Original Article

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Minimal Ablation of the Tibial Stump Using Bony Landmarks Improved Stability and Synovial Coverage Following Double-Bundle Anterior Cruciate Ligament Reconstruction

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Purpose: To evaluate the clinical effects of using anatomical bony landmarks (Parsons' knob and the medial intercondylar ridge) and minimal ablation of the tibial footprint to improve knee anterior instability and synovial graft coverage after double-bundle anterior cruciate ligament reconstruction.

Materials and Methods: We performed a retrospective comparison of outcomes between patients who underwent reconstruction with minimal ablation of the tibial footprint, using an anatomical tibial bony landmark technique, and those who underwent reconstruction with wide ablation of the tibial footprint. Differences between the two groups were evaluated using second-look arthroscopy, radiological assessment of the tunnel position, postoperative anterior knee joint laxity, and clinical outcomes.

Results: Use of the anatomical reference and minimal ablation of the tibial footprint resulted in a more anterior positioning of the tibial tunnel, with greater synovial coverage of the graft postoperatively (p=0.01), and improved anterior stability of the knee on second-look arthroscopy. Both groups had comparable clinical outcomes.

Conclusions: Use of anatomical tibial bony landmarks that resulted in a more anteromedial tibial tunnel position improved anterior knee laxity, and minimal ablation improved synovial coverage of the graft; however, it did not significantly improve subjective and functional short-term outcomes.

Keywords: **Knee, Anterior cruciate ligament, Reconstruction, Double-Bundle, Tibial bony landmark**

Introduction

Several studies have sought the optimal reconstruction method to improve the mechanical stability of anterior cruciate ligament (ACL) grafts with regard to graft choice, number of bundles, preservation of the remnant, and tunnel positioning[1-4]. Preservation of the remnant has been shown to provide several advantages, including better vascularization and synovial coverage of the graft[5,6], preservation of the mechanoreceptors, and facilitation of mesenchymal stem cell migration[7-9]. However, the clinical benefit of remnant preservation has not been clearly established, with recent meta-analyses reporting similar clinical outcomes and mechanical stability after ACL reconstruction performed with and without remnant preservation[10,11]. Furthermore, although one study has reported on the importance of preserving a tibial stump as a minimum, if the remnant cannot be fully preserved[12], another study demonstrated that the tunnel position rather than remnant preservation is more important to reproduce the function of the original ACL after reconstruction[13].

Functional stability would further be enhanced after reconstruction by inducing good synovial coverage of the graft and by

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accurately placing aperture of the tibial tunnel within the tibial footprint of the ACL. We focused on two aspects of the reconstruction technique mainly to acquire good synovial coverage and to create a reproducible anatomical tibial tunnel: preservation of a tibial stump by the use of minimal ablation (MA) of the tibial footprint of the ACL[12)] and the use of bony landmarks (Parsons' knob[14)] and the medial intercondylar ridge[15)]) on the tibia to determine the position of the tibial tunnel. Our aim was to compare the outcomes of our double-bundle ACL reconstruction, using bony anatomical landmarks on the tibia performed with MA of tibial stump, to those of double-bundle reconstruction performed with wide ablation (WA) of the tibial stump of the ACL. We hypothesized that MA would improve synovial coverage of the graft and that placement of the tibial tunnel based on the tibial bony landmarks during ACL reconstruction would enhance anterior knee stability post-reconstruction.

Materials and Methods

This study was approved by our Institutional Review Board, and all patients provided informed consent prior to participation. Between January 2012 and March 2015, 83 consecutive patients underwent an outside-in double-bundle ACL reconstruction using hamstring autografts, performed by 2 surgeons. The medical records and intraoperative arthroscopic videos for these patients were reviewed to determine the procedure used: MA versus WA and tunnel positioning with or without reference to the bony landmarks. For procedures performed between January 2012 and March 2014, WA of the ACL stump was used, with creation of anteromedial (AM) and posterolateral (PL) tibial tunnels (WA group). Since April 2014, we modified our surgical technique on the tibial side of the reconstruction, using Parsons' knob and the medial intercondylar ridge to position the tibial tunnel and attempting to preserve as much of the ACL stump as possible (MA group), for following two reasons: first, we hoped the native ACL fibroblasts would be incorporated as part of the new composite graft to enhance synovial coverage of the graft; and second, preservation of the remaining ACL mechanoreceptors might have a beneficial effect on clinical outcomes[12)]. Among the 83 patients who underwent ACL reconstruction during the study period, 26 underwent the MA procedure and the remaining 57, the conventional WA procedure. From this latter group of 57, we selected 26 patients, matched on demographics to the 26 patients in the MA group.

1. Evaluation of Outcomes

The relevant characteristics of the study group are reported in Table 1, with no preoperative difference between the two groups identified. Outcomes were assessed based on measurement of the position of the AM and PL tibial tunnels on reconstructed computed tomography (CT) images, direct examination of the graft during second-look arthroscopy, quantification of anterior knee stability, and patient-reported clinical outcomes measured 2 years after reconstruction, including the Lysholm knee score, the International Knee Documentation Committee (IKDC) score, and the Knee Injury and Osteoarthritis Outcome Score (KOOS).

2. Surgical Procedure

A double-bundle, outside-in arthroscopic ACL reconstruction was performed in all patients, with the graft formed using the semitendinosus tendon (ST) and, if necessary, the gracilis tendon, as follows. A double bundle was constructed solely from the ST when the harvested ST was >24 cm, with the tendon cut transversely into two equal portions. When the harvested ST was <24 cm, additional harvesting of the gracilis tendon was performed to obtain two equal portions (MA group, 3; WA group, 5). The harvested tendons were double-looped over an Endobutton fixation device (Smith & Nephew, Andover, MA, USA), with the distal

Table 1. Demographic and Clinical Characteristics

Characteristic	MA group	WA group	p-value
No. of patients	26	26	-
Age (yr)	26.5±9.2 (16–41)	23.7±5.2 (16–33)	0.60
Sex (male:female)	12:14	13:13	-
Meniscus injury (rasping/meniscectomy/repair)	14 (7/1/6)	13 (5/2/6)	
Body mass index (kg/m^2)	22.0±2.5 (17.7–27.6)	22.4±2.7 (18.0–26.9)	0.46
Interval from injury to ACL surgery (day)	127.6±56.5 (32–280)	119.7±51.7 (35–272)	0.57
Interval from ACL surgery to second-look arthroscopy (day)	419.7±61.9 (253–417)	411.4±133.8 (273–452)	0.23

Values are presented as mean±standard deviation (range).
MA: minimal ablation, WA: wide ablation, ACL: anterior cruciate ligament.

ends anchored using a Krackow suture, thus recreating the AM and PL bundles of the ACL. To prevent elongation of the grafts, a continuous 30 second loading with 70 N was applied twice to the graft (70 N, 1 min), and then the same loading was repeatedly applied (70 N, 2 min)[16]. The femoral tunnel was created using an outside-in technique. The longitudinal linear resident's ridge[17] and the posterior cartilage, used as landmarks for the ACL femoral footprint, were identified. Two 2.4-mm guide pins were then inserted, separately, from the outside into the ACL footprint, posterior to the resident's ridge and just anterior to the articular margin, using an anterolateral-entry femoral aimer (Smith & Nephew). A 5.5-mm to 6.5-mm tunnel was then created for the AM and the PL grafts by over-drilling of the guide pins. Two Endobutton-CLs (Smith & Nephew) were connected to the end of each loop graft. The length of the CLs was matched to the length of the femoral tunnel so as to introduce sufficient graft materials (>13 mm) into the bone tunnels. The ACL remnant was resected with a shaver, preserving only the tibial stump.

3. Creation of the Tibial Tunnels for the WA and MA Groups

Using the conventional WA procedure, in the WA group, the anterior horn of the lateral meniscus (LM) was identified as a reference landmark[18], and the tunnel was created using WA within the ACL footprint. The AM tunnel was aligned with the anterior horn of LM, with the PL tunnel positioned in the posterior area within the footprint (Fig. 1). This WA approach does not preserve the tibial stump.

To preserve the tibial stump in the MA group, the AM tibial bony landmarks (Parsons' knob and the medial intercondylar ridge) were identified and ablation was limited to the medial side of the tibial footprint. The AM tunnel was created just lateral to the medial intercondylar ridge and just posterior to the Parsons' knob. The PL tunnel was created posterior to the AM tunnel and lateral to the medial intercondylar ridge, so as not to overlap with the AM tunnel (Fig. 1).

In all cases, tibial fixation of the graft was performed with the knee flexed at 20°, with an initial tension of 20 N applied to the PL bundle and 30 N to the AM bundle. The tension in each bundle was independently measured using a tensiometer[19].

4. CT Image-Based Measurement

CT images were obtained using an Asteion 4 Multislice CT System (Toshiba Medical Systems, Tochigi, Japan), at 120 kVp and 150 mA, with 1-mm slice thickness. CT reconstruction of the tibial condyles, in the axial plane, was completed using a three-dimensional volume-rendering technique (AZE Virtual Place software; AZE Ltd., Tokyo, Japan). The position of the apertures of the tibial and femoral tunnels was obtained using a rectangular measurement grid. On the femoral side, the location of the insertion sites was described as a percentage of the distance both parallel and perpendicular to Blumensaat's line. On the tibial side, the location of the insertion sites was described as a percentage of the anteroposterior and mediolateral dimensions (Fig. 2).

5. Second-Look Arthroscopic Examination

Second-look arthroscopy was performed, with patients' consent, at approximately 1 year post-reconstruction for the removal of the two double-spike plates (Meira, Aichi, Japan), fixed with screws into the tibia, which were used for the tibial fixation of the ACL graft. These data were retrospectively collected from the

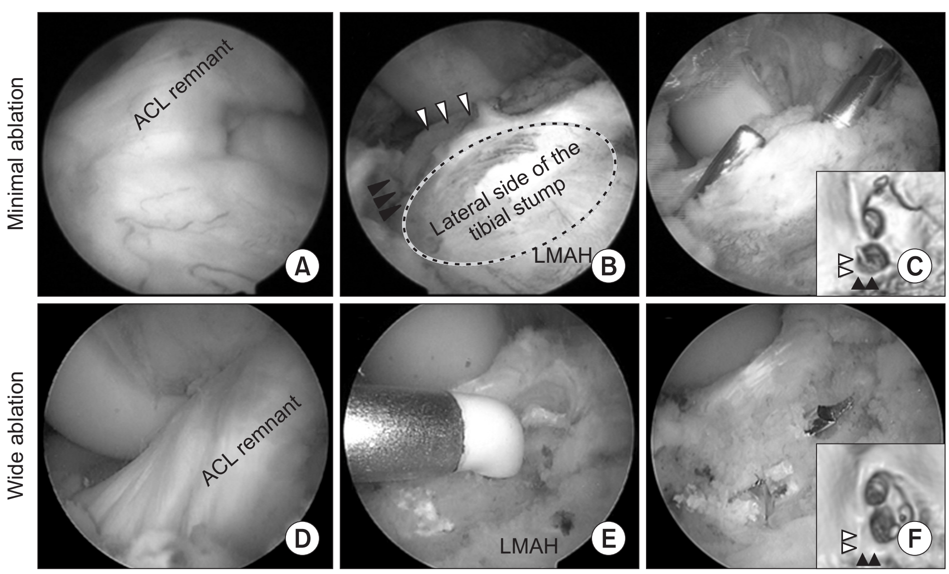

Fig. 1. Ablation range and tunnel creation within the anterior cruciate ligament (ACL) tibial footprint in the two groups. Tibial tunnel aperture of the left knee for the minimal ablation group (A–C), with ablation performed just medial to the footprint (B). (D–F) Wide ablation of the tibial stump, with no ACL stump retained. Black arrowheads: Parsons' knob, white arrowheads: medial intercondylar ridge, black circle: lateral side of the tibial stump, LMAH: lateral meniscus anterior horn.

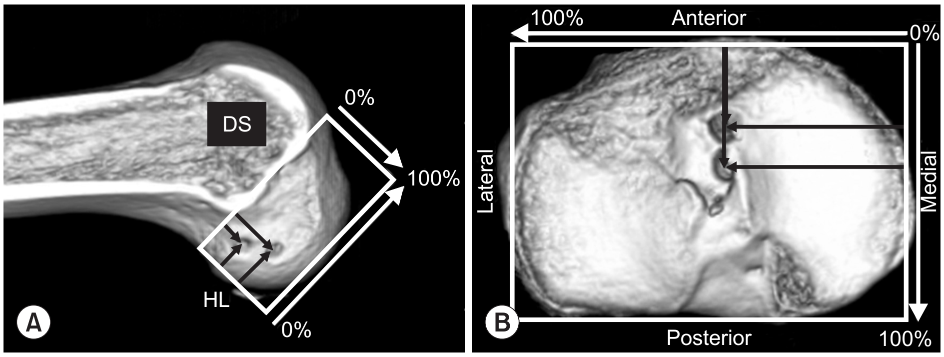

Fig. 2. Computed tomography image-based measurement of insertion sites in the femur and tibia. The total sagittal diameter of the lateral femoral condyle measured along Blumensaat's line. (B) The location of the insertion sites on the tibia was expressed as a percentage of the anterior-to-posterior and medial-to-lateral dimensions. DS: deep-to-shallow distance, HL: high-to-low distance.

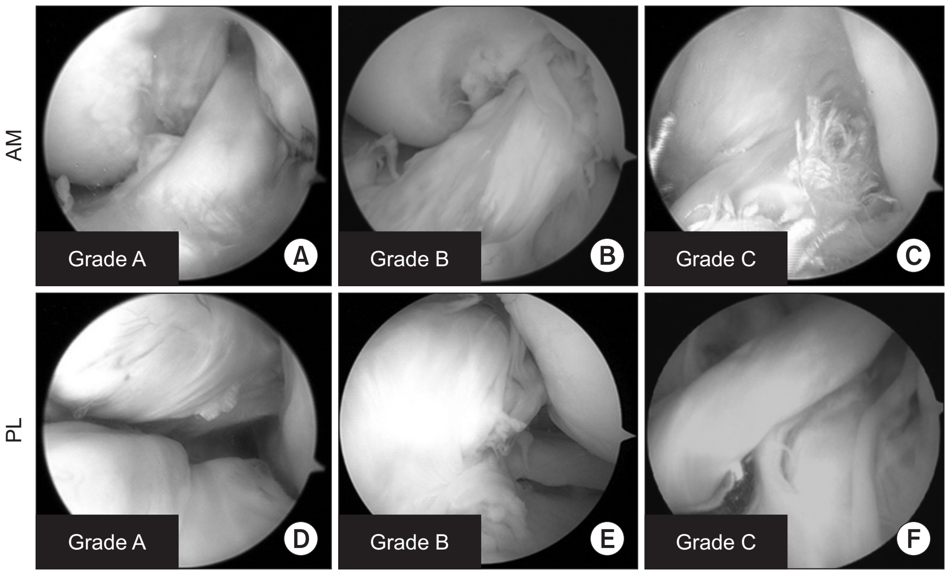

Fig. 3. Evaluation of synovial coverage. Arthroscopic grading of synovial coverage of the transplanted anteromedial (AM) (A–C) and posterolateral (PL) (D–F) bundle grafts. Grade A: synovium covers >75% of the graft (A, D), Grade B: coverage between 50% and 75% (B, E), Grade C: coverage <50% (C, F).

records and confirmation from the review of arthroscopic videos. Arthroscopic evaluation was performed using the 3-point synovial coverage scale as reported by Kondo and Yasuda[5], as follows: grade A, 3 points; grade B, 2 points, and grade C, 1 point (Fig. 3).

6. Evaluation of Clinical Outcomes

Anterior knee laxity and rotational stability were measured under anesthesia by two experienced surgeons (TF and SM). Anterior tibial translation was assessed at the primary surgery and second-look evaluation using a KT-2000 arthrometer at maximum manual tension, with the knee in 20° of flexion, as per a previously described procedure[20]. Rotational stability was assessed using the manual pivot shift test, as previously described[21], at the time of the second-look arthroscopy. The pivot shift test was subjectively determined by the examiner based on the IKDC criteria: none (−), glide (+), clunk (++), or gross instability (+++). Functional outcomes were assessed 2 years after surgery using the Lysholm knee score, the IKDC form, and the KOOS, with scores obtained at each visit.

7. Statistical Analyses

Data were presented as means±standard deviations. Differences between the two groups were evaluated using the Mann-Whitney *U*-test, with a p-value <0.05 considered significant. Intra- and inter-observer repeatability in measurement of the position of the tibial tunnel was assessed by calculating the intraclass correlation coefficient (ICC), with the Kappa value used for grading of synovial coverage of the graft.

Results

1. Tunnel Diameter and Position

Comparison of the position of the tibial and femoral tunnels between the two groups is reported in Table 2. Measurement of the tunnel position was consistent, with ICC values of 0.899–0.912 for intraobserver repeatability and 0.902–0.925 for interobserver repeatability. There was no significant difference in the position of the femoral tunnel between the MA and WA groups. However, there was a significant difference between the two groups in the

Table 2. Comparison of the Position of the Tibial and Femoral Tunnels between the Two Groups

Characteristic	MA group (n=26)	WA group (n=26)	p-value
Tibial tunnel			
AM bundle			
AP (%)	31.6±2.3	35.2±4.5	<0.01[a]
ML (%)	44.0±1.4	46.8±1.7	<0.01[a]
PL bundle			
AP (%)	47.6±3.2	48.7±2.3	0.10
ML (%)	44.1±1.7	46.1±1.5	<0.01[a]
Femoral tunnel			
AM bundle			
High-low	23.7±1.7	23.9±2.0	0.71
Deep-shallow	22.9±1.9	23.5±2.7	0.50
PL bundle			
High-low	51.2±1.8	50.1±2.4	0.16
Deep-shallow	32.3±1.9	31.5±2.4	0.23

Values are presented as mean±standard deviation.
MA: minimal ablation, WA: wide ablation, AM: anteromedial, AP: anteroposterior, ML: mediolateral, PL: posterolateral.
[a]p<0.05.

anteroposterior and mediolateral dimensions of the AM tibial tunnel (31.6%±2.3% and 44.0%±1.4%, respectively, for the MA group, and 35.2%±4.5% and 46.8%±1.7%, respectively, for the WA group; p<0.01) and the mediolateral dimension of the PL tibial tunnel (44.1%±1.7% for the MA group and 46.1%±1.5% for WA group; p<0.01).

2. Synovial Coverage Evaluation

Comparison of the arthroscopic evaluation between the two groups is reported in Table 3. The determination of the grade of synovial coverage was consistent, with a Kappa value of 0.72. Good synovial coverage (grade A) of the AM graft was identified in 85% of cases (22 knees) in the MA group and 54% of cases (14 knees) in the WA group, with poor coverage (grade C) identified in 8% of cases (2 knees) in the WA group. The synovial coverage scale of the AM bundle, based on Kondo's synovial coverage grade, was 2.8±0.4 in the MA group and 2.4±0.7 in the WA group (p=0.03). No difference in the synovial coverage scale was identified between the two groups for the PL bundle (p=0.51).

3. Clinical Outcomes

A comparison of the clinical outcomes at the time of the second-look arthroscopy examination between the two groups is reported in Table 4. The KT-2000 values were significantly lower for the MA group than for the WA group (0.6±0.5 mm and 1.4±0.8 mm, respectively, p<0.01). With regard to rotation stability, the pivot test was negative for 50 patients, with a positive "glide (+)" assessed for 2 patients and with no differences between the two groups. Furthermore, there were no differences between the

Table 3. Comparison of Arthroscopic Evaluation Results between the Two Groups

Characteristic	MA group (n=26)	WA group (n=26)	p-value
AM synovial coverage, no. (%)			
Grade A	22 (85)	14 (54)	
Grade B	4 (15)	10 (38)	
Grade C	0 (0)	2 (8)	
Synovial coverage score, mean±SD	2.8±0.4	2.4±0.7	0.03[a]
PL synovial coverage, no. (%)			
Grade A	18 (69)	13 (50)	
Grade B	6 (23)	10 (38)	
Grade C	2 (8)	3 (12)	
Synovial coverage score, mean±SD	2.5±0.7	2.3±0.7	0.51

Synovial coverage score was evaluated on a 3-point scale: grade A, 3 points; grade B, 2 points; and grade C, 1 point.
MA: minimal ablation, WA: wide ablation, AM: anteromedial, SD: standard deviation, PL: posterolateral.
[a]p<0.05.

Table 4. Comparison of the Clinical Outcome at the Final Follow-up between the Two Groups

Characteristic	MA group (n=26)	WA group (n=26)	p-value
Lysholm knee score	95.9±4.3	95.7±6.6	0.87
IKDC evaluation	83.7±9.7	83.8±8.9	0.97
KOOS pain	93.0±6.1	92.7±5.6	0.74
Symptom	92.4±7.9	87.3±8.5	0.06
Activities of daily living	98.1±4.8	97.5±3.4	0.54
Sport/recreation	85.5±12.7	88.1±8.9	0.59
Quality of life	86.7±11.1	80.9±14.9	0.19
KT-2000 at second-look (mm)	0.6±0.5	1.4±0.8	0.003[a]
Pivot shift test at second-look (%)			0.84
None (–)	26 (100)	24 (92)	
Glide (+)	0	2 (8)	

Values are presented as mean±standard deviation.
MA: minimal ablation, WA: wide ablation, IKDC: International Knee Documentation Committee, KOOS: Knee Injury and Osteoarthritis Outcome Score.
[a]p<0.05.

two groups in the Lysholm score, IKDC score, and KOOS.

Discussion

The most important findings of our study were that the use of anatomical tibial bony landmarks[14,15] (Parsons' knob and the medial intercondylar ridge) provided a more AM position of the AM tibial tunnel, improving anterior knee laxity. In addition, MA of the tibial stump was associated with better synovial coverage of the AM graft than WA.

Various landmarks for creating tibial tunnels in anatomically defined positions have been proposed to date[22-24]. Until 2014, we used the anterior horn of the LM as a reference for tunnel positioning[18], with this landmark being easily identified during arthroscopy. However, Ferretti et al.[25] stated that because of variations in the positional relationship between the anterior horn of the LM and the ACL attachment, this structure is unsuitable for use as a landmark to determine the positioning of the AM and PL tunnels. Tensho et al.[15] described that the tibial attachment of the ACL was located within a narrow area, surrounded by characteristic anatomic landmarks, based on their macroscopic and microscopic evaluations of the attachment sites of the ACL using 3-dimensional CT imaging. Based on this report, we thought that the use of two of these six bony landmarks would be sufficient to create a reproducible positioning of the tibial tunnel. In our study, positioning of the more AM tibial tunnel within the ACL footprint improved anterior stability of the knee after reconstruction. Moreover, MA, limited to the medial side of the tibial footprint, provided better visualization of the bony landmarks, which would improve the accuracy in the position of the AM tunnel. In addition to the tunnel position, we attempted to retain as much of the ACL stump as possible for two reasons. First, we considered that preservation of the remaining ACL mechanoreceptors might be beneficial to functional recovery, and second, we anticipated that the native ACL fibroblasts would be incorporated as part of the new composite graft.

The importance of preserving a tibial stump was reported by Schutte et al.[12] who demonstrated that the majority of mechanoreceptors are located close to the tibial insertion of the ACL. Although maintaining these mechanoreceptors could, theoretically, improve clinical outcomes at 2 years post-reconstruction, we did not identify a significant difference between the MA and WA groups. Although not reflected in our clinical results, good synovial coverage of the graft would further provide a potential source of nerve fibers, which could enhance the reinnervation of implanted grafts[8]. We do demonstrate better synovial coverage of the graft with the MA procedure. Based on research to date, it may be beneficial for ACL reconstruction to perform partial preservation on the tibial ACL stump and to achieve good synovial coverage, even if complete residual preservation is not achievable.

Using a tibial remnant preservation approach similar to ours, Lee et al.[26] reported good proprioceptive and functional outcomes after ACL reconstruction. However, they positioned the tibial tunnel at the center of the normal ACL tibial remnant. Recent anatomical studies have provided evidence that positioning the tibial tunnel at the center of the ACL footprint may damage the anterior meniscal roots[27-29] and that an anterior tibial tunnel position improved anterior knee laxity post-reconstruction[30].

The limitations of our study need to be acknowledged. Foremost, the number of cases included in our analysis was limited (n=52), and our analysis was retrospective in nature. Verification of our outcomes with large prospective studies is needed. Second, the follow-up period was within 2 years of ACL reconstruction. Therefore, we cannot speculate whether there will be differential effects between the two procedures on long-term outcomes of knee function. Third, the synovial tissue might contain some scar tissue, which would influence results. The amount of scar tissue in the synovial tissue should be objectively measured under microscope assessment. Lastly, although preservation of the remnant also preserves mechanoreceptors, we did not compare proprioceptive function between the two groups, due to the retrospective nature of the study.

Conclusions

Our findings suggest that a more AM tibial tunnel position would improve anterior knee laxity and MA would improve synovial coverage of the AM bundle of the graft.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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