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Research Article

Comparison of subjective outcomes between single-bundle and double-bundle anterior cruciate ligament reconstruction in patients with flat lateral tibial slope

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ABSTRACT

Objective: A high lateral tibial slope (LTS) has been associated with an increased risk of graft failure and inferior subjective outcomes following anterior cruciate ligament reconstruction (ACLR), but the impact of a flat LTS remains unclear. This study aimed to compare long-term subjective outcomes of single-bundle (SB) and double-bundle (DB) ACLR in patients with a flat LTS to determine the more favorable approach.

Methods: The study comprised 136 patients with an LTS less than 7.4 degrees who underwent SB-ACLR (64 cases) or DB-ACLR (72 cases). Lateral tibial slope was measured on preoperative magnetic resonance imaging. Patient-reported outcomes, including the University of California Los Angeles (UCLA) Activity Score, the Lysholm Knee Score, and International Knee Documentation Committee (IKDC) Score, were collected and compared between those undergoing SB- and DB-ACLR at a mean follow-up of 14.06 ± 2.98 years. Categorical and continuous variables were analyzed using chi-square and independent-samples *t*-tests, respectively. A *P*-value less than .05 was considered statistically significant.

Results: The mean LTS was similar between the SB and DB groups (4.76 ± 1.48 vs. 4.23 ± 1.82, *P*=.06). The DB group had significantly better postoperative UCLA (9.32 ± 0.95 vs. 8.55 ± 1.99, *P* < .01), Lysholm (94.26 ± 5.61 vs. 88.23 ± 13.45, *P* < .01), and IKDC score (82.99 ± 4.55 vs. 77.67 ± 11.21, *P* < .01). Specifically, among male patients, no significant differences were found between SB and DB groups, though trends favored DB-ACLR.

Conclusion: In patients with a flat LTS, DB-ACLR was associated with higher long-term patient-reported outcome measures than SB-ACLR; however, the clinical relevance of these differences should be interpreted with caution.

Level of Evidence: Level III, Therapeutic study

Introduction

Anterior cruciate ligament (ACL) injuries are a prevalent concern within the general population. Anterior cruciate ligament reconstruction (ACLR) stands as the primary therapeutic approach for those aiming to return to their pre-injury levels of activity.[1,2] A myriad of factors, ranging from anatomical variations and biomechanical considerations to graft selection and genetic predispositions, influence the likelihood of primary ACL tears and the success of ACLR.[3,4]

One anatomical factor of particular interest is the posterior tibial slope, with the lateral tibial slope (LTS) emerging as a significant risk determinant.[5,6] An increased LTS has been linked to greater anterior tibial translation and rotatory shearing forces, exerting additional stress on both the native ACL and its graft.[7] Previous studies have demonstrated that an increased posterior tibial slope was associated with a higher risk of ACL injury and graft failure following ACLR.[5,8-10]

The choice of surgical procedure also holds implications for ACLR outcomes. The field predominantly employs single-bundle (SB) and double-bundle (DB) techniques. Biomechanical and clinical evidence suggests that DB-ACLR may offer enhanced knee stability and laxity restoration, as well as better subjective outcomes.[11-13] However, other studies reported that DB-ACLR is not superior to SB-ACLR in objective and subjective outcomes.[14-18] The difference in outcomes between these 2 surgical techniques remains controversial. Therefore, comparing outcomes in specific patient groups may provide value for clinical decision-making. As mentioned above, a larger LTS has a negative impact on outcomes. However, there is a lack of research comparing outcomes between SB- and DB-ACLR in patients with either a steep or flat slope.

Given this background, the study aimed to investigate whether subjective outcomes differ between patients with a flat LTS undergoing SB vs. DB ACL reconstruction. A flat LTS was defined as < 7.4°, based on the magnetic resonance imaging (MRI)-based threshold reported by Grassi et al, which was associated with

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a lower risk of graft failure.[9,10] Despite the reduced rotatory shearing force and anterior translation in patients with a flat LTS, given the enhanced knee stability following DB-ACLR, it was hypothesized that the functional outcomes between the 2 surgical techniques will exhibit significant disparities.

Material and methods

Study design and data collection

This investigation obtained approval from the Chang Gung Medical Foundation Institutional Review Board (Approval No.: 202201347B0; Date: December 9, 2022) and waived the necessity for informed consent owing to its retrospective design. A total of 64 patients who underwent SB-ACLR and 72 patients who underwent DB-ACLR at a single medical center from 2005 to 2014 were reviewed. Each patient was followed for a minimum of 10 years, with a mean follow-up time around 14.06 ± 2.98 years. Inclusion criteria were patients who received primary SB-ACLR and DB-ACLR using hamstring tendon and bio-absorbable screws by the same orthopedic surgeon. Patients with loss of follow-up (15 in the SB group; 17 in the DB group), incomplete radiographic records, multi-ligament injuries, previous knee surgery history, malignant bone tumors, congenital knee anomalies and deformities, or knee malalignment requiring osteotomy were excluded from the study. Cases involving combined ACLR/LET (lateral extra-articular tenodesis) or ACLR/ALLR (antero-lateral ligament reconstruction) were also excluded.

Prior to surgery, knee MRI and clinical assessments were conducted. Patient demographic data, associated injuries, and radiographic analysis were collected for all the patients. Patients with a LTS of 7.4 degrees or above were excluded. The threshold was established based on the MRI-based research by Grassi et al.[10] The measurement method LTS is described below.

Radiographic evaluation

Magnetic resonance imaging was used to measure LTS in this study. The tibial slopes were measured by 2 orthopedic residents and then confirmed by an attending orthopedic physician. The measurement method for the LTS was based on that described by Hashemi et al and Jahn et al.[19,20]

Magnetic resonance imaging scans were viewed using the picture archiving and communication systems. The sagittal view was utilized to define the LTS. An axial slice of the tibial plateau was referenced. After the reference line of the sagittal slice was placed on the center of the tibial plateau on the axial slice, that sagittal slice was used to determine the tibial axis. The tibial longitudinal axis was defined by 2 circles. The first circle was drawn with its perimeter tangent to the proximal, anterior, and posterior cortices of the tibia. The second circle was drawn with its perimeter tangent to the anterior and posterior cortices, with its center positioned on the perimeter of the first circle. A line passing through the centers of both circles was defined as the tibial axis. Thereafter, when the reference line of the sagittal slice was placed on the center of the lateral tibial plateau on the axial slice, that sagittal slice was used to measure the LTS. A line connecting the peak points on the anterior and posterior aspects of the plateau is drawn. The LTS was measured as the angle between the line connecting the peak points of the lateral tibial plateau on sagittal slices and the line perpendicular to the tibial longitudinal axis. The measurement method is shown in Figure 1. Patients with LTS less than 7.4 degrees were included in this study, while those with LTS of 7.4 degrees or above were excluded.

HIGHLIGHTS

- In patients with a flat lateral tibial slope (<7.4°), double-bundle anterior cruciate ligament reconstruction was associated with statistically higher long-term patient-reported outcome measures (PROMs) than single-bundle reconstruction.
- The between-group differences in Lysholm and International Knee Documentation Committee scores did not reach reported minimal clinically important difference thresholds, suggesting limited clinical relevance.
- These findings suggest that reconstruction techniques may influence long-term PROMs even in patients with favorable tibial slope anatomy, and further studies are needed to confirm clinical significance.

Surgical techniques

All surgeries were performed under general anesthesia using standard procedures. Meniscus tears were either repaired or partially resected depending on the location and extent of the lesions. Then, all tendon grafts were harvested from the hamstring tendon. Both semitendinosus and gracilis tendons were used. For SB-ACLR, the graft diameter ranged from 7 to 10 mm. For DB-ACLR, the anteromedial (AM) bundle graft diameter ranged from 6 to 10 mm and the posterolateral (PL) bundle ranged from 5 to 7 mm.

The SB-ACLR procedure started with the precise anatomical placement of the graft to mimic the native ACL's AM bundle and then fixed with bioabsorbable screws. Double-bundle-anterior cruciate ligament reconstruction using autografts and bioabsorbable screws involved the creation of both the AM and PL tunnels, aiming to replicate the complex structure of the native ACL more precisely for enhanced joint stability.

Clinical function evaluation

Each patient was followed up at a minimum of 10 years. Patient-reported outcome measures (PROMs) were collected during outpatient follow-up visits. The functional and subjective outcomes were assessed with the University of California Los Angeles (UCLA) Activity Score, the Lysholm Knee Score, and the International Knee Documentation Committee (IKDC) Score. The demographic data and the subjective outcomes were compared between the SB and the DB groups.

Statistical analysis

The statistical evaluation of the data was performed using the IBM SPSS Statistics software, version 22 (IBM SPSS Corp.; Armonk, NY, USA), and Microsoft Office Excel 2013. Chi-square tests were used to assess the independence of categorical data between the 2 surgical techniques (SB-ACLR and DB-ACLR). Independent sample *t*-tests were utilized to compare continuous variables, such as the subjective outcomes between SB and DB groups. Fisher's exact test was used to compare treatment modalities for meniscal injuries between the SB and DB groups. All tests were 2-tailed, and the results were considered statistically significant at a P value < .05.

Results

Demographic data

The demographic characteristics of patients undergoing SB- and DB-ACLR are shown in Table 1. The average age at surgery was similar between the SB (32.03 ± 10.28 years) and DB groups (30.59 ± 8.41 years, P=.37). Gender distribution was significantly different, with a higher proportion of males in the DB group (68 males: 4 females) compared to the SB group (44 males: 20 females) (P < .01). There were

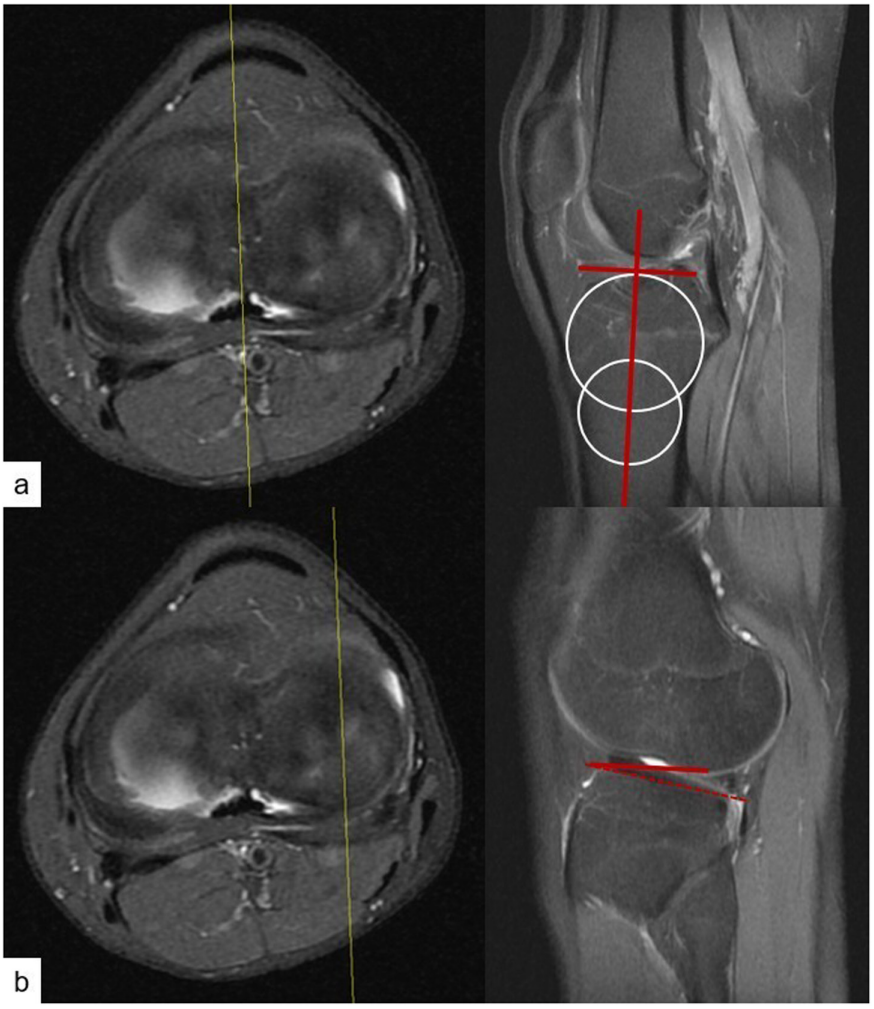

Figure 1. Measurement method of lateral tibial slope (LTS) on knee MRI. (a) shows the steps to establish the tibial longitudinal axis: The reference line (yellow) is placed on the center of the tibial plateau. The linking line of the centers of the 2 white circles on the sagittal view was drawn to determine the tibial longitudinal axis (red solid line). The line perpendicular to the longitudinal axis was also drawn (red dotted line). (b) shows the steps to measure the LTS: The reference line is adjusted to the center of the lateral tibial plateau. A line tangent to the uppermost part of the anterior and posterior peaks on the sagittal image is drawn (yellow line on the sagittal view). The LTS is defined by the angle between this yellow line on the sagittal view and the red dotted line that is perpendicular to the tibial longitudinal axis.

no significant differences in body mass index (P=.09) or LTS (P=.06). The mean follow-up time was 14.06 ± 2.98 years.

Table 2 showed the meniscal injury status and treatment strategies for the SB and DB groups. The proportion of patients with intact medial menisci (MM) was similar between groups (SB: 59.4%, DB: 56.9%, P=.77). The proportion of patients with intact lateral menisci (LM) was significantly lower in the SB group (29.7%) compared to the DB group (47.2%) (P=.04). The treatment for the injured MM and LM is shown in Table 2. The treatment modalities for MM and LM injuries were comparable between the SB and DB groups (P=.40 and P=.09, respectively).

Table 1. Demographic data

	Single bundle (n=64)	Double bundle (n=72)	*P*
Age at surgey (years)	32.03 ± 10.28	30.59 ± 8.41	.37
Gender (M : F)	44 : 20	68 : 4	<.01**
Height (cm)	168.94 ± 8.29	173.55 ± 6.21	<.01**
Weight (kg)	73.40 ± 15.70	80.84 ± 15.80	<.01**
BMI (kg/m^2)	25.49 ± 3.88	26.76 ± 4.64	.09
Mean LTS (degree)	4.76 ± 1.48	4.23 ± 1.82	.06
Mean follow-up time (years)		14.06 ± 2.98	

Values of age at surgery, height, weight, BMI, mean LTS, and mean follow-up time are mean ± SD.
The statistical method for the independence of gender is chi-square test, and the statistical method for the other categories is independent sample *t*-tests.
BMI, body mass index; F, females; LTS, lateral tibial slope; M, males; n, case numbers.
*P < .05.
**P < .01.

Table 2. Meniscus injury status and treatment strategies in SB and DB groups

	SB (n=64)	DB (n=72)	*P*
Medial meniscus			
Intact	38	41	.77
Injured	26	31	
Repair	18	16	.40
Meniscectomy	6	9	
Repair+meniscectomy	2	3	
Left in situ	0	3	
Lateral meniscus			
Intact	19	34	.04*
Injured	45	38	
Repair	28	14	.09
Meniscectomy	13	15	
Repair+meniscectomy	3	7	
Left in situ	1	2	

The statistical method for the ratio of meniscus injury is chi-square test. The statistical method used to compare treatment modalities for meniscal injuries between the SB and DB groups was Fisher's exact test.
DB, double bundle; n, case numbers; SB, single bundle.
*P < .05.
**P < .01.

Subjective outcomes following single-bundle and double-bundle anterior cruciate ligament reconstruction

The comparison of subjective outcomes between SB and DB groups is shown in Table 3. The DB group had significantly higher postoperative UCLA scores (9.32 ± 0.95) compared to the SB group (8.55 ± 1.99) (P=.01), as well as higher Lysholm scores (94.26 ± 5.61 vs. 88.23 ± 13.45, P < .01), and IKDC scores (82.99 ± 4.55 vs. 77.67 ± 11.21, P < .01).

Subjective outcomes by gender

Table 4 depicts a comparison of subjective outcomes between males and females following ACLR. Males had significantly higher postoperative UCLA scores (9.29 ± 1.08 vs. 7.42 ± 2.43, P < .01), Lysholm scores (92.79 ± 9.23 vs. 85.04 ± 13.52, P=.01), and IKDC scores (82.25 ± 6.29 vs. 72.25 ± 13.14, P < .01) compared to females.

Subjective outcomes among males

There are 44 males undergoing SB-ACLR and 68 males undergoing DB-ACLR. The comparison of male subjective outcomes between the 2 surgical techniques is shown in Table 5. There were no significant differences in LTS (SB: 4.56 ± 1.57 vs. DB: 4.25 ± 1.80, P=.36), preoperative UCLA scores (SB: 3.61 ± 2.56 vs. DB: 3.09 ± 1.87, P=.25), postoperative UCLA scores (SB: 9.20 ± 1.23 vs. DB: 9.34 ± 0.97, P=.52), Lysholm scores (SB: 90.32 ± 12.83 vs. DB: 94.40 ± 5.37, P=.05), or IKDC scores (SB: 80.98 ± 8.25 vs. DB: 83.07 ± 4.49, P=.13) between the SB and DB groups for males.

Discussion

The study showed that, in patients with a LTS of less than 7.4 degrees, DB-ACLR was associated with higher long-term subjective outcome scores, including the UCLA, Lysholm, and IKDC, compared with SB-ACLR. In the male patient group, there was also a trend toward higher subjective outcome scores in the DB group, although these differences did not reach statistical significance. However, the clinical relevance of these findings should be interpreted with caution.

Biomechanical studies demonstrated that both SB- and DB-ACLR are associated with restoration of normal knee kinematics, with DB-ACLR being superior to SB-ACLR in terms of restoration of anteroposterior stability.[11] Some clinical studies have reported that DB-ACLR may provide improved anterior and rotatory stability and slightly better subjective outcomes compared with SB-ACLR; however, other studies have shown no clear superiority, and the clinical benefit remains controversial.[12-18,21] The study focused on long-term patient-reported outcomes and included patients with relatively flat LTS. The cutoff of flat LTS was set at less than 7.4 degrees, based on the study by Grassi et al, which showed a higher ACLR failure rate in patients with LTS over 7.4 degrees.[10] Patients with lower LTS have been reported to have better long-term subjective outcomes, whether following SB-ACLR or DB-ACLR.[22,23] The results demonstrated the differences in PROMs between patients undergoing DB-ACLR and SB-ACLR with LTS less than 7.4 degrees. Studies comparing the 2 techniques in patients with LTS of 7.4 degrees or above could further investigate whether DB-ACLR can mitigate the adverse effect of steeper LTS on outcomes. In addition, several new surgical techniques have emerged, such as combined ACL with anterolateral reconstruction, which have been shown to have superior clinical outcomes and lower graft failure rates compared to isolated ACLR in previous studies.[24,25] Future studies could also compare the outcomes between these different ACLR techniques in specific patient populations.

Whether the observed differences in Lysholm and IKDC score between the SB- and DB-ACLR groups reach established minimal clinically important difference (MCID) thresholds was also evaluated. A recent systematic review on knee-ligament reconstruction found that the Lysholm and IKDC scores exhibited reported MCID values of 9.9/100 and 13.8/100, respectively.[26] In addition, a long-term cohort study in patients undergoing ACLR followed for over 5 years postoperatively demonstrated MCID values of 10.1 for the Lysholm score and 8.7 for the IKDC score.[27] In the study, the mean difference (DB minus SB) in postoperative Lysholm was +6.0 and in IKDC +5.3. Although both differences were statistically significant, they were lower than the MCID benchmarks (Lysholm 9.9-10.1; IKDC 8.7-13.8). Therefore, the average between-group differences may not be clinically meaningful. This discrepancy suggested that while DB-ACLR was associated with statistically significantly better PROMs than SB-ACLR, the magnitude of difference may not be large enough to reach what patients typically perceive as minimally important. Given this, caution is warranted before claiming that DB-ACLR is definitively "clinically superior." Future analyses should include responder analysis and patient-acceptable symptom state or substantial clinical benefit thresholds, to better characterize the real-world clinical advantage of DB over SB.

In addition, concomitant meniscus and ACL injuries are common, and the status of the meniscus has been demonstrated to play a role

Table 4. Comparison of subjective outcomes between males and females following either SB- or DB- ACLR

	Male (n=112)	Female (n=24)	*P*
SB : DB	44 : 68	20 : 4	<.01**
Lateral tibial slope	4.37 ± 1.71	5.00 ± 1.45	.10
Preoperative UCLA score	3.29 ± 2.18	2.83 ± 1.01	.12
Postoperative UCLA score	9.29 ± 1.08	7.42 ± 2.43	<.01**
Lysholm	92.79 ± 9.23	85.04 ± 13.52	.01*
IKDC	82.25 ± 6.29	72.25 ± 13.14	<.01**

Values of LTS and subjective outcomes are mean ±SD.
The statistical method for the ratio of SB/DB in males and females is chi-square test, and the statistical method for the other categories is independent sample *t*-tests.
DB, double bundle; IKDC, the International Knee Documentation Committee Score; LTS, lateral tibial slope; Lysholm, the Lysholm Knee Score; n, case numbers; SB, single bundle; UCLA score, the University of California Los Angeles Activity Score.
*P < .05.
**P < .01.

Table 3. Comparison of subjective outcomes following SB-ACLR and DB-ACLR

	SB (n=64)	DB (n=72)	*P*
Preoperative UCLA score	3.38 ± 2.22	3.07 ± 1.83	.38
Postoperative UCLA score	8.55 ± 1.99	9.32 ± 0.95	.01*
Lysholm	88.23 ± 13.45	94.26 ± 5.61	<.01**
IKDC	77.67 ± 11.21	82.99 ± 4.55	<.01**

Values are mean ±SD.
DB-ACLR, double-bundle anterior cruciate ligament reconstruction; IKDC, the International Knee Documentation Committee Score; LTS, lateral tibial slope; Lysholm, the Lysholm Knee Score; SB-ACLR, single-bundle anterior cruciate ligament reconstruction; UCLA score, the University of California Los Angeles Activity Score.
*P < .05.
**P < .01.

Table 5. Comparison of subjective outcomes in males following SB-ACLR and DB-ACLR

	SB (n=44)	DB (n=68)	*P*
Lateral tibial slope	4.56 ± 1.57	4.25 ± 1.80	.36
Preoperative UCLA score	3.61 ± 2.56	3.09 ± 1.87	.25
Postoperative UCLA score	9.20 ± 1.23	9.34 ± 0.97	.52
Lysholm	90.32 ± 12.83	94.40 ± 5.37	.05
IKDC	80.98 ± 8.25	83.07 ± 4.49	.13

Values of LTS and subjective outcomes are mean ±SD.
DB, double bundle; IKDC, the International Knee Documentation Committee Score; LTS, lateral tibial slope; Lysholm, the Lysholm Knee Score; n, case numbers; SB, single bundle; UCLA score, the University of California Los Angeles Activity Score.

in patient outcomes.[28,29] In a study by Cox et al, MM repair and partial excision were associated with worse outcomes compared to intact MM, whereas untreated tears and partial excisions of LM were associated with better outcomes compared to intact LM.[30] Treatment strategies for meniscal lesions are also important, with meniscal repairs showing better long-term subjective outcomes compared to meniscectomy.[31] In the cohort, the DB group had a significantly higher proportion of intact LM, as well as a higher proportion of patients who underwent meniscectomy. These factors were reported as potential prognostic variables; however, the DB group still demonstrated better postoperative Lysholm and IKDC scores. The main strength of this study is the long follow-up period. Each patient had a minimum follow-up of 10 years, with an average of 14.06 ± 2.98 years. In addition, this study is a single-surgeon series with a relatively large cohort.

There were some limitations in this study. First, due to the lack of female cases in the DB group, the gender ratio between SB and DB groups in this study differed significantly (male: female = 44 : 20 in SB group; 68 : 4 in DB group, $P < .01$). Female patients undergoing ACLR were reported to have inferior subjective and functional outcomes, with comparable results on objective parameters and rates of revision, and a lower re-rupture rate.[32,33] Ryan et al's study showed no difference in graft failure risk, contralateral ACL rupture risk, postoperative knee laxity on physical examination, or patient-reported outcomes according to sex.[34] A review article reported that although females had worse patient-reported outcomes in the first 2 years following ACLR, longer-term studies demonstrated no difference between males and females.[35] In the study, the mean follow-up time was approximately 14 years, with a minimum of 10-year follow-up. The differences in subjective outcomes between males and females were also investigated, showing that male patients had significantly better UCLA, Lysholm, and IKDC scores compared to female patients. Therefore, considering the small sample size of females in the DB group, outcomes between SB- and DB-ACLR were further compared in male patients only, with 44 males undergoing SB-ACLR and 68 males undergoing DB-ACLR. The results showed a trend toward better outcomes following DB-ACLR compared to SB-ACLR, although not significant statistically. These findings suggest that, in addition to the enhanced stability provided by DB-ACLR, male gender might also be an important factor contributing to superior long-term subjective outcomes following ACLR. Secondly, this was a retrospective study, which may be subject to selection biases. In the study, the proportions of gender were significantly different between the SB and DB groups. Future studies with a similar gender ratio or those focusing on a specific gender could be conducted. Besides, knee arthrometer examination was not part of the institution's protocol for ACL-injured patients until 2019. This study was limited by the lack of objective clinical examinations (e.g., range of motion and stability tests) and radiographic assessment at final follow-up. Therefore, the potential influence of pathologies such as new meniscal tears or osteoarthritic progression cannot be fully excluded. Another limitation was the absence of preoperative PROMs, which prevented determination of baseline functional comparability between the SB- and DB-ACLR groups and accurate evaluation of the magnitude of postoperative improvement attributable to each reconstruction technique in patients with a flat LTS. Finally, future studies with larger sample sizes are needed to validate the findings.

In conclusion, among patients with an LTS of less than 7.4°, DB-ACLR was associated with statistically higher long-term subjective outcome scores compared with SB-ACLR. However, the absolute between-group differences in Lysholm and IKDC scores were smaller than established MCID thresholds reported in the literature, indicating that the magnitude of difference, while statistically significant, may not consistently reach a level that is perceptible or meaningful to most patients. In male patients with a flat LTS, although outcomes tended to be higher in the DB-ACLR group, similar considerations regarding clinical relevance apply. These findings suggest that the observed differences may be modest in clinical magnitude and should be interpreted with caution.

Data Availability Statement: The data that support the findings of this study are available on request from the corresponding author.

Artificial Intelligence Usage Statement: The authors declared that no Artificial Intelligence tool was used in the preparation of the manuscript.

Ethics Committee Approval: Ethical committee approval was received from the Institutional Review Board of Chang Gung Medical Foundation (Approval No.: 202201347B0; Date: December 9, 2022).

Informed Consent: Written informed consent was obtained from the patients who agreed to take part in the study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – S.Y.Y., K.Y.L., C.P.Y.; Design – S.Y.Y., K.Y.L.; Supervision – Y.S.C., C.P.Y.; Resources – Y.S.C., C.H.C.; Materials – Y.S.C, C.H.C.; Data Collection and/or Processing – Y.C.H., S.F.H., Y.J.C.; Analysis and/or Interpretation – S.Y.Y., K.Y.L.; Literature Search – S.Y.Y., K.Y.L.; Writing – S.Y.Y., K.Y.L.; Critical Review – Y.S.C., C.S.H., C.P.Y.

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