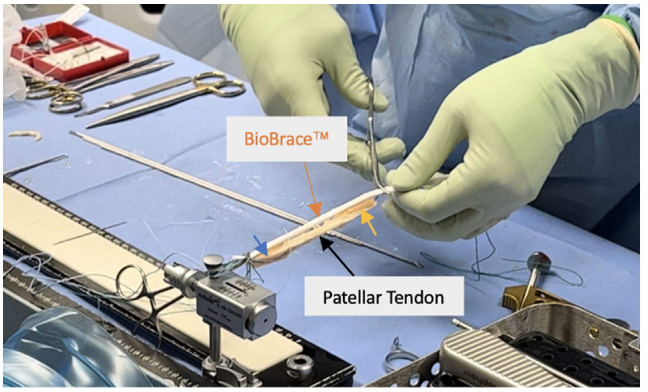

Fig 2. Clamps are used to secure the BioBrace and the sutures at both ends of the graft. The blue and yellow arrows represent the femoral and tibial bone block, respectively.

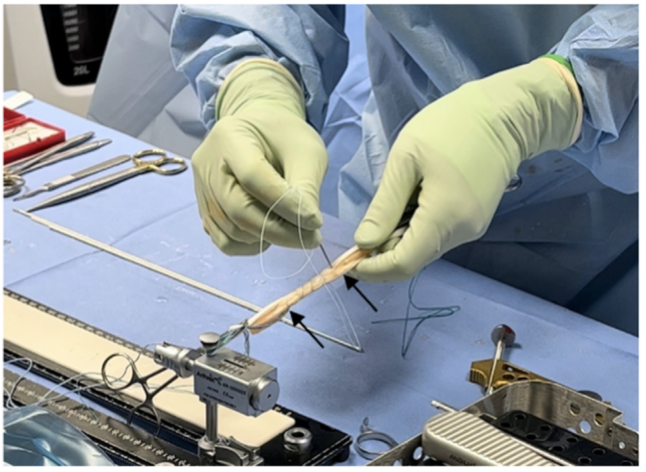

Fig 3. The junctions between the bone blocks and the tendon are indicated by black arrows. Sutures are passed through the BioBrace and the patellar tendon until the junction between the tendon and tibial bone block is met.

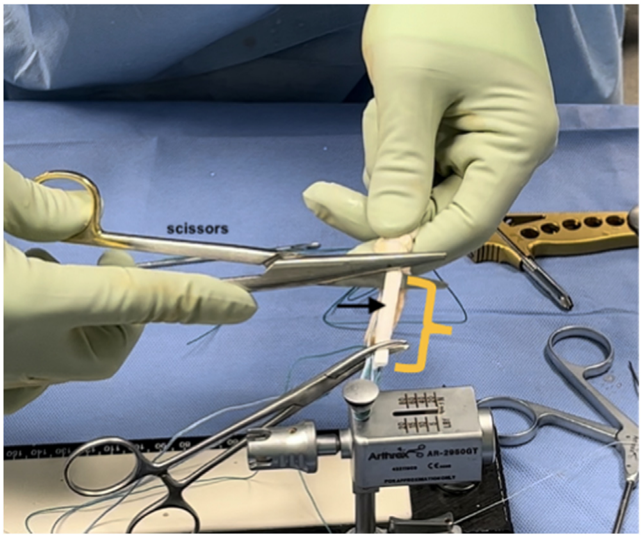

Fig 4. The excess BioBrace (black arrow) is cut at the start of the sutures (yellow brackets).

back edge of the tibial tunnel to smooth bone and avoid graft abrasion.

Graft Passage

The graft passage is completed using classically described techniques. Using the passing suture, the graft is shuttled through the tibial tunnel and docked into the femoral tunnel proximally. Once at the appropriate position, the graft is then secured with an interference screw in the femur in hyperflexion (Fig 9). The knee is then cycled 20 times with tension on the graft to remove any residual creep. The tibial bone block is secured with a bioabsorbable interference screw with the knee in extension while a gentle posterior drawer force is applied. The graft is inspected arthroscopically, and a repeat exam with the patient under anesthesia is performed (Fig 10).

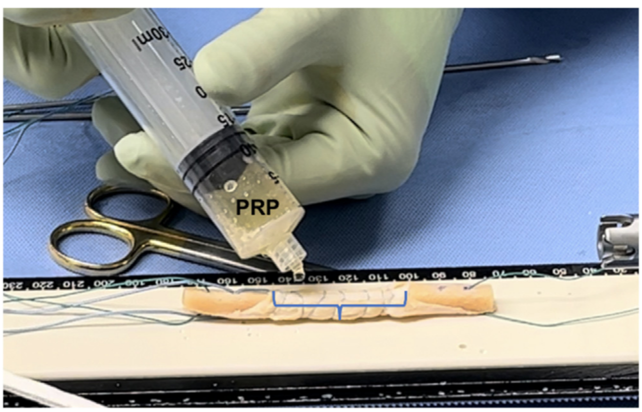

Fig 5. The BioBrace (blue brackets) and the graft are hydrated with platelet-rich plasma (PRP).

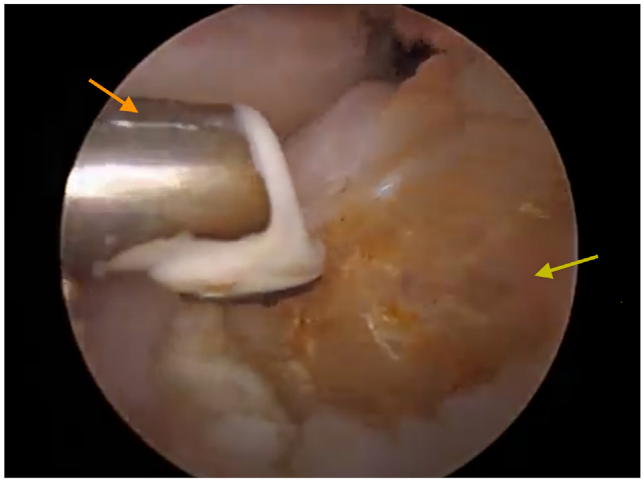

Fig 6. Standard diagnostic arthroscopy is performed through the anterolateral and anteromedial portals. After inspection of the joint and meniscus, the anterior cruciate ligament remnants at the femoral and tibial ends are removed. The orange arrow denotes the radiofrequency ablation wand; the yellow arrow identifies the tibial footprint.

Discussion

This surgical technique describes the use of a bio-composite scaffold implant to augment an ACLR using a BTB allograft. Biologic augmentation using the bio-composite scaffold aims to provide the graft with improved remodeling and biologic integration in addition to increased mechanical strength.

The feasibility of BioBrace was proven in large animal models, where it was seen to incite connective tissue formation.[4] Further efficacy has been observed during applications at various anatomic sites within humans, such as medial collateral ligament, distal bicep tendon, and rotator cuff.[5-8] BioBrace is reported to increase tensile strength by 140N (per Biorez, New Haven, CT,

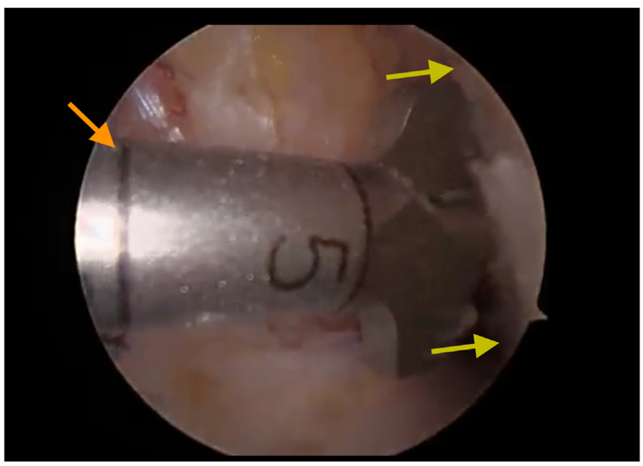

Fig 7. A low-profile reamer (orange arrow) is used to drill a tunnel into the femur (yellow arrows). This tunnel should approximate the diameter and length of the bone plug.

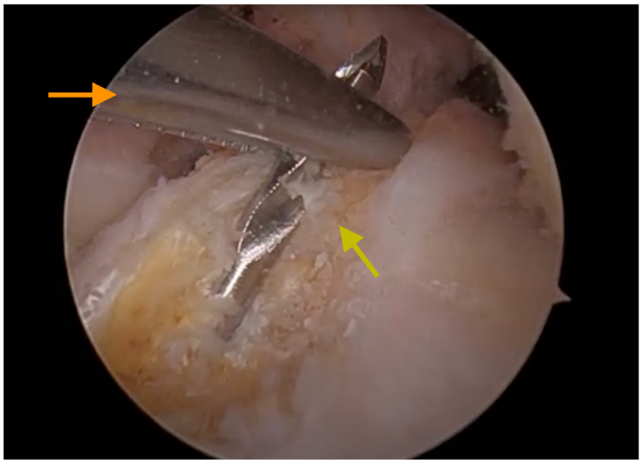

Fig 8. After positioning from an anterior cruciate ligament tibial guide, a guide pin is inserted into the tibial footprint (yellow arrow) and over-reamed with the appropriate diameter barrel reamer (orange arrow).

internal data) and evoke a strong, native healing response.

Other ACL biologic augmentation approaches have investigated the addition of PRP,[9] bone marrow aspirate concentrate,[10] and amnion.[11] A review from 2019 identified promising results for PRP, suggesting that it reduces patient-reported postoperative pain and improves healing when measured by magnetic resonance imaging signal intensity.[12] More recently, Forsythe et al. concluded bone marrow aspirate concentrate accelerated ligamentization and induced greater magnetic resonance imaging signal intensity at 3 months after operation from a BTB allograft ACLR in a randomized control trial.[13] Not only does our technique provide biologic augmentation, but BioBrace also adds mechanical strength properties at time zero.[8]

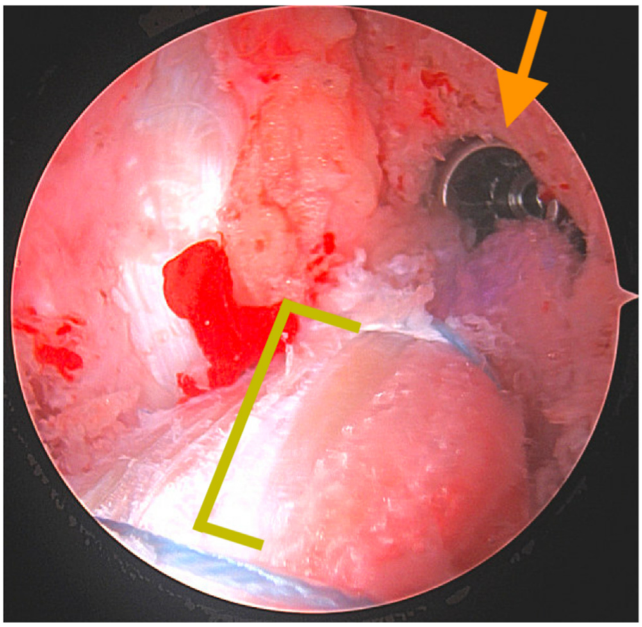

Fig 9. After shuttling the graft into place, an interference screw (orange arrow) secures the graft at the femoral tunnel while the knee is in hyperflexion. The BioBrace can be seen along the graft (yellow bracket). After cycling, a bioabsorbable interference screw secures the tibial insertion in similar fashion while the knee is in extension with gentle posterior drawer force.

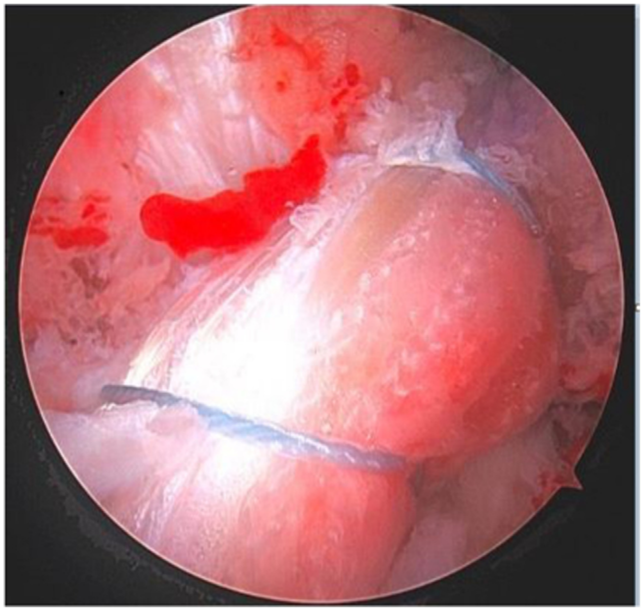

Fig 10. The completed repair is shown: anterior cruciate ligament reconstruction using a bone-tendon-bone allograft, augmented with BioBrace.

Table 1. Advantages and Disadvantages

Advantages	
	Ease of technique reproducibility
	Increases tendon cross sectional area for BTB graft
	In addition to BTB being stiffer at time zero compared to soft tissue grafts, BioBrace also offers increased biomechanical strength at time zero.
	Possibility of enhancing the anterior cruciate ligament graft biology with maturation, collagen thickness, and graft incorporation
	BTB allograft has less variability in graft quality and sizing compared to autograft techniques
	BioBrace acts as a collagen sponge to hold potential PRP, BMAC, or hemarthrosis blood as opposed to the allograft
	BTB allograft reduces donor site morbidity compared to BTB autograft
Disadvantage	
	Increased cost due to allograft and BioBrace components
	Increased time for graft preparation
	Low risk of inflammatory response due to poly (l-lactide) microfilaments within BioBrace and inherent risks of allograft
	Possibility of increased infection risk
	Lack of long-term clinical outcomes

BTB, bone-tendon-bone; BMAC, bone marrow aspirate concentrate; PRP, platelet-rich plasma.

Table 2. Pearls and Pitfalls

Pearl	
	Ensure appropriate length of BioBrace to match graft length
	Ensure appropriate hydration of the BioBrace in platelet-rich plasma
	During graft preparation, make sure to pierce the BioBrace on each pass to ensure appropriate fixation to the underlying graft
Pitfall	
	Avoid doubling over a BioBrace on a thicker graft to avoid arthrofibrosis or overstuffing of the notch
	If BioBrace tails overlap the bone blocks, can create the need for a larger bone tunnel

Augmentation using synthetic material such as an internal brace has also been studied, demonstrating favorable biomechanics of adding a tape suture to reinforce the graft, which reduces lengthening, subsequently protecting the graft during maturation and remodeling.[14] In a study investigating the effect of suture augmentation on hamstring grafts, patients who received suture augmentation reported improved outcomes, less pain, and reduced time for return to preinjury activity level.[15] These are also promising options; however, they may not directly improve the biology of the graft. BioBrace integrates into the graft, offering supplemental strength for two years before reasorbing (per Biorez, New Haven, CT; internal data).

Our aim is for the BioBrace augmentation to offer a potential enhancement of the biologic and mechanical properties of the reconstruction. The advantages and disadvantages are found in Table 1. The pearls and pitfalls are found in Table 2.

Disclosures

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: A.M. reports a consulting or advisory relationship with Arthrex Inc, Miach Orthopedics, Fidia Pharma, Reparel, and USA Inc; and serves on the editorial or governing board of *Arthroscopy*. A.C. reports a consulting or advisory relationship with Arthrex Inc. E.B. reports a consulting or advisory relationship with Link Orthopaedics and Orthopaedic NA.

References

1. Sanders TL, Maradit Kremers H, Bryan AJ, et al. Incidence of anterior cruciate ligament tears and reconstruction: A 21-year population-based study. *Am J Sports Med* 2016;44:1502-1507.
2. Sonnier JH, Paul RW, Sando HE, et al. Patient decision making in anterior cruciate ligament reconstruction: A discrete choice experiment examining graft preference. *Orthop J Sports Med* 2023;11:23259671221144983.
3. Buerba RA, Boden SA, Lesniak B. Graft selection in contemporary anterior cruciate ligament reconstruction. *J Am Acad Orthop Surg Glob Res Rev* 2021;5:e21.00230.
4. Walsh W, Carter A, Lovric V, et al. Tissue-engineered augmentation of a rotator cuff tendon using a novel bio-inductive biocomposite scaffold: A preliminary study in sheep. Annual Meeting; February 12-16, 2021. *Poster presented virtually at the Orthopaedic Research Society* 2021.
5. LeVasseur MR, Uyeki CL, Garvin P, McMillan S, Arciero RA. Knee medial collateral ligament augmentation with bioinductive scaffold: surgical technique and indications. *Arthrosc Tech* 2022;11:e583-e589.
6. Le D, McMillan S. A Novel Distal Biceps Rupture Repair Technique Utilizing a Biocomposite Scaffold. *Surg Technol Int* 2023;42:1656.
7. Cheesman QT, Szukics PF, Stark M, Kramer SC, McMillan S. Arthroscopic rotator cuff repair technique using a bio-composite scaffold for tissue augmentation. *Arthrosc Tech* 2022;11:e517-e522.
8. Carter A, Lovric V, Morberg P, et al. Characterization of a novel bio-inductive biocomposite scaffold for tendon and ligament healing. Annual Meeting; February 12-16, 2021. *Poster presented virtually at the Orthopaedic Research Society* 2021.
9. McRobb J, Kamil KH, Ahmed I, Dhaif F, Metcalfe A. Influence of platelet-rich plasma (PRP) analogues on healing and clinical outcomes following anterior cruciate ligament (ACL) reconstructive surgery: A systematic review. *Eur J Orthop Surg Traumatol* 2023;33:225-253.
10. Fortier LM, Gursoy S, Singh H, Chahla J. Two-stage revision anterior cruciate ligament reconstruction with cannulated allograft bone dowels soaked in bone marrow aspirate concentrate. *Arthrosc Tech* 2021;10:e2699-e2708.
11. Lavender C, Bishop C. The fertilized anterior cruciate ligament: an all-inside anterior cruciate ligament reconstruction augmented with amnion, bone marrow concentrate, and a suture tape. *Arthrosc Tech* 2019;8:e555-e559.
12. Riediger MD, Stride D, Coke SE, Kurz AZ, Duong A, Ayeni OR. ACL reconstruction with augmentation: A scoping review. *Curr Rev Musculoskelet Med* 2019;12:166-172.
13. Forsythe B, Chahla J, Korrapati A, et al. Bone marrow aspirate concentrate augmentation may accelerate allograft ligamentization in anterior cruciate ligament reconstruction: A double-blinded randomized controlled trial [published correction appears in *Arthroscopy* 2023;39:1595]. *Arthroscopy* 2022;38:2255-2264.
14. Noonan BC, Bachmaier S, Wijdicks CA, Bedi A. Independent suture tape reinforcement of tripled smaller-diameter and quadrupled grafts for anterior cruciate ligament reconstruction with tibial screw fixation: A biomechanical full construct model. *Arthroscopy* 2020;36:481-489.
15. Bodendorfer BM, Michaelson EM, Shu HT, et al. Suture augmented versus standard anterior cruciate ligament reconstruction: A matched comparative analysis. *Arthroscopy* 2019;35:2114-2122.