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Small Intercondylar Notch Size Is Not Associated with Poor Surgical Outcomes of Anatomical Single-Bundle Anterior Cruciate Ligament Reconstructions

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Background: Although many studies have been conducted on the association between the intercondylar notch size and the risk of anterior cruciate ligament (ACL) injury, few studies have examined its relationship with the condition after surgical treatment. Therefore, this study aimed to investigate the surgical outcomes of anatomical single-bundle ACL reconstruction according to intercondylar notch volumes.

Methods: Medical records of patients who underwent anatomical single-bundle ACL reconstruction using a tibialis anterior allograft between 2015 and 2019 were retrospectively reviewed. For each sex, eligible patients were classified into two groups based on their percentile of intercondylar notch volumes, which were measured using postoperative three-dimensional computed tomography images (group S, ≤ 50th percentile of included patients; group L, > 50th percentile of included patients). Additional grouping was performed based on the group's percentiles of normalized values of intercondylar notch volumes to body heights. Between-group comparative analyses were performed on the perioperative data and surgical outcomes in both objective and subjective aspects.

Results: One hundred patients were included in the study. For male patients, there were no differences in the overall surgical outcomes between groups, whereas group L showed a significantly greater knee anteroposterior (AP) laxity than group S at the final follow-up ($p = 0.042$ for the side-to-side differences [SSD] at the maximum manual force). Similarly, there were no differences in the female patients in the overall surgical results between the groups, whereas group L showed a significantly greater knee AP laxity at the final follow-up ($p = 0.020$ for the SSD at 134 N; $p = 0.011$ for the SSD at the maximum manual force). Additional analyses based on the normalized values of the intercondylar notch volume showed consistent results for male patients, and additional grouping for female patients was identical to the existing grouping.

Conclusions: The surgical outcomes of anatomical single-bundle ACL reconstruction in patients with relatively small intercondylar notch volumes were comparable to those with large notch volumes, but rather showed favorable outcomes in postoperative knee AP laxity.

Keywords: *Knee, Anterior cruciate ligament, Intercondylar notch, Anterior cruciate ligament reconstruction*

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The bony morphology of the knee is known to be associated with the development of anterior cruciate ligament (ACL) injury.[1] Among several anatomical factors, a small intercondylar notch is reported as a potential risk factor for ACL injury.[2-5] Within a narrow intercondylar notch, the ACL can be prone to tearing during the range of motion of the knee.[6] Accordingly, individuals with small intercondylar notches are required to be aware of the risks of ACL injuries.[2-5]

While many studies have been conducted on the correlation between the intercondylar notch size and the risk of ACL injury, few studies have examined the relationship between the intercondylar notch size and surgical outcomes in patients who underwent ACL reconstructions. Anatomically placed ACL grafts could theoretically be affected by intercondylar notch sizes, as in natural ACLs, which may affect surgical outcomes. Indeed, Wolf et al.[7] reported that a smaller intercondylar notch dimension is not a risk factor for graft failure after anatomic ACL reconstruction. However, there may be limitations in accurately assessing the influence of the intercondylar notch size, since the previous study was conducted on patients who underwent individualized ACL reconstructions (single-bundle or double-bundle reconstructions based on intraoperative measurements).[7,8] To accurately evaluate the effect of intercondylar notch sizes on the surgical outcomes of anatomic ACL reconstructions, an investigation should be conducted on patients who underwent consistent surgical processes, including graft characteristics. Considering the increasing incidence of ACL procedures,[9] analysis of the surgical outcomes according to the intercondylar notch sizes in patients who undergo anatomical ACL reconstruction is crucial for establishing appropriate treatment strategies.

Therefore, this study aimed to investigate the surgical outcomes of anatomical single-bundle ACL reconstruction according to intercondylar notch volumes. It was hypothesized that patients with relatively small notch volumes would have poor surgical outcomes.

METHODS

This study was approved by the Ethics Committee of Gangnam Severance Hospital (No. 3-2022-0040), which waived the requirement for informed consent from the patients owing to the retrospective nature of the study.

Patient Enrollment

Electronic medical records of patients who underwent ACL reconstruction at our institution between January 2015 and December 2019 were retrospectively reviewed. In the present study, to evaluate patients with a relatively consistent graft diameter, patients who underwent a single-bundle ACL reconstruction through the transportal technique using a tibialis anterior allograft were included.[10] The exclusion criteria were as follows: (1) follow-up duration less than 2 years; (2) no postoperative computed tomography (CT) evaluation performed on the day of surgery; (3) revision ACL reconstruction; (4) combined other ligament surgeries (including the surgical procedures for the posterior cruciate ligament [PCL], the posterolateral corner structures of the knee, the medial collateral ligament, and the anterolateral ligament); (5) cartilage lesions more severe than grade 2 according to the International Cartilage Repair Society grading system for the tibiofemoral joint;[11] (6) subtotal meniscectomy; and (7) presence of postoperative infections. In addition, patients who underwent notchplasty during the surgery were excluded.[12] Patients eligible for inclusion in the study were classified into two groups by sex based on their femoral intercondylar notch volumes:[3,4] (1) group S, patients with relatively small femoral intercondylar notch volumes (≤ 50th percentile of the included patients); (2) group L, patients with relatively large femoral intercondylar notch volumes (> 50th percentile of the included patients) (Fig. 1). Furthermore, additional grouping was made based on the normalized values of intercondylar notch volumes to respective body heights (group NS, patients with relatively small normalized femoral intercondylar notch volumes [≤ 50th percentile of included patients]; group NL, patients with a relatively large normalized femoral intercondylar notch volume [> 50th percentile of included patients]).[13] All groupings were performed according to sex since intercondylar notch sizes have been reported to show sex-based differences.[3]

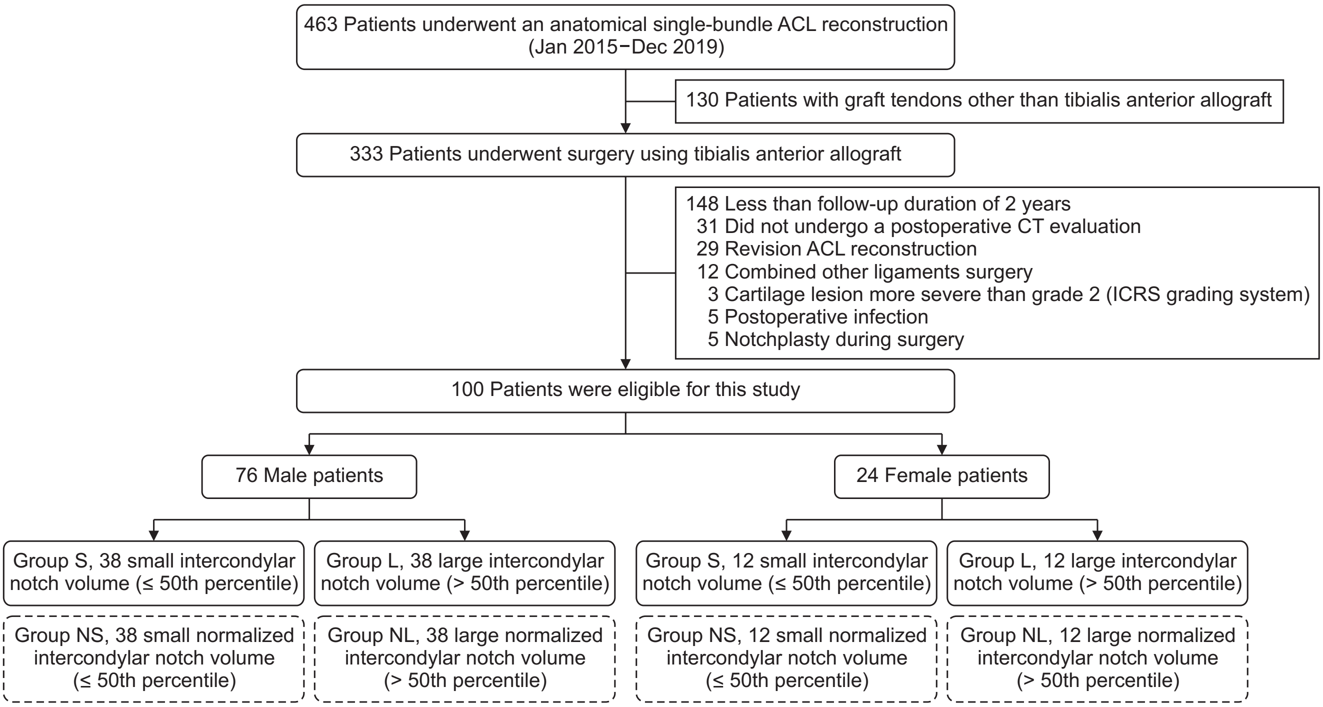

Fig. 1. Flowchart of patient inclusion in the study. ACL: anterior cruciate ligament, CT: computed tomography, ICRS: International Cartilage Repair Society.

Surgical Procedures and Postoperative Rehabilitation

Patients were allowed to choose a graft for ACL after being explained the available graft options (autogenous hamstring tendon graft, allogeneic tendon graft, and autogenous bone–patellar tendon–bone graft) along with their pros and cons. For patients included in this study, tibialis anterior allograft tendons sterilized with low-dose gamma irradiation (12.8–12.9 kGy, cobalt 60) were used after thawing in normal saline mixed with antibiotics at room temperature. The diameter of the two-stranded graft tendon was measured using a slotted sizing block. The graft was then pre-tensioned at about 70–100 N using a graft preparation board (Graft Master III, Smith & Nephew) for 20 minutes to minimize postoperative creep.

Surgical procedures were performed by two independent orthopedic surgeons at our institution (SHK and MJ). First, diagnostic arthroscopy was performed using a parapatellar high anterolateral portal. For accompanying intra-articular lesions such as meniscus tears or cartilage defects, appropriate surgical procedures were performed depending on the lesion's characteristics and patient factors. After identifying the ACL injury, a tibial tunnel was created on the footprint of the ACL with reference to remnant tissue and anatomical landmarks. Subsequently, an independent femoral tunnel was aimed to be made at the femoral footprint using a far anteromedial portal at about 120° of knee flexion. The tunnel diameter was prepared equal to that of the previously prepared graft. The graft was placed into the femoral tunnel and fixed with a fixed-loop cortical suspension device (EndoButton CL, Smith & Nephew). The graft construct was then pulled distally, and its suture limbs were held with the tensioning device placed on the anterior tibial cortex (ConMed Linvatec, Largo). The graft was pulled with a force of approximately 70–100 N, and repetitive cyclic tensioning was applied. Finally, while maintaining tension, a bioabsorbable interference screw was fixed in the tibial tunnel at about 15° of knee flexion, and the part of the graft outside the tibial tunnel was further supplemented with a cortical screw and washer.

The same rehabilitation program was applied to all patients except those who underwent meniscus repair or cartilage restoration procedures. Tolerable weight-bearing with the use of crutches and knee range of motion exercises were allowed immediately after surgery. At 6 weeks postoperatively, all patients were permitted full weight-bearing gait and encouraged to perform closed kinetic chain exercises. Open kinetic chain exercises, as well as jogging and swimming, were allowed 6 months after surgery. Return to previous sporting activities was permitted 9 months after surgery.

Clinical Evaluations

Clinical evaluations were performed on both objective and subjective aspects, both before and after surgery. For objective assessments, the anteroposterior (AP) and rotational laxity measures of the knee were analyzed. The AP laxity of the knee was evaluated by measuring anterior tibial translation with a KT-2000 arthrometer (Medmetric) with a force of 134 N and a maximum manual force.[14] Subsequently, the measured values of the affected knee were compared with those of the contralateral knee, and the side-to-side (SSD) difference values were recorded. The rotational laxity of the knee was assessed using a manual pivot-shift test, which was recorded as 0 (absent; normal), 1 (glide; nearly normal), 2 (jump; abnormal), or 3 (transient lock; severely abnormal). The International Knee Documentation Committee (IKDC) subjective score, Lysholm score, and Tegner activity scale were used for functional assessments.[15,16] The aforementioned variables were measured before surgery, at 2 years postoperatively, and at the last follow-up and were compared between the groups. In addition, cases reporting subjective knee instability or showing pathologic laxity of the knee (more than 5 mm of SSD in anterior tibial translation or grade 2 to 3 in the pivot-shift test) during the follow-up period were defined as graft failure.[17]

Radiographic Measurements

Radiographic measurements were obtained using plain radiographs, CT images, and magnetic resonance imaging (MRI). Measurements with plain radiographs include the osteoarthritis grade on standing AP knee radiographs, the posterior tibial slope on lateral knee radiographs,[18] and the hip-knee-ankle angle on full-length weight-bearing lower extremity AP radiographs.[19]

CT images obtained on the day of surgery were used to assess the ACL femoral tunnel positions and femoral intercondylar notch volume. CT evaluations were performed using a CT scanner (Sensation 64, Siemens Healthcare) with tube parameters of 120–140 kVp and 86–253 mA. The slice thickness, scan field of view, and acquisition matrix were 0.6–1 mm, 134–333 mm, and 512 × 512 pixels, respectively. The Digital Imaging and Communications in Medicine data of the CT scan were then obtained from the picture archiving and communication system (GE Medical Systems Information Technologies) and imported into Mimics software (version 17, Materialize) to segment the three-dimensional (3D) volumetric model of the femur. Measurements of ACL femoral tunnel position were performed using a 3D femur model. 3D rotation of the femur model was performed according to a previous study, and the reference frame for the measurements was based on the lateral walls of the intercondylar notches (represented as height and depth).[20] Assessments of the femoral intercondylar notch volume were performed using Mimics software, which allows measurements on CT images to appear simultaneously on 3D models. Measurements were made using the truncated-pyramid shape simulation method proposed by Iriuchishima et al.[4] Following the measurement process reported in a previous study, the intercondylar notch volume was calculated by measuring the cross-sectional area of the intercondylar notch at the most proximal and most distal levels of the Blumensaat line that corresponded to the axial plane perpendicular to the long axis of the distal femur, as well as the intercondylar notch height (Fig. 2). The femoral intercondylar notch volume was calculated as follows: volume (cm^3) = h (S1 + S2 + $\sqrt{[S1S2]}$) / 3 (Fig. 3). Two orthopedic surgeons (HSM and HJK), who were blinded to patient information, measured the femoral intercondylar notch volume to increase the reliability of the study. The mean of the two measured values was used in the analyses.

Graft maturity was assessed using 3T MRI performed 1 year after surgery (Achieva, Philips Healthcare; or Discovery 750w, GE Healthcare). Turbo spin-echo T2-weighted sequences with a 3-mm thickness were used for the analyses. Measurements were made using the Mimics software according to the method by Tashiro et al.[21] by measuring the mean signal intensity (SI) of a region of interest at the proximal third, mid-substance, and distal third of the ACL graft. Then, the signal-to-noise quotient (SNQ) value was obtained to evaluate the graft maturity; this was done by normalizing the graft SI value with the SI value of the PCL and that of the background as follows: SNQ = (SI of ACL graft – SI of PCL) / SI of the background.

Statistical Analysis

Before the study, sample size calculations were conducted to detect differences in objective and subjective surgical outcomes between the groups. The objective outcome was based on the SSD in anterior tibial translation measured by the KT-2000 arthrometer, and the subjective outcome was based on the IKDC and Lysholm scores. Reference values for sample size calculations were adopted from established clinically meaningful values (SSD in anterior tibial translation = 3 mm; IKDC subjective score = 11.5; Lysholm score = 8.9) and standard deviations reported in previous studies (SSD in anterior tibial translation = 2.21; IKDC subjective score = 13.06; Lysholm score = 8.5).[14-16,22-24] The significance level (α) was set at 5%, and the power ($1 - \beta$) was set at 90%. The results revealed that 28 patients per group

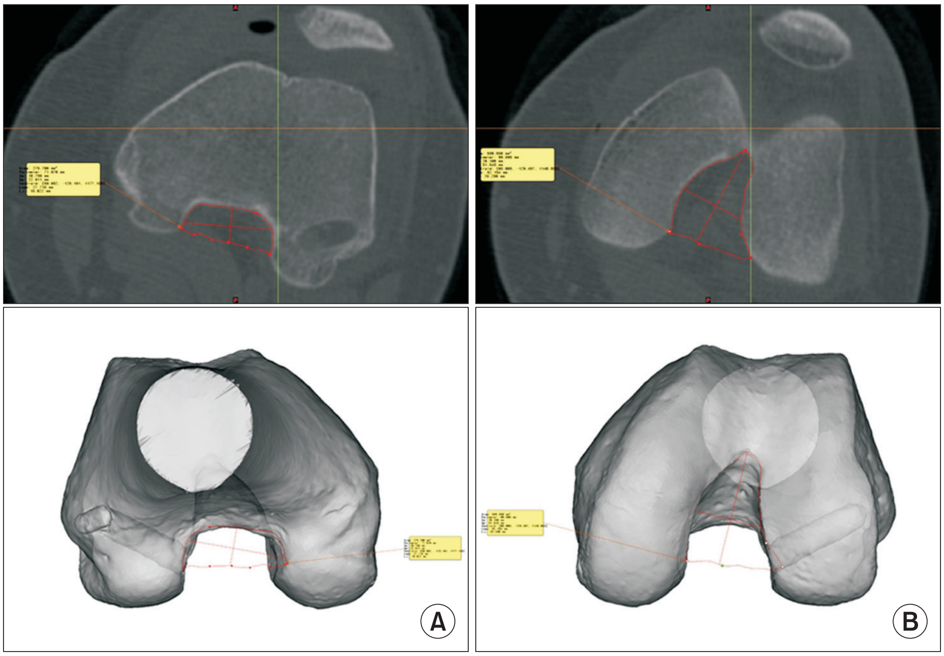

Fig. 2. Measurements for the cross-sectional area of the intercondylar notch in the computed tomography images, which are simultaneously reflected in the reconstructed three-dimensional femur model. Measurements at the most proximal (A) and distal (B) levels of the Blumensaat's line correspond to the axial plane perpendicular to the long axis of the distal femur.

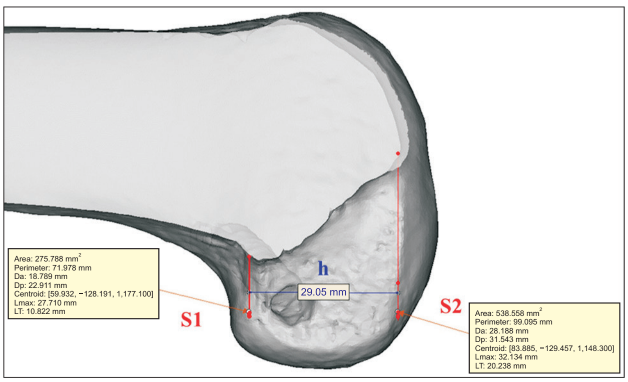

Fig. 3. The femoral intercondylar notch volume was obtained using the truncated-pyramid shape simulation method with the following formula: volume (cm^3) = h (S1 + S2 + $\sqrt{[S1S2]}$) / 3. S1 and S2 represent the cross-sectional area of the intercondylar notch at the most proximal and distal levels of Blumensaat's line, respectively. 'h' represents the vertical distance between the two intercondylar notch areas.

were required to detect between-group differences (12 patients for the SSD in anterior tibial translation, 28 patients for IKDC subjective scores, and 20 patients for Lysholm scores).

Statistical analyses were performed using the IBM SPSS Statistics for Windows ver. 26.0 (IBM Corp.). For comparative analyses of continuous variables, Student *t*-test was used when the sample size of each group was 30 or greater assuming a normal distribution according to the central limit theorem,[25] and the Mann-Whitney *U*-test was used when each group had less than 30 samples. For categorical variables, Pearson's chi-square test or Fisher's exact test was used. The measurement reliabilities for intercondylar notch volume were calculated using the intraclass correlation coefficient (ICC) set at a 95% confidence interval. A p-value of < 0.05 was considered significant.

RESULTS

A total of 100 patients were eligible for inclusion in this study. There were 76 men and 24 women, and the patients were classified according to the intercondylar notch volumes of each sex (38 male patients in groups S and L; 12 female patients in groups S and L) (Fig. 1). Additional grouping based on the normalized value of the intercondylar notch volume by body height was also performed in the same way (38 male patients in groups NS and NL; 12 female patients in groups NS and NL). The ICC for interobserver agreement between two investigators in measuring the femoral intercondylar notch volume was 0.932.

For male patients, there were no statistically significant differences between groups S and L in the demographic and perioperative data, except for variables related to the intercondylar notch volume (Tables 1 and 2). For the postoperative data, group L showed significantly greater knee AP laxity than group S at the final follow-up (p = 0.042 for the SSD in anterior tibial translation at the maximum manual force) (Table 3). In addition, although not statistically significant, a relatively higher graft failure rate was observed in group L than in group S (group S, 2.6%; group L, 18.4%) (Table 3). Furthermore, additional

Table 1. Comparison of Demographic Data

Variable	Group S	Group L	*p*-value
Male	38	38	
Age (yr)	28.8 ± 13.4	26.0 ± 8.3	0.281*
Height (cm)	172.5 ± 5.5	174.8 ± 4.6	0.051*
Body mass index (kg/m^2)	25.4 ± 3.5	27.2 ± 7.5	0.181*
Affected side			
Right : left	16 : 22	16 : 22	> 0.999†
Pre-injury Tegner activity score	6.5 ± 1.3	6.4 ± 1.4	0.676*
Time from Injury to surgery (wk)	19.6 ± 41.5	16.9 ± 23.9	0.733*
Follow-up duration (yr)	3.2 ± 1.2	2.9 ± 1.1	0.309*
Follow-up MRI at 1 year after surgery			
Yes : no	22 : 16	23 : 15	> 0.999†
Female	12	12	
Age (yr)	28.4 ± 11.6	29.3 ± 11.0	0.862‡
Height (cm)	160.2 ± 7.0	165.4 ± 7.6	0.100‡
Body mass index (kg/m^2)	23.0 ± 2.2	24.2 ± 5.3	0.665‡
Affected side			
Right : left	9 : 3	4 : 8	0.100†
Pre-injury Tegner activity score	4.7 ± 2.0	5.2 ± 2.0	0.534‡
Time from Injury to surgery (wk)	31.3 ± 66.8	12.9 ± 12.3	0.907‡
Follow-up duration (yr)	3.3 ± 1.3	2.8 ± 1.0	0.411‡
Follow-up MRI at 1 year after surgery			
Yes : no	3 : 9	6 : 6	0.214†

Values are presented as number of patients or mean ± standard deviation. Group S: patients with relatively small femoral intercondylar notch volumes (≤ 50th percentile of the included patients), Group L: patients with relatively large femoral intercondylar notch volumes (> 50th percentile of the included patients).
MRI: magnetic resonance imaging.
*Student *t*-test. †Fisher's exact test. ‡Mann-Whitney *U*-test.

analyses conducted with patients reclassified into group NS and group NL showed similar results as when comparing group N and group L ($p = 0.041$ for the SSD in anterior tibial translation at 134 N; $p = 0.035$ for the SSD in anterior tibial translation at the maximum manual force) (Supplementary Tables 1-3).

Regarding female patients, no significant differences were found in the demographic and perioperative data, except for parameters related to the intercondylar notch volumes between groups S and L (Tables 1 and 4). Meanwhile, as in male patients, group L showed significantly greater knee AP laxity than group S at the final follow-up ($p = 0.020$ for the SSD in anterior tibial translation at 134 N; $p = 0.011$ for the SSD in anterior tibial translation at the maximum manual force) (Table 5). Additional analyses based on the normalized value of the intercondylar notch volume were not performed in female patients because the results of the additional grouping were identical to those of the existing grouping.

DISCUSSION

The principal finding of the present study was that in both men and women, the surgical outcomes of anatomical sin-

Table 2. Comparison of Perioperative Data in Male Patients

Variable	Group S (n = 38)	Group L (n = 38)	*p*-value
Preoperative data			
Hip-knee-ankle angle (°)	1.9 ± 2.4	2.2 ± 2.8	0.629*
Posterior tibial slope (°)	7.5 ± 2.3	7.7 ± 2.3	0.773*
Kellgren-Lawrence grade			
0 : 1	35 : 3	36 : 2	> 0.999†
Knee laxity			
SSD in anterior tibial translation			
134 N (mm)	5.2 ± 2.5	5.9 ± 2.3	0.197*
Manual maximum force (mm)	6.2 ± 2.9	6.9 ± 2.5	0.245*
Pivot-shift test			
0 : 1 : 2 : 3	0 : 7 : 20 : 11	1 : 11 : 20 : 6	0.343†
Clinical score			
IKDC subjective score	53.2 ± 18.6	48.8 ± 18.1	0.297*
Lysholm score	61.7 ± 25.6	58.3 ± 24.3	0.546*
Tegner activity score	1.9 ± 1.7	1.8 ± 1.6	0.788*
Intraoperative data			
Graft diameter (mm)	8.9 ± 0.5	8.9 ± 0.5	> 0.999*
Femoral tunnel position			
Height (%)	51.9 ± 7.3	55.1 ± 9.9	0.117*
Depth (%)	29.3 ± 5.9	28.3 ± 4.9	0.395*
Femoral intercondylar notch			
Volume (cm^3)	8.4 ± 0.6	10.6 ± 1.1	< 0.001*
Distal base area (mm^2)	428.0 ± 45.1	510.5 ± 55.2	< 0.001*
Proximal base area (mm^2)	207.8 ± 39.9	246.6 ± 24.6	< 0.001*
Height (mm)	27.1 ± 1.3	28.6 ± 1.3	< 0.001*
Ratio to graft diameter	1.1 ± 0.1	0.9 ± 0.1	< 0.001*
Meniscal procedure			
Medial (no : meniscectomy : repair)	17 : 5 : 16	21 : 1 : 16	0.268†
Lateral (no : meniscectomy : repair)	25 : 6 : 7	25 : 5 : 8	> 0.999†

Values are presented as mean ± standard deviation or number of patients. Group S: patients with relatively small femoral intercondylar notch volumes (≤ 50th percentile of the included patients), Group L: patients with relatively large femoral intercondylar notch volumes (> 50th percentile of the included patients).
SSD: side-to-side difference, IKDC: International Knee Documentation Committee.
*Student *t*-test. †Fisher's exact test.

Table 3 Comparison of Postoperative Data in Male Patients

Variable	Group S (n = 38)	Group L (n = 38)	*p*-value
Postoperative 2 yr			
Knee laxity			
SSD in anterior tibial translation			
134 N (mm)	1.7 ± 1.6	2.1 ± 1.8	0.354*
Manual maximum force (mm)	2.1 ± 1.9	2.6 ± 1.8	0.250*
Pivot-shift test			
0 : 1 : 2	31 : 7 : 0	31 : 6 : 1	> 0.999†
Clinical score			
IKDC subjective score	77.9 ± 12.8	78.0 ± 10.2	0.968*
Lysholm score	87.7 ± 10.0	84.7 ± 9.1	0.171*
Tegner activity score	4.3 ± 1.8	4.1 ± 1.8	0.697*
At final follow-up			
Knee laxity			
SSD in anterior tibial translation			
134 N (mm)	1.6 ± 1.5	2.3 ± 1.8	0.083*
Manual maximum force (mm)	1.8 ± 1.4	2.6 ± 2.0	0.042*
Pivot-shift test			
0 : 1 : 2	33 : 5 : 0	29 : 8 : 1	0.375†
Clinical score			
IKDC subjective score	77.6 ± 13.3	79.8 ± 11.4	0.429*
Lysholm score	85.7 ± 11.1	85.1 ± 11.2	0.813*
Tegner activity score	4.0 ± 1.8	4.2 ± 1.8	0.523*
Kellgren-Lawrence grade			
0 : 1	32 : 6	30 : 8	0.768†
ACL graft maturity, SNQ	4.6 ± 11.2	7.0 ± 12.6	0.268‡,§
Graft failure			
Yes : no	1 : 37	7 : 31	0.056†

Values are presented as mean ± standard deviation or number of patients. Group S: patients with relatively small femoral intercondylar notch volumes (≤ 50th percentile of the included patients), Group L: patients with relatively large femoral intercondylar notch volumes (> 50th percentile of the included patients).
SSD: side-to-side difference, IKDC: International Knee Documentation Committee, ACL: anterior cruciate ligament, SNQ: signal-to-noise quotient.
*Student *t*-test. †Fisher's exact test. ‡Mann-Whitney *U*-test. §For patients who underwent follow-up magnetic resonance imaging at 1 year after surgery (20 in group S and 22 in group L).

gle-bundle ACL reconstruction in patients with relatively small intercondylar notch volumes were comparable to those in patients with large intercondylar notch volumes. Rather, patients with relatively small intercondylar notch volumes showed more favorable surgical outcomes in objective aspects, especially knee laxity. Therefore, a small intercondylar notch volume may not be a risk factor for the surgical outcomes of anatomical ACL reconstructions.

Table 4. Comparison of Perioperative Data in Female Patients

Variable	Group S (n = 12)	Group L (n = 12)	*p*-value
Preoperative data			
Hip-knee-ankle angle (°)	0.6 ± 1.9	–0.5 ± 2.4	0.166*
Posterior tibial slope (°)	7.2 ± 1.6	6.7 ± 3.0	0.402*
Kellgren-Lawrence grade			
0 : 1 : 2	10 :1 : 1	12 : 0 : 0	0.478†
Knee laxity			
SSD in anterior tibial translation			
134 N (mm)	5.1 ± 2.3	6.2 ± 2.1	0.153*
Manual maximum force (mm)	6.2 ± 2.9	7.1 ± 2.1	0.296*
Pivot-shift test			
0 : 1 : 2	2 : 9 : 1	3 : 7 : 2	0.714†
Clinical score			
IKDC subjective score	43.1 ± 13.9	51.4 ± 12.5	0.132*
Lysholm score	59.2 ± 23.4	69.5 ± 16.6	0.371*
Tegner activity score	1.3 ± 0.5	1.3 ± 1.2	0.801*
Intraoperative data			
Graft diameter (mm)	8.7 ± 0.5	8.6 ± 0.5	0.68*
Femoral tunnel position			
Height (%)	55.6 ± 8.1	57.8 ± 6.3	0.644*
Depth (%)	29.3 ± 4.1	30.7 ± 4.2	0.686*
Femoral intercondylar notch			
Volume (cm^3)	6.1 ± 0.5	7.9 ± 0.6	< 0.001*
Distal base area (mm^2)	309.5 ± 33.5	412.5 ± 29.5	< 0.001*
Proximal base area (mm^2)	171.2 ± 17.2	201.3 ± 19.4	0.001*
Height (mm)	25.8 ± 1.4	26.4 ± 1.3	0.225*
Ratio to graft diameter	1.4 ± 0.1	1.1 ± 0.1	< 0.001*
Meniscal procedure			
Medial (no : meniscectomy : repair)	9 : 2 : 1	10 : 0 : 2	0.590†
Lateral (no : meniscectomy : repair)	10 : 0 : 2	11 : 0 : 1	> 0.999†

Values are presented as mean ± standard deviation or number of patients. Group S: patients with relatively small femoral intercondylar notch volumes (≤ 50th percentile of the included patients), Group L: patients with relatively large femoral intercondylar notch volumes (> 50th percentile of the included patients).
SSD: side-to-side difference, IKDC: International Knee Documentation Committee.
*Mann-Whitney *U*-test. †Fisher's exact test.

Table 5. Comparison of Postoperative Data in Female Patients

Variable	Group S (n = 12)	Group L (n = 12)	*p*-value
Postoperative 2 yr			
Knee laxity			
SSD in anterior tibial translation			
134 N (mm)	1.2 ± 2.5	2.0 ± 1.4	0.050*
Manual maximum force (mm)	1.5 ± 2.1	2.6 ± 2.0	0.156*
Pivot-shift test			
0 : 1	9 : 3	7 : 5	0.667†
Clinical score			
IKDC subjective score	72.5 ± 17.0	77.1 ± 12.8	0.665*
Lysholm score	77.8 ± 18.0	86.3 ± 11.7	0.213*
Tegner activity score	3.3 ± 2.2	3.3 ± 1.6	0.681*
At final follow-up			
Knee laxity			
SSD in anterior tibial translation			
134 N (mm)	0.7 ± 1.8	2.0 ± 1.5	0.020*
Manual maximum force (mm)	0.8 ± 1.7	2.6 ± 2.0	0.011*
Pivot-shift test			
0 : 1	8 : 4	6 : 6	0.680†
Clinical score			
IKDC subjective score	77.3 ± 11.5	77.7 ± 13.7	0.931*
Lysholm score	83.3 ± 10.4	86.0 ± 11.5	0.450*
Tegner activity score	3.2 ± 1.9	3.5 ± 1.5	0.576*
Kellgren-Lawrence grade			
0 : 1 : 2	10 : 0 : 2	10 : 2 : 0	0.230†
ACL graft maturity, SNQ	3.2 ± 2.7	3.8 ± 6.4	0.606*,‡
Graft failure			
Yes : no	1 : 11	2 : 10	> 0.999†

Values are presented as mean ± standard deviation or number of patients. Group S: patients with relatively small femoral intercondylar notch volumes (≤ 50th percentile of the included patients), Group L: patients with relatively large femoral intercondylar notch volumes (> 50th percentile of the included patients).
SSD: side-to-side difference, IKDC: International Knee Documentation Committee, ACL: anterior cruciate ligament, SNQ: signal-to-noise quotient.
*Mann-Whitney *U*-test. †Fisher's exact test. ‡For patients who underwent follow-up magnetic resonance imaging at 1 year after surgery (3 in group S and 6 in group L).

While numerous studies have been conducted on the association between the characteristics of femoral intercondylar notches and the occurrence of ACL injuries,[2-5,7] few studies have examined the relationships with the condition after surgical treatment. Since postoperative complications such as residual knee laxity, graft failure, and arthritis progression still remain to be resolved, it is necessary to evaluate the effect of theoretically possible risk factors on surgical outcomes after ACL reconstruction. Analyses of surgical outcomes according to the femoral intercondylar notch volume might be helpful in evaluating the prognosis of surgery and establishing appropriate treatment strategies.

Although still controversial, a small intercondylar notch is generally accepted as a potential risk factor for ACL injury.[2-5] However, in this study, patients with relatively small intercondylar notch volumes showed comparable surgical outcomes, including graft failure rates, compared to patients with larger intercondylar notch volumes. The discrepancies between the findings reported in previous studies that did not include postoperative patients and the results shown in this study are thought to be due to the morphological differences between the native ACL and graft tendons. The cross-sectional area of the mid-substance of the native ACL was approximately 40 mm^2,[26,27] whereas the diameter of the graft tendon used in the patients included in this study was 8.8 ± 0.5 mm. Accordingly, although a direct comparison is not possible, it is estimated that the cross-sectional area of the graft tendons used in the included patients was larger than that of the native ACL. Therefore, graft tendons with a relatively large cross-sectional area of the mid-substance of the tendon, where impingement mainly occurs,[6] may be relatively stronger against impingement compared to the native ACL. Although a previous study reported that the risk of graft impingement increases as the graft size increases,[28] it can be expected that the effect of the impinging force on the graft may not be significant enough to damage the graft. Furthermore, a previous study by Wolf et al.[7] also showed similar results to our findings. For the reasons mentioned above, this study may have shown different results from those previously reported regarding the relationship between the intercondylar notch sizes and ACL injuries.

Interestingly, patients with smaller intercondylar notch volumes showed relatively favorable surgical outcomes in objective aspects compared to those with larger notch volumes. These findings were prominent in postoperative knee AP laxity, and although not statistically significant, the graft failure rate tended to be low in male patients with relatively small intercondylar notch volumes. This may be attributed to the differences in graft sizes and intercondylar notch size ratios. The graft diameters of the patients included in the study were relatively consistent, and there were no intergroup differences. Therefore, patients with small intercondylar notch volumes would have relatively large ACL grafts relative to their body size. Graft diameter has been reported to show a positive correlation with the surgical outcomes of ACL reconstruction,[29,30] and this may explain why patients with relatively large ACL grafts showed favorable surgical results in this study. The cause remains unclear; however, it is expected that knees with relatively large ACL grafts may be able to better resist the applied loads.

This study has several limitations. First, this study was based on a retrospective review, which may be associated with the risk of bias in evaluation. Second, unlike the male patients, the number of female patients did not meet the sample size required to detect differences in surgical outcomes between the groups, which may result in a type II error. Although it was sufficient to detect differences in the objective surgical outcomes, the number of female patients was not adequate for the comparison between the groups to evaluate the subjective outcomes. Third, not all patients included in the study underwent a follow-up MRI. However, it was necessary to secure as many subjects as possible for analysis, and there were no differences in the frequency of follow-up MRI in all between-group comparisons. Fourth, the grouping of patients was not performed based on a specific reference value for intercondylar notch volume but on the percentiles of the patients. Although this is not feasible because there are no previous studies reporting clinically meaningful values related to intercondylar notch volumes (e.g., cutoff values), analyses by grouping according to percentiles of patients were an unavoidable limitation. Fifth, surgeries were performed by two independent surgeons. The surgical indication, surgical procedures, and postoperative rehabilitation protocols were the same between the two surgeons. However, there may be subtle differences between them, which may have affected the surgical outcomes. Finally, various bony morphometric parameters that could be associated with ACL injuries have not yet been fully evaluated. Although the femoral tunnel position and tibial slope were assessed in this study, all possible bony morphological risk factors should be analyzed to minimize evaluation biases.[1] A comprehensive investigation of these factors may be required in the future.

A small intercondylar notch can be problematic during ACL reconstructions, leading surgeons to consider notchplasty or graft diameter reduction to avoid possible graft impingement. However, this study found that a small intercondylar notch volume did not adversely affect the surgical outcomes, indicating that additional procedures such as notchplasty or graft diameter reduction are unnecessary simply because the intercondylar notch is small. The findings of this study could serve as the basis for a treatment strategy related to intercondylar notch size during anatomical ACL reconstruction.

The surgical outcomes of anatomical single-bundle ACL reconstruction in patients with relatively small intercondylar notch volumes were comparable to those with large notch volumes, but rather showed favorable outcomes in postoperative knee AP laxity.

CONFLICT OF INTEREST

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

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SUPPLEMENTARY MATERIAL

Supplementary material is available in the electronic version of this paper at the CiOS website, www.ecios.org

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