Partial tears of anterior cruciate ligament: Results of single bundle augmentation

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Abstract

Background: Partial tears of the anterior cruciate ligament (ACL) are common and usually present with symptomatic instability. The remnant fibers are usually removed and a traditional ACL reconstruction is done. But with increased understanding of ACL double bundle anatomy, the remnant tissue preservation along with a single bundle augmentation of the torn bundle is also suggested. The purpose of this study was to evaluate the results of selective anatomic augmentation of symptomatic partial ACL tears. Our hypothesis is that this selective augmentation of partial ACL tears could restore knee stability and function.

Materials and Methods: Consecutive cases of 314 ACL reconstructions, 40 patients had intact ACL fibers in the location corresponding to the anteromedial (AM) or posterolateral (PL) bundle and were diagnosed as partial ACL tears perioperatively. All patients underwent selective augmentation of the torn bundle, while keeping the remaining fibers intact using autogenous hamstring graft. A total of 38 patients (28 males, 10 females) were available with a minimum of 3 years followup. 26 cases had AM bundle tears and 12 cases had PL bundle tears respectively. Patients were assessed with International Knee Documentation Committee (IKDC) 2000 Knee Evaluation Form, Lysholm score; instrumented knee testing was performed with the arthrometer (KT 2000). Statistical analysis was performed to compare the preoperative and postoperative objective evaluation.

Results: At 3 years followup, 31.6% patients were graded A, 65.8% were graded B and 2.6% was graded C at IKDC objective evaluation. Manual laxity tests, Lysholm's score, mean side to side instrumental laxity and Tegner activity score improved significantly. 76% patients returned to preinjury level of sports activity after augmentation.

Conclusion: The results of anatomic single bundle augmentation in partial ACL tears are encouraging with excellent improvement in functional scores, side to side laxity and return to sports activity.

Key words: Anteromedial bundle, partial anterior cruciate ligament tear, posterolateral bundle, selective augmentation
MeSH terms: Anterior cruciate ligament, anterior cruciate ligament reconstruction, cruciate ligament

Introduction

Partial tear of the anterior cruciate ligament (ACL) is a very common injury. The incidences have been reported to be 28% by Noyes *et al.*,[1] 25% by Zantop *et al.*,[2] 10-28% by Jacquot *et al.*[3] and 38% by Liljedahl *et al.*[4] However, symptomatic partial ACL tear seen during reconstruction is 5-10%[5,6] and 14%[7] in different studies. Several studies suggest that a significant number of these tears may go on to become complete tears or that additional injuries to the meniscus or articular cartilage may develop in these patients.[8-11] According to Fruensgaard and Johannsen[12] 50% of partial lesions evolve into complete tears, whereas Noyes *et al.*[11] put this rate at 38%. Danylchuk *et al.*[13] in their study have reported that partial ACL tears can evolve into complete tears because of the interruption of blood supply, which leads to necrosis of the intact fibers. The amount of initial ligament damage is a statistically significant predictive factor of evolution into a complete tear. In a study by Bak *et al.*,[8] only 30% of patients with partial ACL tears were able to return to the preinjury level of sporting activity at 5 years followup, whereas Buckley *et al.*[9] in their study have reported 44% return to preinjury level of sports in 18 months. However, when treatment is required, a standard ACL reconstruction was frequently used sacrificing the residual portion of the ACL, to avoid overstuffing the intercondylar notch and prevent impingement of tissues that can lead to decreased range of motion.[14] Electrothermal shrinkage was found to have a low rate of success in clinical studies, so suggested to be unsuitable.[15] In the last decade, anatomic double-bundle

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ACL reconstruction has become popular, in which the anteromedial (AM) and posterolateral (PL) bundles are created at their anatomic footprints. Hence now researchers have defined symptomatic partial ACL tears as individual bundle tears based on the combination of the patient's history and complaints, clinical examination, magnetic resonance imaging (MRI) and arthroscopic evaluation.[6,15] Many patients with symptomatic instability show ACL remnants attached both on the femur and tibia. Chen *et al*.[16] described four types of ACL remnants: Type 1 is partial ACL tear with the AM or PL bundle that still bridges the femur to the tibia; Type 2 complete interruption of ACL at the femoral side, Type 3 is complete interruption of ACL at the tibial side; and Type 4 is a residual ACL remnant too small to form an envelope around the graft. With the assessment of attachments of the remnants on the femur and tibia, along with careful probing to see the quality and thickness of the remnant tissue, the partial tears can be safely divided into groups of AM and PL bundle tears. Hence, if only one bundle of the ACL is torn, isolated AM or PL bundle reconstruction is considered.

This study prospectively evaluates results of anatomic single bundle augmentation of symptomatic partial tears of ACL with autogenous hamstring graft and determine the effectiveness of this procedure.

Materials and Methods

In a consecutive case series of 314 ACL reconstructions performed between 2006 and 2010 at a tertiary care centre; 40 cases were diagnosed to have partial tear of ACL and anatomic single bundle augmentation of ACL was carried out. Approval from the hospital ethics committee was taken. A written informed consent was obtained from all patients. Clinical evaluation of patients was done on an outpatient clinic first and reassessment was done under anesthesia prior to surgery. The results of Lachman, anterior drawer and pivot shift tests were noted by both authors independently. The patients with equivocal findings clinically at the outpatient clinic, i.e. none of the three clinical tests (anterior drawer, Lachman and pivot shift tests) were Grade III positive, but one of the tests is Grade II positive with a definite end point, were diagnosed to have partial ACL tear. These patients were subjected to MRI examination. Two independent radiologists, who were unaware of clinical details, analyzed the status of ACL on MRI.

Decision for arthroscopy was taken based on the complaint of instability episodes. We performed augmentation when the ACL remnant was thick, with good quality tissue on probing and was attached at the anatomic footprint. Otherwise a standard single or double bundle reconstruction was performed and it was excluded from the study. The cases with additional ligament injury greater than Grade II, history of previous knee surgery, mechanical or anatomic malalignment and Outerbridge[17] Grade III or IV arthritic knees were also excluded from the study.

We excluded 2 patients who did not complete the study protocol and followup. Finally, 38 patients (28 males, 10 females) were available with a minimum followup of 36 months (range 36-64 months). The mean age of the patients at the time of surgery was 28 years (range 15-46 years). The delay between injury and surgery was 6.5 months (range 2-26 month), with 12 patients operated more than 6 months after injury (32%).

Operative procedure

The patient was positioned supine on the operating table the "leg on table" position and a tourniquet was placed approximately 20 cm proximal to the knee. Standard anterolateral portal close to the patellar tendon and low AM portal were created for arthroscopy. It is very important to partially debride the fat pad to a certain extent in order to have a good arthroscopic view into the intercondylar notch with increased knee flexion. A diagnostic arthroscopy was performed and the morphology of the ACL remnant was examined by probing at different knee flexion angle and "figure of four" position to decide, which bundle is torn and require reconstruction [Figures 1a and 2a]. Remnants of the AM or PL bundle was used as landmarks for orientation and care was taken to preserve these intact ACL fibers. Semitendinosus tendon was harvested by an oblique incision[18] measuring 4 cm in length over the pes anserinus. The graft was quadrupled and looped around an Endobutton CL (Smith and Nephew Endoscopy, Andover, MA) for use. The graft was pretensioned on the suture board. The augmentation is performed in a similar fashion to a single bundle ACL reconstruction. The footprints were carefully identified and debrided while sparing the intact bundle and the bone tunnels are drilled according to the size of the graft to achieve a tendon-to-bone press fit. AM portal was used for drilling femoral tunnel in all the cases.

Isolated AM bundle reconstruction

The center of the femoral AM tunnel is marked with an AM portal femoral aimer in 100-110° of knee flexion [Figure 1c]. In this position, the center of the AM insertion is horizontal to that of the PL bundle. Then a guide wire is positioned into the aimer and the knee is flexed to a maximum and the guide wire was drilled through followed by the 4.5 mm reamer for Endobutton. The tunnel length was measured (usually 34-40 mm in length). The femoral tunnel was drilled with a flower headed reamer of similar diameter to that of the

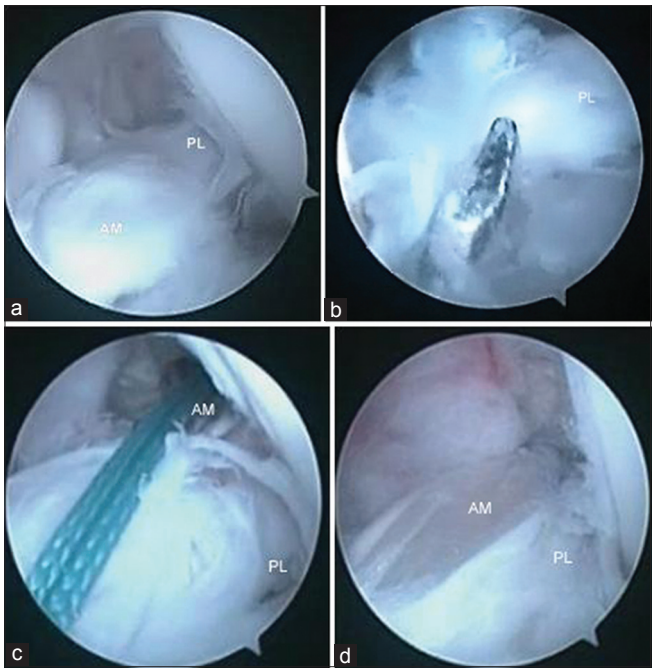

Figure 1: Arthroscopy views showing (a) tear of anteromedial bundle and intact posterolateral bundle (b) tibial tunnel position for anteromedial bundle augmentation (c) femoral tunnel position for anteromedial bundle augmentation (d) final picture of anteromedial bundle augmentation keeping posterolateral bundle intact

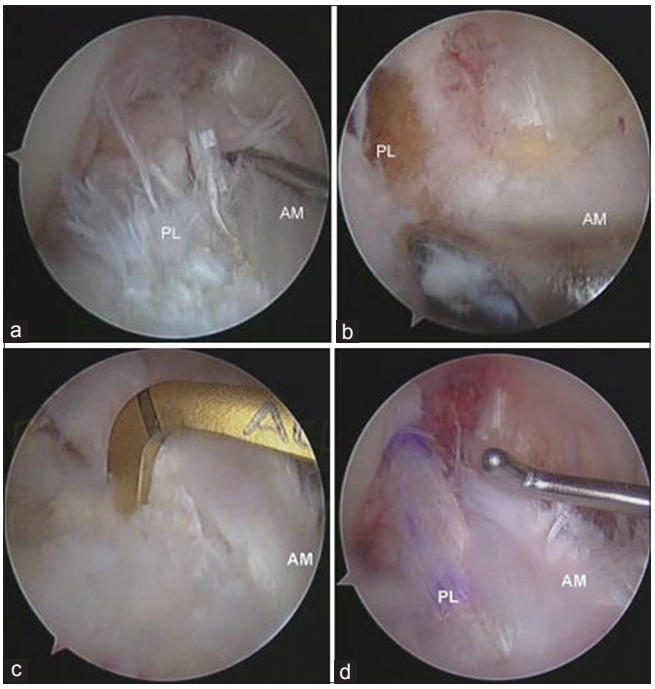

Figure 2: Arthroscopic pictures showing (a) intact anteromedial bundle and tear of posterolateral bundle (with anteromedial bundle retracted) (b) femoral tunnel for posterolateral augmentation (c) tibial tunnel position for posterolateral bundle augmentation (d) final picture of posterolateral bundle augmentation keeping anteromedial bundle intact

quadrupled graft for 25 mm without damaging the intact PL bundle and the cartilage of the medial femoral condyle. For the tibial AM bone tunnel, the tibial drill guide is set to 60° and on the distal tibial cortex it is placed 1.5 cm medial to the tuberosity in the sagittal plane. The intraarticular tip is positioned in the AM part of the tibial ACL insertion 4-5 mm lateral to the medial tibial spine of the medial tibial plateau and 4-5 mm posterior to the anterior rim of the ACL footprint [Figure 1b]. The anterior border of the ACL insertion is carefully preserved to avoid anterior intercondylar roof impingement, damage to the transverse intermeniscal ligament and damage to the articular cortical bone or the articular cartilage. A guide wire is overdrilled by a conventional reamer according to the size of the AM graft preserving the intact insertion of the PL bundle.

Isolated PL bundle reconstruction

The center of the femoral PL bone tunnel was marked with a microfracture awl in 100-110° of knee flexion [Figure 2b]. In this position, the center of the PL insertion is horizontal to the center of AM and an average of 5 mm posterior to the shallow articular cartilage of the lateral femoral condyle. A guide wire was drilled in 130° of knee flexion through the AM portal. The tunnel was then overdrilled with 4.5 mm reamer, tunnel length was measured (usually 32-36 mm) and further dilated with flower headed reamer of the same size of graft for 20 mm length. For tibial PL bone tunnel drilling, the ACL drill guide was set to 65°. On the distal tibial cortex, it was placed approximately 3.5 cm medial to the tuberosity. The intraarticular tip of the drill guide was positioned in the PL part of the tibial ACL insertion an average of 4-5 mm medial to the lateral intercondylar eminence and 4-5 mm anterior to the posterior root of the lateral meniscus [Figure 2c]. The guide wire was carefully overdrilled by a conventional reamer without damaging the root of the posterior horn of the lateral meniscus, the cortical bone, the articular cartilage of the medial tibial plateau, the lateral bony intercondylar wall, or the intact tibial AM bundle insertion.

Graft fixation

On the femoral side, 15 mm loop Endobutton CL was used for fixation in cases of PL augmentation whereas it was 20 mm loop Endobutton CL in cases of AM augmentation. On the tibial side, graft fixation might be established by a 25-30 mm long bioresorbable interference screw (BIORCI; Smith and Nephew Endoscopy), with the PL bundle fixed in 10° of flexion and the AM bundle in 50° to 60° of flexion [Figures 1d and 2d].

Rehabilitation

We followed a semiconservative rehabilitation program similar to that for a standard ACL reconstruction. Physiotherapy emphasizes early restoration of full extension and quadriceps function and allows partial (20 kg) weight bearing in the 1st postoperative week and full weight

bearing thereafter. Flexion greater than 90° was achieved by the 6th postoperative week. Patients were allowed to ride exercise bicycles at 6 weeks and to perform gymnasium exercises at 8 weeks. Isometric quadriceps-strengthening, closed kinetic chain exercise and bracing was continued during the first 3 months. Running was allowed at 3 months, with return to full activities after 6 months. High level sporting activities were permitted after 12 months.

Clinical evaluation

Detailed clinical examination and functional assessment were performed at monthly intervals in the first 3 months and then every 6 months. Subjective evaluation consisted 2000 International Knee Documentation Committee (IKDC scale: 0-10) functional score and Lysholm score (scale: 0-100). Clinical testing included manual laxity tests (anterior drawer and pivot shift tests), the 2000 IKDC, manual KT-2000 arthrometer (MedMetric corp., San Diego, CA) measurements at 30° using force 134 N. Patients' activity level was assessed using Tegner activity score (scale: 0-10), both the preinjury and presurgery levels were noted. The outcome at 3 years of surgery was compared with the preoperative status.

Statistical analysis

All statistical analysis were performed with IBM SPSS version 21 software (IBM Corporation, New York). The unpaired *t*-test was used to analyze the difference of means for parametric data. The Wilcoxon signed-rank test was used to compare the preoperative and postoperative instrumented side to side laxity. A marginal homogeneity test was used to compare the preoperative and postoperative anterior drawer, pivot shift testing and IKDC objective evaluation. The level of significance was set at $P = 0.05$.

Results

Of the 314 cases, 38 cases (12.1%) were available with a minimum 3 years followup after anatomic single bundle augmentation of ACL; 8.3% (26 cases) had AM bundle tears and 3.8% (12 cases) had PL bundle tears respectively. The clinical tests for diagnosis under anesthesia showed a firm anterior end point in all. The patient with AM bundle tear showed more laxity on anterior drawer test but pivot shift was usually negative; whereas the patients with PL bundle tear had more pivot shift test positive [Table 1]. Both radiologists reported 17 patients as partial tear, 6 patients as complete tear and 2 as normal. In the rest 13 cases, the radiologists had difference of opinion (κ - 0.05; strength of agreement: Poor).

During the surgery, 14 patients had a meniscal tear that was treated during the same operative session: 2 lateral meniscal repairs, 6 partial lateral meniscectomies, 2 medial meniscal repairs and 4 partial medial meniscectomies. Minor traumatic chondral injuries were noted in 5 knees (3 lesions of the medial femoral condyle and 2 lesion of the lateral femoral condyle), but the concerned patients did not complain of pain at followup. The articular cartilages were intact for the remaining patients.

Postoperatively all results in the anterior drawer test were negative except for 5 cases with Grade I laxity; 4 in the AM group and 1 in the PL group [Table 1]. In the pivot shift test, all results were negative except for 6 glide cases; 2 in AM

Table 1: Pre and postoperative evaluation

Evaluation parameters	AM augmentation (*n*=26)			PL augmentation (*n*=12)		
	Preoperative	Postoperative	*P*	Preoperative	Postoperative	*P*
Anterior drawer test						
Equal	0	22	<0.0001	0	11	<0.001
I	5	4		9	1	
II	21	0		3	0	
III	0	0		0	0	
Pivot shift test						
Equal	10	24	<0.0001	0	8	<0.001
Glide	14	2		4	4	
Gross	2	0		8	0	
Marked	0	0		0	0	
IKDC objective evaluation						
A	0	9	<0.0001	0	3	<0.0001
B	5	16		3	9	
C	19	1		7	0	
D	2	0		2	0	
Lysholm score: Mean±SD (range)	75.7±5.1 (70-85)	94.5±4.1 (89-98)	<0.0001	73.6±5.4 (68-84)	95.3±3.8 (89-97)	<0.0001
Mean side to side: Instrumental laxity (mm)	3.8 (3-5)	0.8 (0-2)	<0.001	2.2 (1-3)	0.7 (0-2)	<0.001
Tegner activity score: Median±SD (range)	4±2 (2-7)	6±2 (4-8)	0.03	4±2 (3-7)	6±2 (4-9)	0.02

AM=Anteromedial, PL=Posterolateral, SD=Standard deviation, IKDC=International knee documentation committee

group and 4 in PL group. Significant differences were found between preoperative and postoperative instrumented laxity testing with KT-2000 knee arthrometer ($P \leq 0.001$), Lysholm's score ($P \leq 0.0001$) and IKDC 2000 knee evaluation ($P \leq 0.0001$) in both AM and PL groups. In IKDC objective evaluation, 12 (31.6%) patients were graded A, 25 (65.8%) were graded B and 1 patient was graded C (2.6%).

Of the 38 patients; 8 were professional sportsmen, 11 were semi professional and 10 were recreational players. The median Tegner activity score in both AM and PL groups were 4 prior to surgery and 6 at 3 years followup ($P < 0.01$). When compared with the preinjury level, 29 patients (76.3%, 20 of the AM group and 9 of the PL group) made a full return. 9 patients (23.7%, 6 of AM group and 3 of PL group) returned at a reduced level of activity.

Four patients had flexion deficit of more than 15° when compared with other side whereas none had extension deficit. No graft failure was noted till the last followup.

Discussion

The principal findings of the present study were that joint stability, IKDC and Lysholm knee scores improved significantly after selective AM or PL bundle reconstruction. The good postoperative results may indicate that the ACL remnant which was preserved as intact bundle is useful functionally.

Partial ACL tears are common, often associate to knee sprains with hemarthrosis. Patients usually complain of unspecific symptoms such as recurrent pain and swelling.[6] More specifically, patients with a symptomatic AM bundle tear describe an anterior instability during activities of daily living and during sports activity similar to a complete ACL tear. On the contrary, patients with a symptomatic PL bundle tear complain of rotational instability with pivoting sports. Patients with PL bundle injuries only may still perform nonpivoting sports activities without major difficulty, but pivoting sports such as soccer or basketball have to be given up.[6] Clinical diagnosis of partial ACL tear is rather difficult. Barrack *et al*.[10] defined partial ACL tear when all of the following three criteria is satisfied; significant portion of at least one bundle was in continuity and was potentially functional as judged by palpation with a probe and arthroscopic anterior drawer testing; the Lachman test scored 0 or 1+ (<5 mm); and the pivot shift was negative or only trace-positive. Siebold and Fu[6] further clarified the difference between AM and PL bundle tears clinically. The AM bundle tears have significantly increased (1-2) anterior drawer test at 90° of knee flexion, anterior translation in the Lachman test at 30° is rather small (0-1) and pivot shift test is negative or only slightly positive (0-1). KT-1000 side to side difference between 2 and 4 mm. Patients with PL bundle tears have positive pivot shift test, anterior drawer test and the Lachman test might be 0-1, the KT-1000 usually shows a small side to side difference of 1-3 mm.[6,19] Our experience is in line with the above. MRI diagnosis of partial ACL tears is difficult with low level of accuracy.[20,21] The development of better adapted MRI protocols may allow for preoperative diagnosis of this type of lesion. Of the 38 cases included in this study, 17 cases were reported as partial tears by both radiologists.

Arthroscopic examination of the torn ACL remnant is the most important factor in decision making. Most of the time, tear is located close to femoral insertion. Identifying the AM bundle tear is rather straight forward. But PL bundle tear is difficult to diagnose; as it can be seen only after retraction of AM bundle fibers or in a figure of 4 position.[22] Furthermore, the normal laxity of PL bundle at 90° flexion can confuse the surgeon as elongation. Hence, the assessment of the attachments of the remnants on femur and tibia, along with careful probing to see the quality and thickness of the remnant tissue is of paramount importance. Based on available literature, preservation of ACL remnant and doing an augmentation procedure is beneficial in four ways thus producing good results.[6,23] First, the preserved bundle of ACL provides mechanical strength in early postoperative period. Thus, it protects the augmented graft, hence may allow faster rehabilitation and early return to sports. Liu *et al*.[24] in an experimental study showed that the degree of anterior instability correlates with the amount of partial ACL disruption. Crain *et al*.[25] examined the anterior laxity using a KT 1000 arthrometer before and after ACL remnant debridement in 48 patients and reported that ACL remnant scarring on the roof of the notch and the lateral wall of the notch, or on the medial aspect of the lateral femoral condyle, contributed to the prevention of tibial anterior laxity. Second, the preserved bundle of ACL may cause rapid vascularization of the augmented graft, causing a quicker return of ACL function. In an animal study by Bray *et al*.,[26] ACL in rabbits was dissected and compared with a control group 4 months after a standardized surgically induced partial ACL tear. The results showed significant increase in blood flow and vascular volume in the induced group. Third, the nerve fibers might come from the preserved ACL bundle and regenerate mechanoreceptors around the augmented graft thus contribute to improved postoperative proprioceptive function of knee joint, better restoration of knee kinematics.[5] This may benefit for the subjective outcome and for a safer return to sports. Finally, the intact bundle serves as the reference for tunnel positions of the torn bundle, thus improves accuracy of tunnel placement into anatomic footprint, which is believed to improve the outcome.[6]

Multiple clinical case series have shown improvement in clinical scores, joint stability and joint position sense after selective single bundle augmentations.[6,7,27-32] The outcome was similar to the healthy knee in one study.[30] Comparative studies which compared augmentation with classical ACL reconstruction[33-36] found no significance difference in clinical outcome between the groups. Only the study by Adachi *et al*.[37] showed better outcome in augmentation group. Selective AM reconstruction group had better control on anterior laxity in a study by Pujol *et al*.[35] In another study by Demirağ *et al*.,[34] tunnel enlargement was found to be less in augmentation group, especially on tibial side. In one comparative study by Park *et al*.[38] which compared augmentation with double bundle ACL reconstruction; the clinical scores, range of motion, instrumental laxity tests are similar between the groups. Only the anterior drawer was better in augmentation group. Our study is in line with the published literature. The potential disadvantage of selective bundle reconstruction can be overstuffing of notch and impingement causing loss of motion as reported by Sonnery-Cottet *et al*.,[7] though not seen in this study.

There are several limitations. The sample size is small and the study group is heterogenous regarding age and chronicity of injury. Due to a lack of a comparative group, the superiority of this procedure over standard ACL reconstruction can't be judged. We do not know if the preserved ACL remnant was actually damaged at initial trauma. The decision of surgery is based on probing ACL remnants which is a subjective technique which may affect the results. The intact fibers of ACL on probing may not correlate to their functionality; thus a dysfunctional bundle may be preserved and affect the result. Furthermore, the procedure is technically demanding. It is difficult to preserve the intact bundle; especially while drilling the tibial tunnel for PL bundle preserving the AM bundle as the AM bundle masks the desired footprint of PL bundle. The position of the femoral tunnels for AM or PL reconstruction may differ from previous studies, although the ideal tunnel position is still controversial. Followup MRI scans was not obtained; it would be interesting to assess the remodeling of the graft by studying the signal intensity changes. A prospective randomized controlled trial comparing ACL reconstruction with ACL augmentation may be necessary to identify that the different factors stated may provide more meaningful conclusions in the future. As for the present, these factors may well be considered in ACL surgeries and provide surgeons with reasons in preserving intact ACL stumps.

To conclude, success after ACL reconstruction may depend not only on the tightness or strength of the reconstruction but also on the preservation of the intact fibers. Anatomic single bundle augmentation is technically demanding, but reproducible. The results are encouraging with excellent side to side laxity. We therefore recommend saving the intact bundle of ACL while augmenting the torn bundle in selective cases.

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