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Modified all-inside versus conventional anterior cruciate ligament reconstruction: A prospective randomized evaluation of knee stability and functional outcomes

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ABSTRACT

Aim: To compare knee stability, quadriceps circumference, and functional outcomes between modified all-inside and conventional anterior cruciate ligament reconstruction techniques and to evaluate the associations between postoperative stability tests and functional scores.

Method: This prospective randomized parallel-group study included 80 patients undergoing anterior cruciate ligament reconstruction. Patients were randomized in a 1:1 ratio using a computer-generated sequence. At 1 year postoperatively, knee stability was evaluated using KT-1000 arthrometry, Lachman, and pivot-shift tests. Quadriceps circumference was measured 10 cm proximally to the patellar joint line. Functional outcomes were assessed using the Cincinnati, Visual Analog Scale, Lysholm, International Knee Documentation Committee, and Knee Injury and Osteoarthritis Outcome Score instruments.

Results: Forty-two patients underwent conventional reconstruction and 38 underwent modified all-inside reconstruction. Knee stability and functional scores were comparable between the groups (p>0.05). The modified all-inside group showed a nonsignificant tendency toward a smaller side-to-side difference in quadriceps circumference (p=0.051). In this group, International Knee Documentation Committee and Knee Injury and Osteoarthritis Outcome Score values differed significantly across Lachman grades (both p=0.008). In the conventional group, functional scores differed significantly across KT-1000 grades, whereas no significant differences were observed across Lachman grades.

Conclusions: Both techniques provided comparable knee stability and functional outcomes at 1 year. Exploratory within-group analyses identified associations between Lachman grades and selected functional outcomes in the modified all-inside group and between KT-1000 grades and functional outcomes in the conventional group. These findings do not establish a technique-specific difference and require confirmation in adequately powered studies using formal interaction analyses.

Keywords: Anterior cruciate ligament, anterior cruciate ligament reconstruction, arthroscopy, knee joint, outcome.

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1. Introduction

The growing participation of adults in sports and recreational activity has been associated with a noticeable rise in the incidence of knee ligament injuries, particularly anterior cruciate ligament tears [1]. Among these structures, the anterior cruciate ligament (ACL) plays a central role in maintaining knee stability, and its rupture can restrict daily activities and athletic performance due to pain, swelling, and functional instability. Epidemiological studies estimate the annual incidence of ACL injuries at approximately 79 cases per 100,000 individuals [1]. Because delayed treatment may predispose patients to secondary complications including chondral degeneration, meniscal tears, and the gradual development of osteoarthritis timely reconstruction remains a critical component of management [2].

The traditional single-bundle reconstruction technique, which involves creating full-length tibial and femoral tunnels, has long been regarded as the standard surgical approach. More recently, however, the all-inside technique has gained attention owing to its less invasive nature. Despite its advantages, concerns have been raised regarding potential graft micromotion, tunnel widening, and the risk of subsequent graft failure [3]. In response to these concerns, several modified all-inside (MAI) or hybrid techniques have been described to enhance graft fixation stability and reduce graft micromotion, with the aim of improving early biomechanical conditions and graft incorporation [4].

As clinical interest in MAI techniques continues to expand, there is a growing need for prospective comparative studies that assess their outcomes in a standardized manner. The present study was therefore designed to compare the MAI and conventional ACL reconstruction techniques regarding knee stability, quadriceps muscle circumference, and functional performance at 1 year postoperatively, while also evaluating whether the MAI technique offers an early advantage in preserving quadriceps muscle mass.

We hypothesized that the modified all-inside and conventional ACL reconstruction techniques would provide comparable knee stability and functional outcomes at the 1-year follow-up. We also explored the associations between postoperative clinical stability grades and patient-reported functional outcomes within each surgical group. These within-group analyses were considered exploratory.

2. Materials and methods

This study was approved by the Ankara Bilkent City Hospital No. 2 Medical Research Scientific and Ethics Evaluation Board (TABED) (approval no: TABED 2-25-896; April 16, 2025). Written informed consent was obtained from all participants prior to enrollment. All procedures were conducted in accordance with the principles of the Declaration of Helsinki.

Between April 2025 and June 2025, patients presenting to the outpatient clinic with a confirmed ACL rupture requiring surgical reconstruction were screened for eligibility. Consecutive sampling was applied. Patients who met the predefined inclusion and exclusion criteria were invited to participate in the study. As illustrated in Figure 1, a total of 115 patients were initially assessed for eligibility. Seventeen patients were excluded because 12 did not meet the inclusion criteria and 5 declined to participate. The remaining 98 patients were enrolled and randomized into either the conventional ACL reconstruction group (n = 50) or the modified all-inside ACL reconstruction group (n = 48).

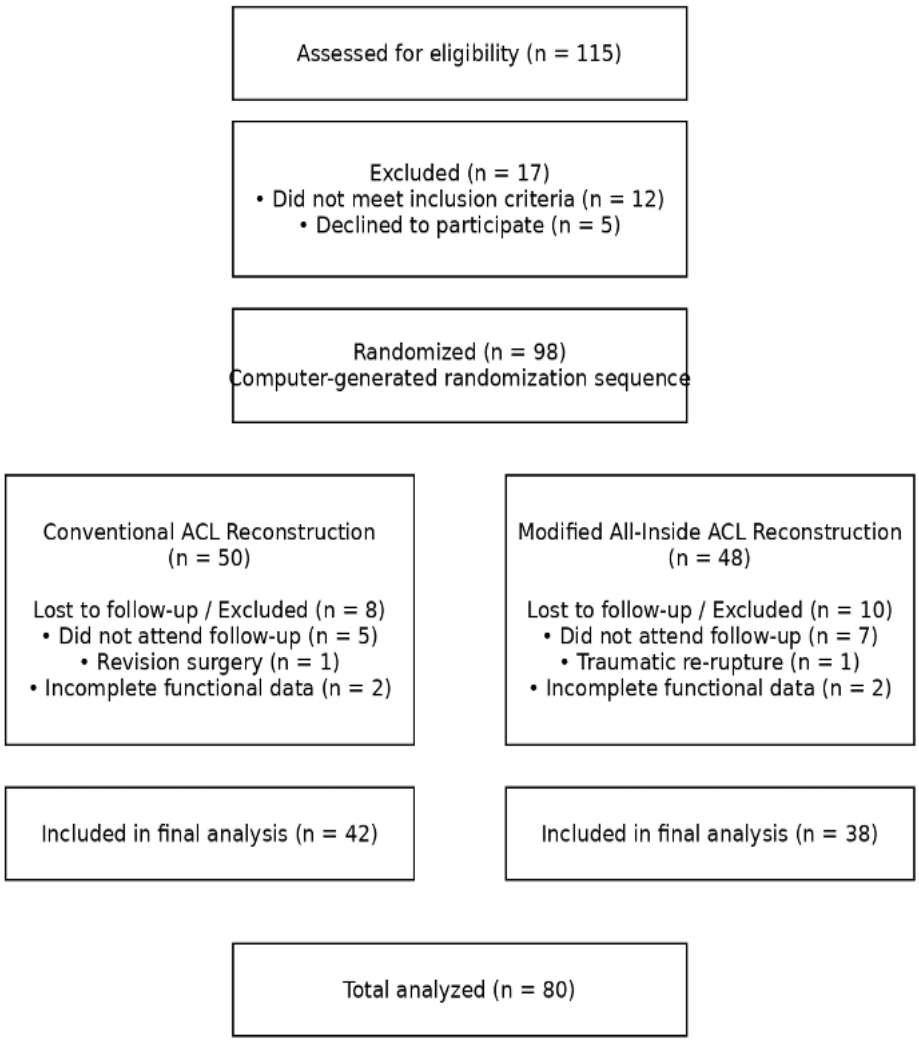

Figure 1. CONSORT flow diagram showing participant screening, randomization, follow-up losses and exclusions, and the final analysis groups.

Randomization was performed in a 1:1 ratio using a computer-generated allocation sequence, with simple randomization and no stratification. Group assignments were placed in sequentially numbered, opaque, sealed envelopes. The envelope was opened in the operating room after the patient had been enrolled, thereby concealing the allocation until surgery. The postoperative clinical assessments were performed by orthopedic surgeons who were blinded to the assigned surgical technique.

During follow-up, 18 patients were excluded from the final analysis due to various clinical reasons. In the conventional group (n = 8), five patients were lost to follow-up, one required revision surgery, and two had incomplete functional outcome data. In the modified all-inside group (n = 10), seven patients were lost to follow-up, one experienced a traumatic re-rupture, and two had insufficient functional data. Ultimately, the study was completed with a final cohort of 80 patients (42 in the conventional group and 38 in the modified group). The primary analysis was conducted according to a per-protocol approach and included the 80 patients who completed the 1-

year follow-up and had complete outcome data. Patients lost to follow-up or lacking the required outcome data were not included in the final analysis.

An a priori sample-size calculation was performed using G*Power version 3.1.9.6 [5]. The 1-year IKDC subjective score was designated as the primary outcome. The calculation was designed to estimate the number of participants required to detect differences in IKDC scores across postoperative stability-test categories using a one-way analysis of variance. In the absence of directly comparable data for the present modified technique, a large standardized effect size of f=0.45 was prespecified, with a two-sided significance level of 0.05 and statistical power of 80%. The minimum required sample size was 60 participants. To account for the planned use of nonparametric comparisons, this number was increased by 15% to 69 patients. Additional recruitment was planned to compensate for possible loss to follow-up, resulting in a target analyzable sample of at least 80 patients. The study was not specifically powered for formal technique-by-stability grade interaction analyses.

***2.1. Functional Outcome Measures*:** The primary endpoint was the 1-year postoperative IKDC subjective score. All other functional scores (Cincinnati, Lysholm, KOOS, and VAS) were considered secondary outcomes.

Functional assessment included the Cincinnati Knee Score, Lysholm Score, International Knee Documentation Committee (IKDC) subjective form, The Knee Injury and Osteoarthritis Outcome Score (KOOS) subscales, and the Visual Analog Scale (VAS) for pain. The Cincinnati Score evaluates symptoms, stability, and activity level (range 120–420, higher scores indicating better function). The Lysholm Score assesses knee function across eight domains (0–100). The IKDC questionnaire evaluates symptoms and activity tolerance on a 0–100 scale, and the KOOS instrument consists of five subscales covering pain, symptoms, daily activities, sports function, and quality of life. Pain intensity was recorded using a 0–10 VAS.

2.2. Clinical Stability Assessment: Anterior knee stability was assessed using a KT-1000 arthrometer by two experienced orthopedic surgeons. Measurements were obtained with the knee positioned at 20° of flexion while applying an anterior tibial load of 89 N. Three consecutive readings were recorded for each knee, and median values were used for analysis. Anterior tibial translation was measured in millimeters (mm) [6]. Clinical stability was further evaluated using the Lachman and pivot-shift tests. The Lachman test was performed with the knee in 20–30° of flexion, assessing anterior translation and end-point quality. The pivot-shift test was carried out with the knee in extension, followed by internal rotation and valgus stress during flexion to evaluate rotational instability.

2.3. Surgical Techniques: In the conventional reconstruction technique, the ipsilateral semitendinosus and gracilis tendons were harvested and prepared as a quadruple-strand autograft. Full-length femoral and tibial tunnels were created using conventional drilling techniques. The femoral tunnel was prepared through either the anteromedial portal or an outside-in approach, whereas the tibial tunnel was drilled using a guide pin introduced through the anterior tibial cortex at approximately 45° [7]. Femoral fixation was achieved using a fixed-loop cortical suspensory device (EndoButton), while tibial fixation was performed using an interference screw supplemented with a U-staple. In the modified all-inside technique, the autograft consisted of

semitendinosus and/or gracilis tendons prepared in a four-strand configuration. A retrograde tibial socket was created using a FlipCutter-type retrograde drill system, allowing socket formation without breaching the tibial cortex. Femoral tunnel preparation followed the conventional approach; no femoral FlipCutter was used. Adjustable-loop suspensory devices (TightRope®) were utilized for fixation on both the tibial and femoral cortices.

The conventional technique is illustrated in Figure 2, whereas the modified all-inside technique is shown in Figure 3.

Figure 2. Postoperative anteroposterior and lateral radiographs demonstrating the conventional anterior cruciate ligament reconstruction technique with femoral cortical suspensory fixation and tibial interference screw fixation.

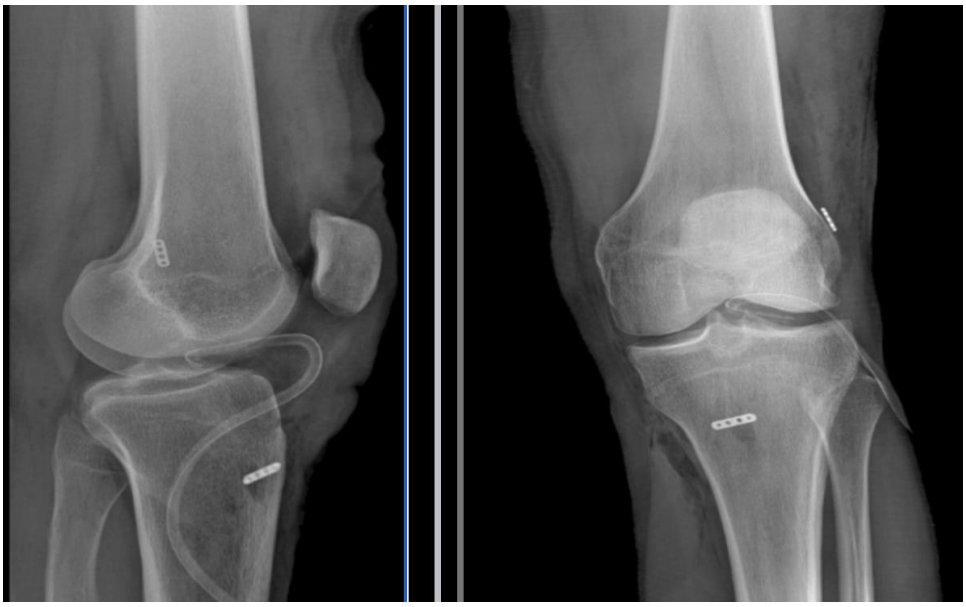

Figure 3. Postoperative lateral and anteroposterior radiographs demonstrating the modified all-inside anterior cruciate ligament reconstruction technique with cortical suspensory fixation on both the femoral and tibial sides.

2.4. Quadriceps Circumference Measurement: Quadriceps circumference was measured with the patient in a supine position and both knees fully extended. To ensure consistency, the tape measure was aligned circumferentially without obliquity. Measurements were taken 10 cm proximal to the patellar joint line on both limbs. Three readings were recorded for each knee, and the median value was analyzed [8].

2.5. Stability Grading: KT-1000 differences between operative and non-operative knees were categorized as Grade A (0–2 mm), Grade B (3–5 mm), or Grade C (>6 mm). Lachman grades were classified as Grade 0, 1+ (firm end point), 2+ (soft end point), and 3+ (absent or markedly soft end point). Pivot-shift findings were recorded as Grade 0 (negative), Grade 1 (glide), Grade 2 (distinct clunk), or Grade 3 (gross shift).

2.6. Postoperative Rehabilitation: All patients followed a standardized postoperative rehabilitation protocol**.** Partial weight-bearing with crutches was permitted from postoperative day 1 as tolerated. Supervised physiotherapy was initiated early, and range-of-motion and strengthening exercises were performed using a hinged adjustable knee brace. Patients were encouraged to achieve 90° of knee flexion by postoperative week 2**,** progressing to 0–120° during the subsequent week.

2.7. Statistical Methodology: Statistical analyses were performed using SPSS software (version 27.0 for Windows). For all analyses, a p-value of <0.05 was considered statistically significant. Descriptive statistics were expressed as percentages and frequencies for categorical variables, and as median (minimum-maximum) and mean ± standard deviation for numerical variables. The normality of data distribution was assessed using the Shapiro-Wilk test, and the homogeneity of variances was examined using Levene's test. Accordingly, the Mann-Whitney U test was employed for comparing two independent groups, and the Kruskal-Wallis H test was utilized for more than two independent groups for variables that were not normally distributed. The Chi-square test was used to examine the relationship between categorical variables. For normally distributed variables, the independent samples t-test was applied for two-group comparisons. In cases where significant main effects or interactions were detected, Bonferroni-corrected post-hoc multiple comparison tests were performed to identify specific differences between groups.

Analyses examining the associations between stability-test grades and functional outcomes within each surgical group were considered exploratory. Because no formal technique-by-stability grade interaction analysis was performed, statistical significance in one group and non-significance in the other were not interpreted as evidence of a statistically significant difference between the surgical techniques.

3. Results

Of the 98 randomized patients, 80 completed the 1-year follow-up and were included in the per-protocol analysis, corresponding to an overall attrition rate of 18.4%. The final cohort consisted of 38 patients in the modified all-inside group and 42 patients in the conventional group. The mean age was 28.5 ± 7.9 years, with a median age of 27.5 years and a range of 18–48 years (Table 1).

KT-1000 grading, Lachman, and pivot-shift results were comparable between the modified all-inside (MAI) and conventional groups at 1 year, with no significant between-group differences ($p > 0.05$) (Table 2).

Table 1. Baseline age distribution and operated side in the modified all-inside and conventional groups.

Techniques and Characteristics	Age					
	Number of patients	**Mean**	**Standard Deviation**	**Median**	**Minimum**	**Maximum**
Modified All-Inside	38	25.9	7.5	25	18	48
Conventional	42	30.9	7.6	31.5	18	46
Side						
Right	40	27.9	8.7	27	18	48
Left	40	29.1	7.1	28	18	46
Total	80	28.5	7.9	27.5	18	48

Table 2. Comparison of KT-1000, Lachman, and pivot-shift results between the modified all-inside and conventional techniques.

Parameters	Modified All-Inside (n=38)	Conventional Technique (n=42)	P*
KT-1000			0.152
Grade A	30 (78.9)	27 (64.3)	
Grade B	8 (21.1)	12 (28.6)	
Grade C	0 (0)	3 (7.1)	
Lachman			0.634
Grade 0	20 (52.6)	28 (66.7)	
Grade 1+	10 (26.3)	8 (19)	
Grade 2+	5 (13.2)	4 (9.5)	
Grade 3+	3 (7.9)	2 (4.8)	
Pivot-shift			0.379
Grade 0	32 (84.2)	38 (90.5)	
Grade 1	5 (13.2)	2 (4.8)	
Grade 2	1 (2.6)	2 (4.8)	

**Chi-square test; n (%); n = number of patients*

Table 3. Comparison of quadriceps circumference and functional scores between the modified all-inside and conventional techniques

Parameters	Modified All-Inside (n=38)	Conventional Technique (n=42)	P*
Side-to-side quadriceps circumference difference (cm)	0 (0-2)	1 (0-4)	0.051
Cincinnati score	310 (190-390)	310 (160-420)	0.805
VAS pain score	2 (0-8)	2 (0-8)	0.474
Lysholm score	85.5 (48-100)	81 (48-100)	0.099
IKDC score	74.68±14.42	72.6±12.71	0.493†
KOOS score	80.5 (44-98)	80 (45-96)	0.668

**Mann–Whitney U test; median (min–max); †Independent samples t-test; mean ± standard deviation; n = number of patients. Quadriceps circumference represents the side-to-side difference between the operated and contralateral limbs.*

At the 1-year follow-up, the side-to-side difference in quadriceps circumference between the operated and contralateral limbs was 0 cm (range, 0–2 cm) in the modified all-inside group and 1 cm (range, 0–4 cm) in the conventional group. This between-group difference did not reach statistical significance (p=0.051). Because preoperative quadriceps circumference measurements were unavailable, this finding cannot be interpreted as evidence of superior preservation or recovery of quadriceps muscle mass (Table 3).

IKDC scores were comparable between groups, with no statistically significant difference (74.68 ± 14.42 in the modified all-inside group vs. 72.6 ± 12.71 in the conventional group; p = 0.493). Similarly, no significant differences were observed in other functional outcome measures, including Cincinnati, Lysholm, VAS, and KOOS scores (p > 0.05) (Table 3).

The postoperative 1-year functional outcomes were compared with KT-1000 measurements as well as Lachman and pivot-shift test findings. In the KT-1000–stratified analysis, IKDC scores differed significantly according to KT-1000 grade in the conventional group (Grade A: 78 (53–97), Grade B: 55 (52–72), Grade C: 78 (75–92); p < 0.001). Similar differences were observed across other functional outcome measures, including Cincinnati, VAS, Lysholm, and KOOS scores (p < 0.01) (Table 4). In contrast, no significant differences in functional outcomes were detected across KT-1000 grades in the modified all-inside group (p > 0.05).

In the exploratory Lachman-stratified analysis, Cincinnati, IKDC, and KOOS scores differed significantly across Lachman grades in the modified all-inside group (p=0.007, p=0.008, and p=0.008, respectively). VAS and Lysholm scores did not

Table 4. Comparison of KT-1000 grades with clinical and functional parameters in patients treated with the conventional technique.

Scores	KT-1000			P*	Multiple comparisons†
	Grade A (n=27)	Grade B (n=12)	Grade C (n=3)		
Cincinnati	330 (290-420)	260 (160-330)	320 (270-370)	**0.001**	A-B
VAS pain	0 (0-8)	4 (0-5)	3 (1-4)	**0.005**	A-B
Lysholm	87 (65-100)	61 (48-78)	83 (81-94)	**<0.001**	A-B; B-C
IKDC	78 (53-97)	55 (52-72)	78 (75-92)	**<0.001**	A-B; B-C
KOOS	88 (61-96)	70 (45-79)	82 (61-89)	**<0.001**	A-B

**Kruskal–Wallis test; median (min–max); †Pairwise comparisons were adjusted using the Bonferroni correction; n=number of patients*

Table 5. Comparison of Lachman grades and clinical/functional parameters in patients treated with the modified all-inside technique.

Scores	Lachman				P*	Multiple comparisons†
	Grade 0 (n=20)	Grade 1+ (n=10)	Grade 2+ (n=5)	Grade 3+ (n=3)		
Cincinnati	310 (200-380)	365 (300-390)	280 (260-370)	210 (190-300)	**0.007**	1-3
VAS pain	2 (0-6)	0 (0-4)	2 (0-6)	5 (2-8)	0.132	-
Lysholm	84.5 (48-96)	95 (79-100)	81 (54-94)	69 (49-89)	0.101	-
IKDC	73.5 (49-90)	90 (71-94)	74 (63-92)	56 (37-67)	**0.008**	1-3
KOOS	76 (57-96)	88 (78-98)	79 (71-84)	62 (44-76)	**0.008**	1-3

**Kruskal–Wallis test; median (min–max); †Pairwise comparisons were adjusted using the Bonferroni correction; n=number of patients*

differ significantly across Lachman grades (p>0.05) (Table 5). No significant differences in functional outcomes across Lachman grades were identified in the conventional group (p>0.05). These within-group findings should be interpreted cautiously because some Lachman categories contained very small numbers of patients and no formal interaction analysis was performed.

Likewise, in both surgical groups, pivot-shift grading showed no significant associations with any of the functional outcome measures at the 1-year follow-up (p > 0.05).

4. Discussion

The principal finding of this study was that the modified all-inside and conventional ACL reconstruction techniques provided comparable knee stability and patient-reported functional outcomes at the 1-year follow-up. In exploratory within-group analyses, Lachman grades were associated with selected functional scores in the modified all-inside group, whereas KT-1000 grades were associated with several functional scores in the conventional group. However, these findings should not be interpreted as demonstrating a definitive technique-specific difference because a formal interaction analysis was not performed.

Kyriakopoulos et al. reported no significant differences in KT-1000 measurements between the all-inside and conventional techniques in their cohort of 44 patients, a finding consistent with the present study, in which anterior tibial translation did not differ statistically between techniques [9]. Similarly, Polat et al. compared the two methods in 40 patients and demonstrated equivalent rotational stability based on the pivot-shift test, while the all-inside group showed superior anterior stability on the Lachman test [10]. In contrast, our findings revealed no significant differences between the groups in either Lachman or pivot-shift grades. Ong et al. reported persistent quadriceps muscle atrophy after ACL reconstruction [11]. In the present study, the side-to-side quadriceps circumference difference between the operated and contralateral limbs was numerically smaller in the modified all-inside group than in the conventional group. However, this between-group difference did not reach statistical significance (p=0.051). Furthermore, because preoperative quadriceps circumference measurements were unavailable, this finding cannot be interpreted as evidence of a technique-related advantage in quadriceps muscle preservation or recovery. In a meta-analysis of 299 randomized controlled trials including 25,816 patients, Matar et al. found minimal differences between the all-inside and conventional techniques, with only a marginal advantage in Lysholm scores and no significant differences in VAS, IKDC, Tegner, or KOOS scores [12]. Our study similarly demonstrated no statistically significant differences in Cincinnati, VAS, Lysholm, IKDC, KOOS or KOOS subscales between the two techniques.

Al-Gburi et al. evaluated 190 patients undergoing ACL reconstruction with different graft types and reported weak relationships between clinical stability tests and patient-reported functional outcomes [13]. In the present exploratory within-group analysis, Cincinnati, IKDC, and KOOS scores differed across Lachman grades in the modified all-inside group, whereas no significant differences were identified in the conventional group. Nevertheless, these subgroup findings do not demonstrate that the relationship differed significantly between the techniques because a formal interaction analysis was not performed.

Moreover, in conventionally treated patients, KT-1000 measurements demonstrated stronger associations with functional outcomes compared with the Lachman test, suggesting that instrumented laxity assessment may more

accurately reflect functional performance in this subgroup. Significant differences in Cincinnati, VAS, Lysholm, IKDC, and KOOS scores across KT-1000 grades support this interpretation.

This study has several limitations. The 1-year follow-up may not reflect long-term outcomes, and the absence of preoperative functional and quadriceps circumference measurements precluded evaluation of changes from baseline. Some subgroup analyses included very few patients, particularly KT-1000 Grade C in the conventional group and Lachman Grade 3+ in the modified all-inside group, and should therefore be interpreted cautiously. Moreover, the exploratory analyses were not supported by formal interaction testing, and the study was not specifically powered to detect technique-by-stability grade interactions. The per-protocol analysis and loss to follow-up may have introduced attrition bias. Finally, technical variations in femoral tunnel drilling, graft composition, and graft diameter were not analyzed separately and may have affected the results.

4.1. Conclusion: Modified all-inside and conventional ACL reconstruction techniques provided comparable knee stability, quadriceps circumference differences, and patient-reported functional outcomes at the 1-year follow-up. The between-group difference in side-to-side quadriceps circumference did not reach statistical significance. Exploratory within-group analyses identified associations between Lachman grades and selected functional outcomes in the modified all-inside group and between KT-1000 grades and functional outcomes in the conventional group. However, these findings do not establish a technique-specific difference and should be interpreted cautiously because of the small subgroup sizes and absence of a formal interaction analysis. Further adequately powered studies using formal interaction testing are required.

ACL – Anterior Cruciate Ligament
MAI – Modified All-Inside
IKDC – International Knee Documentation Committee
KOOS – Knee Injury and Osteoarthritis Outcome Score
VAS – Visual Analog Scale
MRI – Magnetic Resonance Imaging
cm – Centimeter
mm – Millimeter
° – Degrees (range of motion)

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Ethical Statement: *This study was approved by the Institutional Review Board of Ankara Bilkent City Hospital on 16 April 2025 (Approval No: TABED 2-25-896). All procedures were conducted in accordance with the Declaration of Helsinki.*
Patient Consent Statement
Written informed consent was obtained from all participants prior to enrollment in the study.
Data Availability Statement: *The de-identified data supporting the findings of this study are available from the corresponding author upon reasonable request, subject to institutional and ethical approval.*

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