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Double-bundle ACL combined with ALL reconstruction for patients at high risk of ACL failure: clinical and radiological results

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Abstract

Background We investigated whether double-bundle (DB) anterior cruciate ligament (ACL) reconstruction (ACLR) combined with anterolateral ligament reconstruction (ALLR) improved clinical and radiological outcomes in patients at high risk of ACL failure. The primary outcome was graft failure, and secondary outcomes included knee stability and patient-reported outcome measures (PROMs).

Patients and methods Fifty-two patients who underwent DB ACLR combined with ALLR were included in this retrospective cohort study. Preoperative risk factors, including femorotibial angle (FTA), lateral tibial slope (LTS), medial tibial slope (MTS), and meniscal tears, were assessed using X-ray and magnetic resonance imaging (MRI). The grade of post-operative pivot shift, Lysholm score, and Tegner activity score were used to assess clinical outcomes. The minimum follow up duration was 2 years.

Results The cohort (mean age, 26.1 ± 9.4 years; 51.9% male) had a mean follow-up duration of 28.9 ± 3.4 months. Preoperatively, 57.8% had lateral meniscus (LM) tears, and 61.0% had a grade 2–3 pivot shift. Postoperatively, no graft failures or revision cases occurred during follow-up. Approximately 90.4% of the patients exhibited a negative pivot shift ($p < 0.001$), with Lysholm and Tegner activity scores of 92.5 ± 6.1 and 5.1 ± 2.0 . The medial meniscus (MM) tear group had a significantly smaller FTA than the intact group ($p = 0.043$). No significant differences in PROMs were found between the LM tear and intact LM groups or between the high and low MTS or LTS groups ($p = n.s.$).

Conclusion DB ACLR combined with ALLR had satisfactory clinical outcomes in patients at high risk of ACL failure, with no graft failures observed during a mean follow-up duration of 2.4 years. The technique effectively reduced the postoperative pivot shift, regardless of preoperative risk factors.

Study design Level IV, retrospective therapeutic case-series.

Trail registration ethical approval number, 202300134B0; ethical committee, the Institutional Review Board of Chang Gung Medical Foundation.

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Keywords Double bundle anterior cruciate ligament reconstruction, Anterolateral ligament reconstruction, Steep tibial slope, Meniscal injury, Magnetic resonance imaging, Radiography, Functional result

Background

Anterior cruciate ligament (ACL) reconstruction (ACLR) is a common surgical procedure that provides satisfactory results in most patients [1, 2]. However, some patients may experience residual rotational instability, particularly those with steep medial or lateral tibial slopes, posterior third meniscal injuries, and anterolateral ligament (ALL) tears [3–7]. This residual instability can lead to secondary cartilage and meniscal injuries and an increased risk of graft failure [8–10].

To address these issues, various surgical techniques have been developed, such as double-bundle (DB) ACLR, different ALL reconstruction (ALLR) methods, and lateral extra-articular tenodesis (LET) [11–14].

The present study aims to determine the correlation between patient demographics and the risk factors for ACL failure and to investigate whether DB ACLR combined with ALLR can overcome unfavorable preoperative conditions and improve clinical outcomes in high-risk patients. The primary outcome was graft failure, and secondary outcomes included knee stability and patient-reported outcome measures (PROMs). We hypothesized that the clinical outcomes of this specific technique would be comparable between patients with and without a high ACLR failure risk.

Materials and methods

Patients

This retrospective study was approved by the Chang Gung Medical Foundation Institutional Review Board (IRB No. 202300134B0). A total of 67 patients who underwent DB ACLR at a single institution by a single surgeon between October 2018 and September 2020 were reviewed. The inclusion criteria were patients with complete radiographic records, including preoperative knee X-rays and magnetic resonance imaging (MRI) scans within 3 months before surgery, and a minimum follow-up of 2 years. The exclusion criteria were previous knee surgery, multi-ligamentous injuries, age over 50 years old, and a lack of follow-up. All patients underwent clinical evaluations before surgery and at the final follow-up. Patients with risk factors for residual pivot shift instabilities included those with a medial tibial slope (MTS) of $>5.6^\circ$ or a lateral tibial slope (LTS) of $>3.8^\circ$ [15] and lateral or medial meniscus (LM or MM) tears [3].

Surgical technique

All patients underwent DB ACLR combined with ALLR [12], and all operations were performed by the same surgeon. After marking the bony landmark, full-length

semitendinosus and gracilis tendon autografts were harvested. The semitendinosus tendon was prepared in a quadruple-folded fashion to form the anteromedial bundle (AMB). The gracilis tendon was prepared as the posterolateral bundle (PLB) and ALL graft. A FiberTape (Arthrex, Naples, FL, USA), an internal brace for PLB and ALL, was shuttled together with the unfolded gracilis tendon (Fig. 1A). Under arthroscopic assistance, meniscus tears were repaired if possible, and a flexible reamer was used to create a femoral AM tunnel using the inside-out drilling technique (Smith & Nephew Endoscopy, Andover, MA, USA). (Fig. 1B, C) The femoral PL tunnel was created using the outside-in technique (Fig. 1D) to avoid undesirable tunnel connections. Tibial ACL and ALL tunnels were created based on their anatomical positions. One No. 5 Ethibond suture (Ethicon, NJ, USA) was passed from the femoral AM tunnel to the tibial ACL tunnel and another one from the femoral PL tunnel to the tibial ACL tunnel. The third no. 5 Ethibond suture was inserted from the lateral tibia ALL footprint to the medial side of the tibia. The single gracilis tendon with the FiberTape was shuttled intraarticularly through the tibial ACL tunnel and pulled out from the femoral PL tunnel. We ensured that the length outside the lateral femoral cortex was enough to create an extraarticular ALL. Subsequently, a hydroxyapatite interference screw (BioRCI-HA screws; Smith & Nephew Endoscopy) that was 1 mm bigger than the graft size in diameter was used to fix the PLB in an outside-in fashion (Fig. 1E).

Thereafter, the AM bundle was tied using an Endo-Button (Smith & Nephew Endoscopy) and shuttled until it was fixed on the femoral cortical surface (Fig. 1F). Another hydroxyapatite interference screw (BioRCI-HA screws; Smith & Nephew Endoscopy) was used to fix the tibial end of both the AMB and PLB grafts in the tibial ACL tunnel at 60 degrees of knee flexion (Fig. 1G). Finally, the single gracilis tendon and the FiberTape were shuttled from the lateral end of the femoral PL tunnel to the lateral end of the tibial ALL tunnel to complete the ALLR with an augmented Swivelock anchor (Arthrex) fixation (Fig. 1H and I).

Clinical and functional evaluation

The evaluation included a preoperative pivot-shift test, a pivot-shift test at the final follow-up, Tegner activity score measurement [16], and Lysholm score assessment [24]. The pivot-shift test was performed by a single examiner, and pain at the ALL attachment sites was recorded [25].

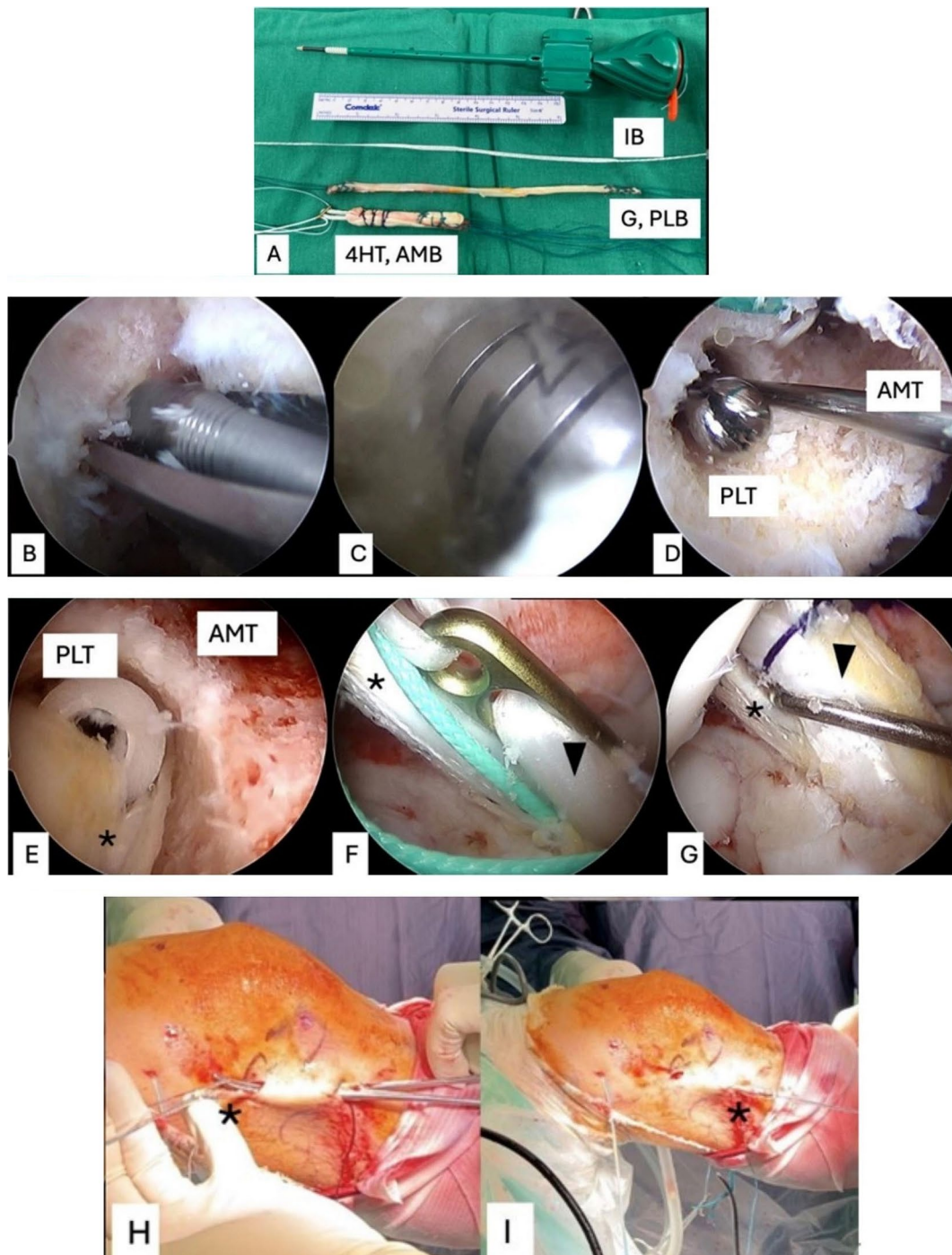


Fig. 1 Tunnel drilling, graft shuttling, and fixation of the right knee double-bundle ACL combined with ALL reconstruction **(A)** The semitendinosus is prepared in a quadruple-folded fashion and used as the anteromedial bundle. The gracilis tendon is prepared and used as the posterolateral bundle and ALL graft. The FiberTape serves as an internal brace for the PLB and ALL. **(B, C)** The femoral AM tunnel is created by the inside-out drilling technique using a flexible reamer. **(D)** The femoral PL tunnel is created using the outside-in technique. **(E)** A hydroxyapatite interference screw is used to fix the PLB in an outside-in fashion. **(F)** The AM bundle is tied with an EndoButton and shuttled intra-articularly. **(G)** The AM and PL bundles of the double-bundle ACL reconstruction **(H, I)** The single gracilis tendon and FiberTape are shuttled from the lateral end of the femoral PL tunnel to the lateral end of the tibial ALL tunnel as the ALLR. ACL, anterior cruciate ligament; ALL, anterolateral ligament; HT, hamstring tendon; G, gracilis tendon; AMB, anteromedial bundle; PLB, posterolateral bundle; IB, internal brace; AMT, anteromedial tunnel; PLT, posterolateral tunnel; asterisk, gracilis graft with the FiberTape; arrowhead, the quadruple hamstring graft

Radiographic evaluation

Lower limb alignment was assessed using standing full-leg radiographs. The MTS and LTS were measured on lateral X-ray and sagittal MRI scans, respectively, using previously described methods [17, 18]. Meniscal injuries, collateral ligament integrity, and cartilage injuries were evaluated on MRI, and the two independent orthopedic surgeons who performed all the radiographic measurements (Table 1) were blinded to the clinical outcomes.

Statistical analysis

Statistical analyses were performed using SPSS (IBM SPSS Statistics 23.0, IBM Inc., Armonk, NY, USA) and Microsoft Office Excel 2016 (Microsoft, Redmond, WA, USA). Categorical data were analyzed using Fisher's exact tests, whereas continuous data were compared using the Mann–Whitney U test or unpaired t-test, as appropriate. The results were considered statistically significant at $p < 0.05$. A post hoc power analysis was conducted, and Pearson correlation coefficients were calculated to assess

Table 1 Demographic, radiographic, and functional data of all patients

	Patients
Demographic factors	
Sex (male)	27 (51.9%)
Operation site (left)	29 (55.8%)
Age (years)	26.1 ± 9.4
Height (m)	1.7 ± 0.1
Body weight (kg)	74.8 ± 17.0
BMI (kg/m ²)	25.1 ± 4.0
Pre-operative data	
Meniscus injury	
Medial	20 (38.4%)
Lateral	33 (63.5%)
Healthy	9 (17.3%)
Pivot shift	
Negative	0 (0%)
Grade 1	0 (0%)
Grade 2	31 (59.6%)
Grade 3	21 (40.4%)
X-ray	
Femorotibial angle (°)	3.6 ± 2.5
Medial tibial slope (°)	7.3 ± 2.8
MRI	
Medial tibial slope (°)	6.1 ± 2.4
Lateral tibial slope (°)	4.3 ± 2.1
Lysholm score	92.4 ± 6.1
Tegner activity score	5.1 ± 2.0
Post-operative pivot shift	
Negative	47 (90.4%)
Grade 1	5 (9.6%)
Grade 2	0 (0%)
Grade 3	0 (0%)

BMI, body mass index; MRI, magnetic resonance imaging

the relationship between MTS or LTS and functional scores.

Results

Demographic, radiological, and functional patient data

Sixty-seven patients were originally enrolled in the study. Of these, 4 were excluded because of a previous surgery and 11 owing to a lack of preoperative images, resulting in a total of 52 patients (77.6%). The mean follow-up duration was 28.9 ± 3.4 months. Our study included 27 (51.9%) male patients; the average age was 26.1 ± 9.4 years; the mean BMI was 25.1 ± 4.0 kg/m², and 29 (55.8%) patients injured their left knee.

Before the operation, there were 30 (57.7%) cases of LM tears and 32 (61.0%) cases of grade 2 pivot shift. The valgus femorotibial angle (FTA) was 3.6° ± 2.5°, and the MTS was 7.3° ± 2.8° on X-ray and 6.1° ± 2.4° on MRI. Forty-three (82.7%) of the 52 patients had meniscus injuries and underwent meniscus repair. The mean size of the AMB was 7.2 ± 0.7 mm. No patient experienced graft failure or required revision surgery during follow-up. The pivot shift was evaluated at the last follow up, and 47 (90.4%) patients had no residual pivot shift. The Lysholm (92.5 ± 6.1) and Tegner activity (5.1 ± 2.0) scores were also recorded. The demographic data are presented in Table 1.

The intact medial meniscus group versus the medial meniscus tear group

Upon comparing patients in the intact MM and MM tear groups, no significant differences were observed in any demographic characteristics, including sex, age, height, weight, BMI, and perioperative pivot shift ($p = n.s.$). A significantly smaller FTA was observed in the MM tear group than in the intact MM group (intact vs. tear, 4.0° ± 2.8° vs. 2.6° ± 1.0°; $p = 0.043$). A steeper MTS was not observed in the MM tear group on X-ray (intact vs. tear, 7.5° ± 2.9° vs. 6.8° ± 2.6°; $p = 0.472$) or MRI (intact vs. tear, 6.2° ± 2.5° vs. 5.8° ± 2.2°; $p = 0.680$), compared with the intact MM group (Table 2).

The intact lateral meniscus group versus the lateral meniscus tear group

Upon comparing patients in the intact LM and LM tear groups, no significant difference was observed in any demographic characteristic ($p = n.s.$). No difference was observed in the FTA between the two groups (intact vs. tear, 3.7° ± 3.2° vs. 3.6° ± 1.9°; $p = 0.959$). There was a non-significant trend of a steeper MTS on X-ray and MRI in the LM tear group compared to the intact LM group (X-ray: intact vs. tear, 6.5° ± 2.0° vs. 7.9° ± 2.9°, $p = 0.088$; MRI: intact vs. tear, 5.3° ± 1.6° vs. 6.7° ± 2.6°, $p = 0.073$) (Table 3). A pre-operative grade 3 pivot shift was significantly more common among patients with LM injuries than among those without LM injuries (97.0% vs. 0%,

Table 2 Comparison of patient variables between intact and injured medial meniscus groups

	MM intact	MM injured	p	Achieved power (%)
Demographic factors				
Sex (female)	16 (50.0%)	10 (50.0%)	0.465	13.4
Age (years)	25.4±7.9	27.8±12.5	0.583	11.8
Height (m)	1.7±0.1	1.7±0.1	0.378	38.6
Body weight (kg)	76.9±18.2	68.7±11.6	0.280	50.7
BMI (kg/m ²)	25.6±4.5	23.91±2.3	0.361	42.0
X-ray				
Femorotibial angle (°)	4.0±2.8	2.6±1.0	*0.043	-
Medial tibial slope (°)	7.5±2.9	6.8±2.6	0.472	16.9
MRI				
Medial tibial slope (°)	6.2±2.5	5.8±2.2	0.680	8.2
Lateral tibial slope (°)	4.4±2.1	4.2±2.3	0.865	4.1
Pivot shift				
Pre-operative (grade 3)	20 (62.5%)	11 (55.0%)	0.522	7.8
Post-operative (grade 0)	30 (93.8%)	17 (85.0%)	0.311	19.9
Lysholm score	92.3±6.7	93.0±4.4	0.803	7.0
Tegner activity score	5.2±2.0	5.0±2.4	0.852	4.8

Thirty-three patients were assigned to the intact (n=15) or injured (n=18) medial meniscus groups

*significant at p<0.05

MM, medial meniscus; BMI, body mass index; MRI, magnetic resonance imaging

Table 3 Comparison of patient variables between the intact and injured lateral meniscus groups

	LM intact	LM injured	p	Achieved power (%)
Demographic factors				
Sex (female)	9 (47.4%)	16 (48.5%)	0.895	3.0
Age (years)	25.9±10.7	24.4±7.9	0.632	7.4
Height (m)	1.7±0.1	1.7±0.1	0.239	38.9
Body weight (kg)	74.6±13.5	73.3±18.6	0.830	4.7
BMI (kg/m ²)	24.7±3.6	25.1±4.0	0.754	5.9
X-ray				
Femorotibial angle (°)	3.7±3.2	3.6±1.9	0.959	2.9
Medial tibial slope (°)	6.5±2.0	7.9±2.9	0.088	52.1
MRI				
Medial tibial slope (°)	5.3±1.6	6.7±2.6	0.073	67.9
Lateral tibial slope (°)	4.2±2.2	4.3±2.1	0.935	3.1
Pivot shift				
Pre-operative (grade 3)	0 (0%)	32 (97.0%)	* < 0.001	
Post-operative (grade 0)	19 (100%)	28 (84.8%)	0.170	34.0
Lysholm score	91.4±4.8	93.8±6.7	0.320	31.9
Tegner activity score	5.8±1.7	5.0±2.3	0.324	31.0

Thirty-three patients were assigned into the intact (n=15) or injured (n=18) medial meniscus groups

*significant at p<0.05

LM, lateral meniscus; BMI, body mass index; MRI, magnetic resonance imaging

Table 4 Comparison of patient variables between the group with a MRI MTS slope of > 5.6° (n = 19) and that with a MRI MTS slope of < 5.6° (n = 14)

MTS degrees	> 5.6°	< 5.6°	p	Achieved power (%)
Demographic factors				
Sex (female)	19 (63.3%)	6 (27.3%)	0.051	74.5
Meniscus injury				
Medial	9 (47.4%)	3 (21.4%)	0.123	48.5
Lateral	13 (68.4%)	7 (50.0%)	0.299	26.7
Age (years)	24.5±7.5	28.3±11.4	0.260	30.0
Height (m)	1.7±0.1	1.7±0.0	0.788	5.4
Body weight (kg)	77.0±20.6	72.0±11.3	0.459	16.2
BMI (kg/m ²)	25.8±4.5	24.3±3.4	0.321	26.6
X-ray				
Femorotibial angle (°)	3.7±2.2	3.3±2.9	0.695	7.1
MRI				
Lateral tibial slope (°)	3.3±0.0	4.1±2.2	0.656	59.6
Pivot shift				
Pre-operative (grade 3)	20 (66.7%)	11 (50.0%)	0.284	22.6
Post-operative (grade 0)	27 (90.0%)	20 (90.9%)	0.738	3.1
Lysholm score	95.0±5.8	89.9±5.5	*0.046	-
Tegner activity score	5.4±2.0	4.9±2.1	0.612	11.5

*significant at p<0.05

MRI, magnetic resonance imaging; MTS, medial tibial slope; BMI, body mass index

p<0.001). No significant differences in clinical scores were observed between the groups (Lysholm score: intact vs. tear, 91.4±4.8 vs. 93.8±6.7, p=0.320; Tegner activity score: intact vs. tear, 5.8±1.7 vs. 5.0±2.3, p=0.324) (Table 3).

MTS and clinical outcomes

Following the method used by Li et al. (27), the patients were separated into a group with MTS>5.6° (n=19) and a group with MTS<5.6° (n=14). The number of female patients was slightly higher in the high MTS group, but this was not significantly different (p=0.051) between the groups. Other demographic data, including age, BMI, and coronal alignment, were not significantly different between the groups (p=n.s.). The LTS and perioperative pivot shifts did not differ significantly between the two groups. The Lysholm score was significantly higher in the high MTS group than in the low MTS group (95.0±5.8 vs. 89.9±5.5, p=0.046) (Table 4).

LTS and clinical outcomes

The patients were divided into a group with a LTS of >3.8° (n=20) and another with a LTS of <3.8° (n=13). No significant differences were found in the demographic characteristics (including sex, age, BMI, coronal alignment, LTS, and perioperative pivot shift) or clinical outcomes

(Lysholm score or Tegner activity score) between the groups ($p=n.s.$) (Table 5).

Discussion

Patients with risk factors for ACL failure, including steep medial or lateral tibial slope, posterior third meniscal injury, or anterolateral ligament (ALL) tears owing to postoperative residual rotational instability, who underwent DB ACLR combined with ALLR achieved similar clinical outcomes to those of patients without these risk factors.

Based on a comparison between patients with multiple, one, and no ACL failures, Grassi et al. concluded that a higher posterior tibial slope on MRI is more common in patients who experienced multiple ACL failures [17]. However, the details of the clinical outcomes and surgical procedures were not provided in their study. Yoon et al. followed up on patients who underwent primary ACLR for at least 10 years and found that patients with increased MTS ($>5.6^\circ$) and LTS ($>3.8^\circ$) exhibited higher failure rates and lower survival rates [19]. In another study that investigated specific factors in patients with a preoperative high-grade pivot shift, Batty et al. found that ligamentous laxity, male sex, posterior third MM or LM injury, increased posterior tibial slope ($>5.6^\circ$), and chronicity were associated with a high-grade pivot shift, which causes ACL failures [3]. In our study, no patient experienced a graft failure during the 2-year follow-up,

and the PROMs were comparable between the groups. Sundemo et al. [20] proposed that anteroposterior and rotatory knee laxities were related to inferior subjective outcomes. In our cohort, patients with or without MM or LM injuries had comparable Lysholm or Tegner activity scores. Neither high MTS nor high LTS were correlated with subjective outcomes. Although the results imply that DB ACLR combined with ALLR seems to eliminate the negative effects of meniscus injury and steep MTS and LTS, cadaveric and biomechanical studies are warranted to confirm this observation.

Different methods of performing ALLR have been reported [21–25]. According to Sonnery-Cottet et al., the subjective postoperative outcomes of using a patella-tendon bone autograft for ACLR and a hamstring autograft for ACLR and ALLR were identical between groups, as were side-to-side laxity differences [26]. However, patients who underwent ACLR and ALLR had lower graft failure rates and higher chances of returning to preinjury levels of sport than those that underwent only ACLR [26]. Analysis of the prognostic factors for graft failure indicated that younger age (<25 years), >7 mm side-to-side difference, and ACL combined with ALLR were associated with a lower graft failure rate. However, the study did not discuss meniscus tears or the degree of tibial slope. Na et al. conducted another systemic review of 20 studies, comparing patients who underwent ACLR with anterolateral extra-articular procedures (including ALLR and LET) with those who underwent ACLR without anterolateral extra-articular procedures. They found that patients who underwent the anterolateral procedures had improved pivot shift grades and lower graft failure rates, and among these patients, those who underwent ALLR had better subjective outcomes and lower knee stiffness than those that underwent LET [27, 28].

Different surgical techniques that combine DB ACLR with ALLR have been developed for treating ACL injuries in recent years. The main differences are in the femoral tunnel location, which is most commonly placed posterior and proximal to the lateral epicondyle. Few surgeons chose an anterior or distal tunnel location. There is minimal variation in the tibial tunnel location, and the most frequently used ALLR graft is a single-stranded gracilis tendon [27, 28]. However, few studies have reported the clinical results of these techniques. Mao et al. reviewed 15 patients who underwent ACL revision with DB ACLR combined with ALLR [29]. After the operation, the international knee documentation committee (IKDC), Lysholm, and Tegner activity scores significantly improved. Long-term clinical results showed that patients who underwent DB ACLR had lower graft failure rates and less residual anterior translation than those who underwent SB ACLR [1, 2, 7, 30–37]. In our study, we used a quadruple-folded semitendinosus

Table 5 Comparison of patient variables between the group with an MRI LTS slope of $>3.8^\circ$ ($n=20$) and that with an MRI LTS slope of $<3.8^\circ$ ($n=13$)

LTS degrees	$>3.8^\circ$	$<3.8^\circ$	p	Achieved power (%)
Demographic factors				
Sex (female)	13 (40.6%)	13 (65.0%)	0.239	39.9
Meniscus injury				
Medial	6 (30.0%)	6 (46.2%)	0.362	22.0
Lateral	11 (55.0%)	9 (69.2%)	0.430	16.7
Age (years)	25.9 \pm 9.2	26.5 \pm 10.0	0.840	4.4
Height (m)	1.7 \pm 0.1	1.7 \pm 0.1	0.759	5.9
Body weight (kg)	76.8 \pm 19.6	71.9 \pm 12.6	0.465	19.9
BMI (kg/m ²)	25.6 \pm 4.6	24.5 \pm 3.1	0.471	19.1
X-ray				
Femoral-tibial angle ($^\circ$)	3.5 \pm 2.6	3.7 \pm 2.4	0.789	5.3
MRI				
Medial tibial slope ($^\circ$)	6.3 \pm 2.6	5.8 \pm 2.1	0.584	11.0
Pivot shift				
Pre-operative (grade 3)	14 (70.0%)	17 (53.1%)	0.414	23.4
Post-operative (grade 0)	17 (85.0%)	30 (93.8%)	0.311	13.6
Lysholm score	91.9 \pm 5.8	93.5 \pm 6.8	0.554	14.3
Tegner activity score	4.7 \pm 2.1	5.9 \pm 1.9	0.204	55.6

* significant at $p<0.05$

MRI, magnetic resonance imaging; LTS, lateral tibial slope; BMI, body mass index

tendon as the AMB and a non-folded gracilis tendon as the PLB. This raised concerns about whether the PLB is strong enough for this application. Therefore, we also passed an internal brace along with the gracilis tendon to augment its strength and improve its stability. Zhao et al. proposed another technique of folding the gracilis tendon into three and thereby increasing the PLB thickness [38]. However, similar to our technique, their technique used only a double-folded semitendinosus tendon as the AMB, thus creating a four-folded intra-articular tendon graft. Further biomechanical studies are required to evaluate these different techniques and their effect on knee stability.

This study has several limitations that should be considered when interpreting its findings. First, the retrospective design and the absence of a control group limit our ability to draw definitive conclusions about the effectiveness of the combined DB ACLR and ALLR technique.

Second, the study was conducted at a single institution, which may limit the generalizability of the results to other settings or populations. Further prospective, randomized controlled trials and multi-center studies with larger and more diverse patient cohorts are required for stronger evidence and generalizability.

Third, the assessment of the long-term outcomes and potential complications of the combined technique was hindered by the relatively short follow-up duration (mean 28.9 ± 3.4 months). Longer follow-up periods would be necessary to evaluate the durability of the results and the risk of late graft failure or osteoarthritis development.

Fourth, our ability to quantify postoperative stability in patients with different risk factors was limited by the lack of objective arthrometer data on residual anterior tibial translation. Future studies should include these objective measurements to better characterize the impact of the combined technique on knee laxity. However, some authors have proposed that graft failure and knee laxity could be related to PROM values [8].

Finally, the study's final sample size ($n=52$) may have been insufficient to detect clinically meaningful differences in outcomes between subgroups. A post hoc power analysis of the Lysholm score, assuming an alpha level of 0.05, an MCID of 10 points, and an SD of 15 points, revealed an estimated power of 0.62 with the current sample size, indicating that the study may have been underpowered to detect a difference. Larger studies with adequate power are needed to confirm our findings and explore the potential effects of risk factors on postoperative outcomes.

In summary, our study observed that some patients with risk factors such as a steep tibial slope, meniscal injury, or ALL tear experienced successful outcomes following standard ACL reconstruction without additional procedures like slope-reducing osteotomy. However,

further research comparing the outcomes of surgeries with and without such additional procedures is needed to draw definitive conclusions about their necessity in managing the risk of residual instability.

Although this study offers insights into the potential benefits of DB ACLR combined with ALLR in high-risk patients, its findings should be interpreted with caution owing to the limitations of its design, sample size, and follow-up duration. Further high-quality research is needed to confirm our results and guide clinical decision-making in this patient population.

Conclusion

In conclusion, DB ACLR combined with ALLR shows promise in addressing the challenges of high-risk patients undergoing ACL reconstruction, providing satisfactory clinical outcomes, and reducing postoperative pivot-shift. Although these findings are encouraging, additional research is necessary to confirm the benefits of this approach and guide its integration into clinical practice. As our understanding of the factors that influence ACL reconstruction outcomes improves, refining surgical techniques to better serve high-risk patients will remain an important goal in sports medicine.

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Author contributions

CY and MC wrote the manuscript. MC measured the radiological result. CW performed the statistics. AC, KH, and YC provided professional opinion regarding DBACL combined ALL reconstruction. CC provided all study cases and reviewed the manuscript.

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Data availability

The datasets used and/or analyzed during the current study available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Approval number, 202300134B0; ethical committee, the Institutional Review Board of Chang Gung Medical Foundation; the Institutional Review Board of Chang Gung Medical Foundation approved the study and waived the requirement for informed consent.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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