

Influence of Graft Bending Angle on Femoral Tunnel Widening After Double-Bundle ACL Reconstruction

Comparison of Transportal and Outside-In Techniques

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Background: Previous studies have suggested that increased mechanical stress due to acute graft bending angle (GBA) is associated with tunnel widening and graft failure after anterior cruciate ligament (ACL) reconstruction. Few studies have compared the GBA between the outside-in (OI) and the transportal (TP) techniques.

Purpose: To evaluate the influence of GBA on clinical outcomes and tunnel widening after ACL reconstruction with OI versus TP technique.

Study Design: Cohort study; Level of evidence, 3.

Methods: Included in the study were 56 patients who underwent double-bundle ACL reconstruction ($n = 28$ in the OI group and $n = 28$ in the TP group). Clinical outcomes (Lysholm, International Knee Documentation Committee, Tegner score, and knee laxity) 1 year postoperatively were evaluated. Computed tomography scans at 5 days and 1 year postoperatively were used for imaging measurements, and the femoral tunnel was divided into the proximal third, middle, and aperture sections. The GBA and cross-sectional area (CSA) were measured using image analysis software and were compared between groups. A correlation analysis was performed to determine if the GBA affected clinical outcomes or tunnel widening.

Results: No significant difference was observed in clinical outcomes between the groups. The GBA of both the anteromedial (AM) and posterolateral bundles were more acute in the OI group compared with the TP group ($P < .05$). The CSA at the AM tunnel aperture increased significantly in the OI group ($84.2\% \pm 64.3\%$) compared with the TP group ($51.4\% \pm 36.7\%$) ($P = .04$). However, there were no differences in the other sections. In the Pearson correlation test, GBA was not correlated with tunnel widening or clinical outcomes.

Conclusion: Regardless of technique, the GBA did not have a significant influence on tunnel widening or clinical outcomes. Considering a wider AM tunnel aperture, a more proximal and posterior AM tunnel position might be appropriate with the OI technique.

Keywords: tunnel widening; outside-in technique; transportal technique; double-bundle ACL reconstruction; graft bending angle

Recently, as anatomic anterior cruciate ligament (ACL) reconstruction has been highlighted, the importance of accurate tunnel position has also been emphasized.^{11,51,57} Based on previous studies, better clinical outcomes and rotational and anterior stability^{4,13,23,28,34,50} have been shown in anatomic versus nonanatomic ACL reconstruction. An incorrect tunnel position causes loss of flexion, knee joint instability, and graft elongation or

impingement.^{17,29,44} Tunnel malposition has also been considered a crucial factor for ACL graft failure.^{16,17,55} Accurate tunnel position has become the main interest in ACL reconstruction to restore normal kinematics and stability.^{2,9,12,35,58} To achieve an accurate position, the transportal (TP) and outside-in (OI) techniques, which allow the femoral tunnel to be placed independently from the tibial tunnel, are commonly used in anatomic ACL reconstruction.^{19,21,37}

Unlike the OI technique, the TP technique has several disadvantages, which include the following: (1) shorter femoral tunnel length with possible nerve or lateral collateral

The Orthopaedic Journal of Sports Medicine, 9(10), 23259671211035780
DOI: 10.1177/23259671211035780
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ligament injury, (2) higher incidence of posterior wall blow-out of the lateral femoral condyle and cartilage damage at the medial femoral condyle during the drilling, (3) higher variability in femoral tunnel length, and (4) technically demanding procedures for a case with a narrow notch or preserving of a remnant ACL fiber.^{22,30,37,42} Therefore, the OI technique has gained popularity. However, several studies^{22,27,47} have reported that the graft bending angle (GBA) is more acute in the OI technique compared with the TP technique. The acute GBA in the OI technique was suggested as a potential concern.^{27,33,39,46,47}

Segawa et al³⁹ indicated that acute GBA can increase mechanical stress in the femoral tunnel wall, which increases tunnel widening. Other studies^{27,36} have also confirmed that acute GBA is associated with tunnel widening. Furthermore, acute GBA affects repetitive bending stress on the graft and thus influences graft healing within the joint.^{33,47,52} Recent studies^{27,46} have shown that magnetic resonance imaging signals of the graft are related to GBA and are considered one of the causes of graft failure. Meanwhile, Sim et al⁴³ showed that the difference in GBA between the OI and TP techniques does not affect graft healing. However, there had been few studies addressing whether the difference in GBA in both techniques affects tunnel widening and clinical outcomes.

In this study, we aimed to evaluate the influence of GBA on tunnel widening and clinical outcomes after ACL reconstruction between the OI versus the TP technique. The hypotheses were that (1) tunnel widening would be larger in the OI technique, (2) clinical outcomes would be inferior with the OI compared with the TP technique, and (3) acute GBA would be associated with tunnel widening.

METHODS

Ethics approval for the study protocol was received from our institution. A retrospective cohort analysis was performed on patients who underwent double-bundle ACL reconstruction with hamstring tendon autograft from December 2010 to March 2014. A single senior surgeon (J.H.W.) conducted all operations. Routine computed tomography (CT) scan evaluation was performed with patient consent at 5 days and at 1 year postoperatively. The study exclusion criteria were patients who underwent (1) revision ACL reconstruction, (2) multiligament

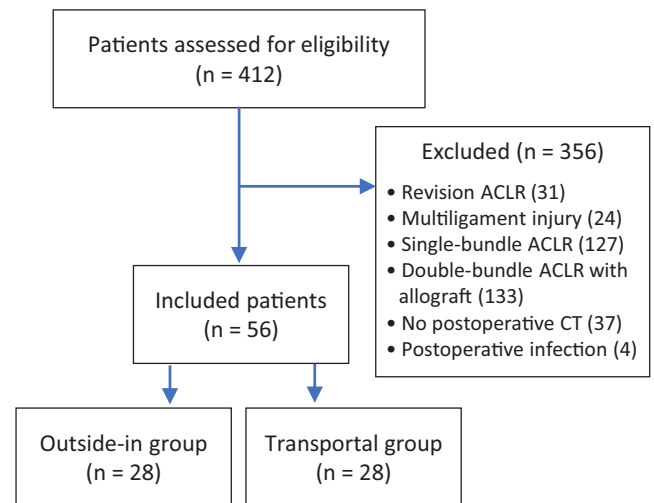


Figure 1. Study flowchart. ACLR, anterior cruciate ligament reconstruction; CT, computed tomography.

reconstruction, (3) single-bundle ACL reconstruction, (4) primary double-bundle ACL reconstruction with allograft, (5) those who did not undergo CT scan evaluation postoperatively, and (6) those with postoperative infection.

In total, 56 patients who met the inclusion criteria were included in this study. The patients were classified into either the OI or TP group (n = 28 each) according to the femoral tunnel technique (Figure 1). The following measures were compared between the groups: clinical outcomes, tunnel widening at 3 sections (measured as percentage change in cross-sectional area [CSA]), femoral tunnel position (using the Bernard quadrant method⁵), tunnel length, reaming diameter of the femoral tunnel, Endobutton length, and graft length in the tunnel.

Surgical Technique

The surgical technique has been described in detail in a previous study.²² The femoral and tibial tunnels were created at the centers of the anatomic footprint. The anatomic femoral tunnel position was determined based on the bony landmark (lateral intercondylar ridge and bifurcation ridge) at 90° of knee flexion.¹⁴ The anteromedial (AM) tunnel center was positioned 6 to 7 mm anterior to the

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Final revision submitted March 8, 2021; accepted April 14, 2021.

One or more of the authors has declared the following potential conflict of interest or source of funding: This research was supported by the Basic Science Research Program through the National Research Foundation of Korea funded by the Ministry of Science and Information and Communications Technology (2015R1A2A1A15054779 and 2017R1A2B3007362). AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

Ethical approval for this study was obtained from Samsung Medical Center (SMC IRB file No. 2018-10-045-001).

posterior cartilage margin or 2 mm from the posterior bony ridge of the lateral femoral condyle and 3 to 4 mm inferior from the extended line of the posterolateral (PL) corner of the intercondylar notch. The PL tunnel center was positioned 5 mm superior to the edge of the joint cartilage on an imaginary line perpendicular to the tangent at the lowermost portion of the lateral femoral condyle. The center of each tunnel was marked with a microfracture awl (ConMed Linvatec) before tunnel formation. The auto-hamstring tendon of all patients was harvested; triple semitendinosus (6.5-9.5 mm) for the AM bundle and triple gracilis (4.5-7 mm) for the PL bundle was used. The diameter of the drill was determined based on the diameter of the harvested graft. The AM and PL tunnel lengths were measured with a ruler after reaming the femoral tunnel. The size of the Endobutton CL (Smith & Nephew Endoscopy) was determined based on the tunnel length, which enabled graft length in the femoral tunnel of minimal 20 mm. The prepared graft was fixed with a cortical suspension system using the Endobutton on the femoral side, and a bioabsorbable interference screw with post tie was used on the tibial side at 0° of knee flexion.

OI Anatomic Double-Bundle Reconstruction. A FlipCutter femoral guide (Arthrex) was inserted through the central midpatellar portal. The center of the guide tip was aimed at the footprint center, which was marked previously. The guide angle was set at 110° for the AM femoral tunnel and 100° for the PL femoral tunnel. After fixing the tip of the drill sleeve into the lateral femoral cortex with tapping, the FlipCutter was passed to the anatomic center of the footprint. After flipping the blade, retrograde reaming was performed.

TP Anatomic Double-Bundle Reconstruction. A 2.4-mm guide pin was inserted 2 to 3 mm by tapping through the accessory AM portal at the center of the femoral insertion site at 90° of knee flexion. With the knee fully flexed, the guide pin was passed through the full femur, then a Sentinel cannulated reamer (ConMed Linvatec) was introduced over the guide pin by pulling the guide pin anterior to prevent iatrogenic injury in the medial femoral condyle and drilled femoral tunnel.

Clinical Outcome Measurement

Clinical outcomes were evaluated at 1-year follow-up using the Lysholm, the International Knee Documentation Committee (IKDC) subjective, and Tegner scores. Anteroposterior knee laxity (side-to-side difference [SSD]) was measured using a KT-2000 arthrometer.

CT Measurements

The CT scans performed at 5 days and 1 year after surgery were used to evaluate radiologic parameters. The same CT scanner and settings (LightSpeed VCT; GE Medical Systems; collimation, 16 × 0.625 mm; tube parameter, 120 kVp, and 200 mA; acquisition matrix 512 × 512; a field of view, 140 mm; slice thickness 0.625 mm) were used for all examinations. The DICOM (Digital Imaging and Communications in Medicine) image data were extracted from the

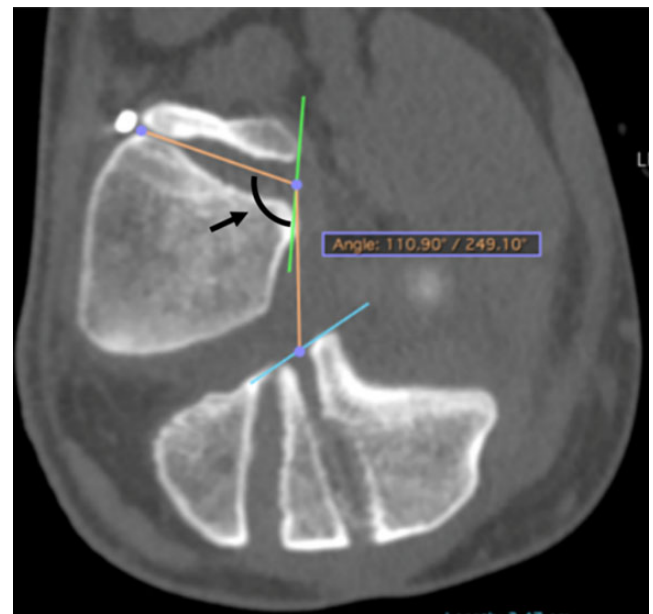


Figure 2. The femoral graft bending angle (GBA) plane in OsiriX image software. The centers of the extra- and intra-articular apertures (green line) of the femoral tunnel and the center of the intra-articular aperture (blue line) of the tibial tunnel were connected together (brown line). The black arrow indicates the GBA.

picture archiving and communication system (Centricity RA-1000; GE Medical Systems), then imported into OsiriX image software (Version 3.8; Pixmeo) to measure GBA and CSA. The program allowed the image to be rotated in the coronal, sagittal, and axial planes, which helped to identify the ideal plane to measure the values.

The measurement method has been detailed in previous studies.^{22,52} The GBA was measured in the femoral GBA plane, in which the centers of the extra- and intra-articular apertures of the femoral tunnel and the center of the intra-articular aperture of the tibial tunnel were viewed together (Figure 2).

The femoral tunnel plane was defined as the imaginary line parallel to the tunnel wall in which the total length of the femoral tunnel was shown in the coronal and sagittal planes. For all measurements except Endobutton length, the femoral tunnel plane was divided into 3 sections: the proximal third (AM1 or PL1), the middle of the tunnel (AM2 or PL2), and the tunnel aperture (AM3 or PL3). The CSA was measured at these 3 sections on a plane perpendicular to the femoral tunnel plane (Figure 3). Tunnel widening was evaluated as the change in CSA between 5-day and 1-year CT scans, calculated using the same formula utilized in a previous study³:

$$\text{Change in CSA(\%)} = \frac{\text{CSA}_{1y} - \text{CSA}_{5d}}{\text{CSA}_{5d}} \times 100$$

A single independent researcher who had no orthopaedic knowledge measured each parameter twice with an

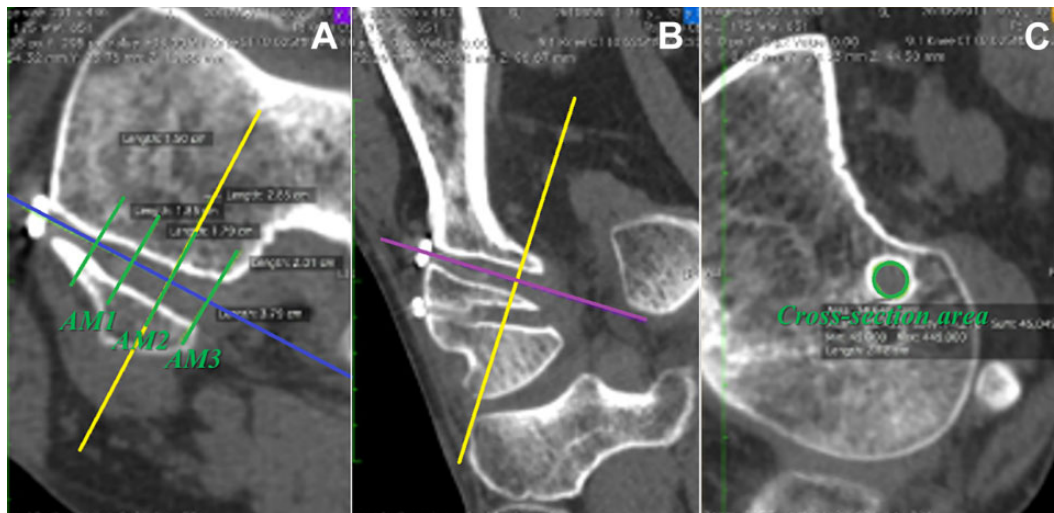


Figure 3. The femoral tunnel plane was determined as the imaginary line parallel to the tunnel wall in which the total length of the femoral tunnel was shown in (A) the coronal plane (blue line) and (B) sagittal plane (purple line). The femoral tunnel plane was divided into 3 sections: proximal third (AM1 [shown] or PL1), middle of the tunnel (AM2 or PL2), and tunnel aperture (AM3 or PL3). (C) The cross-sectional area was measured at these 3 sections on a plane perpendicular from the femoral tunnel plane (yellow line in A and B). AM, anteromedial; PL, posterolateral.

interval of 4 weeks between measurements. The reliability of the measurements was assessed using the intraclass correlation coefficient (ICC).

Statistical Analysis and Reliability

Distributions of all continuous variables were checked with the Shapiro-Wilk test, which indicated that some of the continuous variables had a nonnormal distribution. The Mann-Whitney test was used to determine the statistical significance of the tunnel widening and clinical outcomes between the 2 groups. The Pearson correlation test was performed to determine if GBA was correlated with tunnel widening and clinical outcomes. In addition, the Pearson correlation test was performed to determine which other factors could affect tunnel widening. A P value $< .05$ was considered statistically significant. All statistical analyses were performed with SPSS Version 20 (IBM).

A power analysis for the Pearson correlation test was performed to determine the adequacy of sample size at an alpha level of .05 and a statistical power of 0.80, and the correlation coefficient (r) was set to 0.4 based on a previous study.²⁷ The calculations based on the sample size of 56 patients showed adequate power (0.88).

RESULTS

The characteristics of the study groups are shown in Table 1. Although there were statistical differences between groups in length of PL tunnel and GBA, no significant differences were noted in other demographic characteristics.

TABLE 1
Characteristics and Radiologic Measurements
for the Study Groups at 5 Days Postoperatively^a

	Outside-In (n = 28)	Transportal (n = 28)	<i>P</i>
Age, y	34.1 ± 12.7	34.1 ± 11.2	.99
Sex, male/female, n	22/6	23/5	.74
Body mass index, kg/m ²	25.2 ± 3.9	25.2 ± 2.3	.95
Femoral tunnel position on Bernard quadrant, %			
AM (deep-shallow direction)	24.4 ± 4.2	25.6 ± 4.4	.23
AM (high-low direction)	27.3 ± 10.4	25.2 ± 6.4	.45
PL (deep-shallow direction)	37.8 ± 6.2	35.6 ± 5.2	.25
PL (high-low direction)	53.5 ± 9.0	51.1 ± 4.6	.29
Tunnel length, mm			
AM	38.0 ± 3.6	36.8 ± 3.7	.11
PL	39.9 ± 3.9	36.6 ± 3.2	.001 ^b
Tunnel diameter (mm)			
AM	7.3 ± 0.6	7.1 ± 0.5	.16
PL	5.5 ± 0.6	5.5 ± 0.6	.70
Graft bending angle, deg			
AM	108.4 ± 11.3	122.6 ± 7.2	.001 ^b
PL	91.2 ± 7.9	105.4 ± 8.9	.001 ^b
Endobutton size (mm)			
AM	17.4 ± 3.3	16.4 ± 3.0	.28
PL	18.6 ± 3.9	17.3 ± 2.9	.26

^aData except for patient sex are expressed as mean ± SD. AM, anteromedial; PL, posterolateral.

^bStatistically significant difference between groups ($P < .05$, Mann-Whitney test).

The intratester ICCs for the measurements ranged from 0.82 to 0.94 (Appendix Table A1).

Comparison of Clinical Outcomes

Regarding clinical outcomes (Lysholm, IKDC, Tegner score, and knee laxity SSD), no statistically significant difference was observed between groups (Table 2).

Comparison of Tunnel Widening

The change in CSA at AM3 was statistically larger in the OI group (84.2% ± 64.3%) compared with the TP group (51.4% ± 36.7%) ($P = .04$). However, the change in CSA in the remaining sections was not significantly different between groups (Figure 4).

Does Acute GBA Affect Tunnel Widening and Clinical Outcomes?

According to Pearson correlation, GBA was not correlated with tunnel widening or clinical outcomes (Lysholm, IKDC, Tegner score, and knee laxity) (Table 3).

Correlation Between Tunnel Widening and Clinical Outcomes

Tunnel widening at AM3 was not significantly correlated with clinical outcomes. However, AM tunnel widening at AM1 and AM2 was significantly correlated with clinical scores (Table 4).

Other Factors Associated With Tunnel Widening

AM tunnel widening at AM1 or AM2 was significantly correlated with PL tunnel widening at PL1 or PL2 (Table 5). The femoral tunnel position, tunnel length, reaming diameter of the femoral tunnel, graft length in the tunnel, and Endobutton length were not significantly correlated with tunnel widening (Appendix Table A2).

DISCUSSION

The principal finding of this study was that tunnel widening in the OI technique could be significantly larger at the AM tunnel aperture compared with the TP technique at 1 year postoperatively. However, no significant difference was observed in other sections. Previous studies^{27,48,56} reported that acute GBA was associated with tunnel aperture widening, which may be attributed to the increased contact pressure and excessive mechanical stress on the sharp edge of the bone tunnel aperture.³⁸ Considering an acute GBA in the OI technique that increases mechanical stress at the tunnel aperture, a larger tunnel widening at the tunnel aperture in the OI technique is understandable. However, GBA was not statistically correlated with tunnel widening in the correlation analysis, which was contrary to what was expected. Yanagisawa et al⁵⁶ reported similar results to ours in their study on double-bundle ACL

TABLE 2
Comparison of Clinical Outcomes Between Groups^a

	Outside-In (n = 28)	Transportal (n = 28)	<i>P</i> ^b
Lysholm score	91.8 ± 8.0	90.4 ± 8.4	.48
IKDC subjective score	78.0 ± 14.3	79.9 ± 15.6	.46
Tegner score	6.3 ± 1.7	5.9 ± 1.7	.64
Knee laxity SSD	1.7 ± 0.9	1.8 ± 1.1	.76

^aData are expressed as mean ± SD. IKDC, International Knee Documentation Committee; SSD, side-to-side difference.

^bMann-Whitney test.

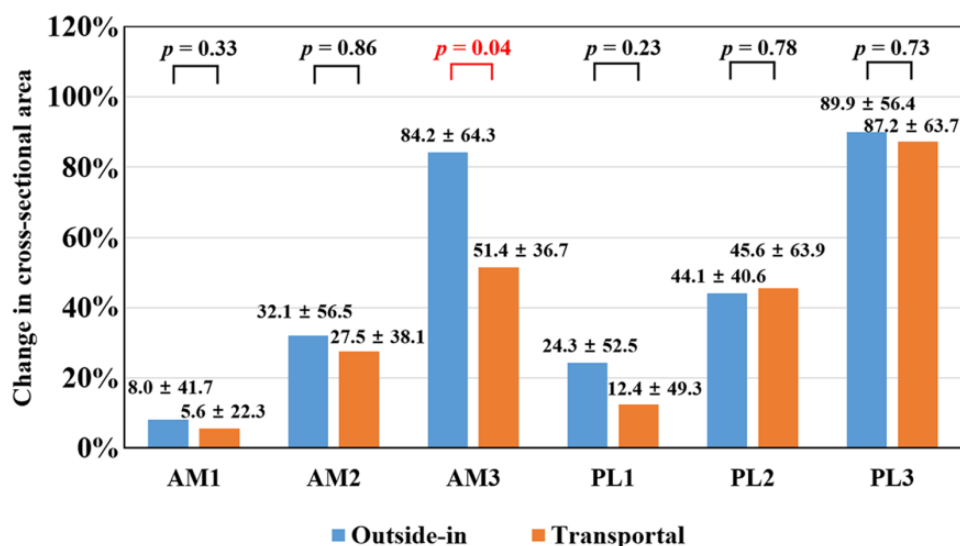


Figure 4. Comparison of femoral tunnel widening between the outside-in and transportal groups. Tunnel widening was measured as change in the cross-sectional area at the proximal third (AM1 or PL1), the middle (AM2 or PL2), and the aperture (AM3 or PL3) of the tunnel. AM, anteromedial; PL, posterolateral.

TABLE 3
Correlation Between Tunnel Widening
and Graft Bending Angle^a

Graft Bending Angle	<i>r</i>	<i>P</i>
AM tunnel		
AM1	-0.04	.79
AM2	0.06	.69
AM3	-0.08	.55
Lysholm	-0.01	.99
IKDC	-0.07	.63
Tegner	-0.10	.42
Knee laxity SSD	-0.11	.44
PL tunnel		
PL1	-0.05	.71
PL2	0.02	.88
PL3	-0.01	.96
Lysholm	-0.02	.90
IKDC	0.17	.22
Tegner	0.01	.95
Knee laxity SSD	-0.15	.30

^aTunnel widening was measured at the proximal third (AM1 or PL1), the middle (AM2 or PL2), and the aperture (AM3 or PL3) of the tunnel. AM, anteromedial; IKDC, International Knee Documentation Committee; PL, posterolateral; SSD, side-to-side difference.

reconstruction. They noted that the change in tunnel widening was larger in the group with a higher GBA, but there was no significant correlation between AM tunnel widening and GBA. A possible explanation is that the difference in GBA in the 2 techniques might not primarily affect tunnel widening, and other unconsidered factors might have more influence on tunnel widening. A previous cadaveric study⁴⁰ has shown that the mechanical effect of cyclic loading causes minimal changes in tunnel widening, but not in conditions with increased instability. Silva et al⁴¹ have reported that a biologic effect might be the main mechanism of tunnel widening. Weber et al⁵³ have reported that younger age, male sex, and delay from injury to surgery might be potential risk factors for tunnel widening. Fahey and Indelicato¹⁰ have reported that tunnel widening can be larger when allograft is used rather than autograft. These results support the notion that biologic factors or conditions increasing biologic factors might be the main mechanism of tunnel widening. In addition, widening of the AM tunnel and PL tunnel were significantly correlated in the present study, such that if one of the tunnels is widened, the other tunnel will increase at the same time. This finding indicates that the main mechanisms of tunnel widening are biologic factors rather than mechanical factors.

Another interesting finding is that the difference in GBA between both techniques was not statistically associated with clinical outcomes. Previously, mechanical stress concentration between the graft and bone interface had been a concern related to acute GBA. Li et al²⁷ reported that GBA was not associated with functional scores, anteroposterior laxity, or rate of return to sports. Niki et al³² compared both techniques and found no significant differences in terms of clinical scores, anteroposterior laxity, or pivot shift.

TABLE 4
Correlation Between Tunnel Widening
and Clinical Outcomes^a

	Lysholm Score		IKDC Score		Tegner Score		Knee Laxity SSD	
	<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>
AM1	-0.36	.002 ^b	-0.39	.001 ^b	-0.31	.006 ^b	-0.07	.6
AM2	-0.25	.08 ^c	-0.31	.022 ^b	-0.22	.09 ^c	-0.09	.5
AM3	-0.11	.4	-0.16	.24	0.02	.89	-0.08	.58
PL1	-0.05	.72	-0.27	.037 ^b	-0.26	.047 ^b	0.13	.33
PL2	0.02	.89	-0.09	.51	-0.16	.23	0.03	.85
PL3	0.08	.55	0.16	.23	0.21	.12	0.1	.46

^aTunnel widening was measured at the proximal third (AM1 or PL1), the middle (AM2 or PL2), and the aperture (AM3 or PL3) of the tunnel. AM, anteromedial; IKDC, International Knee Documentation Committee; PL, posterolateral; SSD, side-to-side difference.

^bStatistically significant ($P < .05$).

^cBorderline statistically significant ($P < .10$).

Moreover, Sim et al⁴³ obtained similar results, which were consistent with the current study. Although there was a difference in GBA between the OI and TP techniques, no significant difference was observed in the short-term clinical outcomes. Therefore, both techniques could be viable options for anatomic ACL reconstruction. However, with respect to graft maturation, several studies^{1,7,27,46} have reported that acute GBA was a risk factor for delayed graft healing. Further studies are needed on whether the difference in graft maturation influences long-term clinical outcomes.

Last, clinical scores (Lysholm, IKDC, and Tegner) were associated with tunnel widening at the proximal third and the middle but not at the tunnel aperture. The tunnel aperture is the part where biologic and mechanical effects, including windshield-wiper effect, bungee effect, and GBA, are acting simultaneously for tunnel widening. By contrast, the mechanical effect becomes minimal in the proximal third and middle areas because of less motion of the graft, and biologic factors are the main mechanism of tunnel widening in those areas. Considering that biological factors are the main mechanism of tunnel widening at the proximal third and middle areas, the clinical scores were also influenced by biological factors. The clinical scoring system is an index based on the clinical symptoms of the patient, and clinical scores might have a relatively low value in case of increased inflammatory reaction. Previously, studies^{8,18,20,54} have reported that tunnel widening is not associated with clinical scores. However, the results of some studies^{3,6} are contrasting. The variation in results on the correlation between clinical scores and tunnel widening might be explained by differences in biologic factors based on tunnel widening measurement at different sites, as well as by rehabilitation and surgical methods.

The major clinical implication of this study is that tunnel widening at the AM tunnel aperture could be larger when the OI technique is used compared with the TP technique.

TABLE 5
Correlation With the Other Parts of Tunnel Widening^a

	AM1		AM2		AM3		PL1		PL2		PL3	
	<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>
AM1	—	—	0.63	.001 ^b	0.35	.009 ^b	0.51	.001 ^b	0.24	.079 ^c	-0.01	.951
AM2	0.63	.001 ^b	—	—	0.54	.001 ^b	0.48	.001 ^b	0.34	.012 ^b	0.13	.35
AM3	0.35	.009 ^b	0.54	.001 ^b	—	—	0.42	.001 ^b	0.17	.212	0.20	.136
PL1	0.51	.001 ^b	0.48	.001 ^b	0.42	.001 ^b	—	—	0.64	.001 ^b	0.40	.002 ^b
PL2	0.24	.079 ^c	0.34	.012 ^b	0.17	.212	0.64	.001 ^b	—	—	0.48	.001 ^b
PL3	-0.01	.951	0.13	.35	0.20	.136	0.40	.002 ^b	0.48	.001 ^b	—	—

^aTunnel widening was measured at the proximal third (AM1 or PL1), the middle (AM2 or PL2), and the aperture (AM3 or PL3) of the tunnel. Dashes indicate the correlation coefficient is meaningless so it was not recorded. AM, anteromedial; PL, posterolateral.

^bStatistically significant ($P < .05$).

^cBorderline statistically significant ($P < .10$).

In recent studies,^{25,26} there has been increasing interest in the graft position in the tunnel, and the location of the reconstructed ACL graft was located eccentrically, not at the center of the tunnel center. The relatively larger tunnel widening at the tunnel aperture indicates that the graft position could have shifted more in the OI technique. Considering the results of tunnel shifting into the anterior and distal directions at the tunnel aperture,⁴⁵ a more proximal and posterior AM femoral position from the center of the AM anatomic footprint might be more appropriate for the OI technique. By contrast, tunnel widening at the tunnel aperture could be relatively less when the TP technique is used, and it might be more appropriate to position the femoral tunnel closer to the original anatomic footprint in the TP technique. In addition, this method might be helpful in reducing the incidence of posterior wall blowout, which can occur if the femoral tunnel is positioned posteriorly in the TP technique.²² Tomihara et al⁴⁹ also noted that the femoral tunnel should be located more posteriorly; their rationale was that the anterior position of the femoral tunnel might increase the GBA.

Another clinical implication is that biologic factors could affect tunnel widening and clinical outcomes. Tunnel widening is known to occur mainly at postoperative 6 weeks.⁵³ Based on the results of the present study, it might be helpful to minimize the biologic reaction during this period to improve clinical scores and minimize tunnel widening. Weber et al⁵³ reported that higher activity levels in younger patients could be associated with tunnel widening, and Hantes et al¹⁵ showed that tunnel widening can be decreased with restrictions in motion, weightbearing, and strength activities. Thus, limited rehabilitation within 6 weeks might be effective in decreasing tunnel widening and in improving clinical scores. Early intervention for ACL injury might be helpful. A delay of >1 year from injury to surgery has also been suggested to be associated with tunnel widening,⁵³ and a delayed operation can result in irreparable meniscal tear,²⁴ thereby worsening inflammatory reactions by increasing contact pressure and decreasing contact area at the medial compartment.³¹ The use of allograft versus autograft has also been suggested to be

related to tunnel widening,¹⁰ and the possible cause is the increased biologic reaction in the allograft.

The current study has several limitations. First, GBA and tunnel widening were analyzed in patients who underwent double-bundle ACL reconstruction. In double-bundle ACL reconstruction, each bundle may act as a covariant, and the association between GBA and tunnel widening may differ in single-bundle ACL reconstruction. Second, the patients who used allograft were excluded from the study, additional analysis with allograft might provide more strength in numbers and could also provide some information about the biological response in the tunnel. Third, the study is a retrospective cohort study with small sample size. Weak correlations might have been missed because of the small sample size. Additional prospective analysis with a larger cohort should be conducted to confirm our findings. Fourth, the follow-up period was short; further study is needed to assess whether the difference in GBA affects long-term clinical outcomes. Last, the interval of the femoral tunnel section was different in each patient as a result of different femoral tunnel lengths, and this difference might have affected the results of tunnel widening. However, tunnel length was not associated with tunnel widening in statistical analysis. Despite these limitations, the current study also has strengths. The study showed that the difference in GBA between the TP and OI techniques may not have a significant influence on tunnel widening and clinical outcomes. Additionally, our results provide evidence that tunnel widening is affected mainly by biological factors, not by mechanical factors.

CONCLUSION

The difference in GBA between the TP and OI techniques did not have a significant influence on tunnel widening and clinical outcomes. Considering larger AM tunnel widening at the tunnel aperture in the OI technique, a more posterior and proximal position might be appropriate for the OI technique.

ACKNOWLEDGMENT

The authors thank Hoon-young Kim for his effort in data collecting and technical support for this study.

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APPENDIX

TABLE A1
Intratester ICC Values for Each Measurement^a

	ICC (95% CI)
Horizontal position of AM	0.89 (0.88-0.94)
Vertical position of AM	0.85 (0.82-0.89)
Horizontal position of PL	0.87 (0.84-0.91)
Vertical position of PL	0.83 (0.8-0.88)
Femoral graft bending angle	
AM	0.82 (0.78-0.87)
PL	0.87 (0.84-0.91)
CSA increase	
AM	0.94 (0.91-0.97)
PL	0.91 (0.88-0.94)

^aAM, anteromedial; CSA, cross-sectional area; ICC, intraclass correlation coefficient; PL, posterolateral.

TABLE A2
Other Associated Factors Affecting Tunnel Widening^a

Correlation With Femoral Tunnel Position on Bernard Quadrant								
	AM (deep-shallow)		AM (high-low)		PL (deep-shallow)		PL (high-low)	
	<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>
AM1	0.08	.54	-0.03	.84	-0.07	.59	-0.05	.74
AM2	-0.04	.77	-0.11	.041	-0.08	.58	-0.01	.96
AM3	0.04	.78	0.14	.3	0.01	.97	0.14	.30
PL1	-0.2	.14	0.15	.29	0.01	.95	0.13	.32
PL2	-0.13	.34	0.17	.22	0.09	.50	0.18	.19
PL3	0.29	.03 ^b	0.19	.16	-0.04	.79	0.09	.53

Correlation With Total Tunnel Length				
	AM (TL)		PL (TL)	
	<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>
AM1	-0.02	.86	-0.2	.13
AM2	-0.13	.34	-0.13	.35
AM3	0.01	.98	-0.02	.88
PL1	-0.15	.28	-0.06	.68
PL2	-0.18	.19	-0.11	.43
PL3	-0.18	.18	0.03	.83

Correlation With Initial Femoral Tunnel Reaming Diameter				
	AM (RD)		PL (RD)	
	<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>
AM1	0.02	.86	-0.06	.68
AM2	0.04	.8	-0.01	.96
AM3	0.05	.74	-0.12	.39
PL1	0.14	.31	-0.07	.59
PL2	-0.06	.66	-0.03	.84
PL3	0.15	.28	-0.13	.33

Correlation With Graft Length in the Tunnel				
	AM (GL)		PL (GL)	
	<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>
AM1	-0.12	.38	-0.28	.03 ^b
AM2	-0.08	.57	-0.11	.42
AM3	-0.02	.88	-0.05	.73
PL1	-0.06	.66	-0.22	.11
PL2	0.08	.54	-0.11	.43
PL3	-0.22	.1	-0.07	.61

Correlation With Endobutton Length				
	AM (EL)		PL (EL)	
	<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>
AM1	0.05	.7	0.03	.84
AM2	-0.1	.48	-0.05	.74
AM3	0.01	.94	0.02	.88
PL1	-0.13	.34	0.14	.32
PL2	-0.26	.05 ^b	-0.02	.86
PL3	-0.06	.64	0.1	.47

^aTunnel widening was measured as the change in cross-sectional area at the proximal third (AM1 or PL1), the middle (AM2 or PL2), and the aperture (AM3 or PL3) of the tunnel. AM, anteromedial; EL, Endobutton length; GL, graft length in the tunnel; PL, posterolateral; RD, reaming diameter; TL, tunnel length.

^bStatistically significant ($P < .05$).