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The Effect of Technical Characteristics of Revision ACL Reconstruction on Functional Outcomes

Taha Kızılkurt,[1] Yiğit Umur Cırdı,[2] Gökhan Polat,[1] Kayahan Karaytuğ,[3] Önder Kılıçoğlu,[1] Mehmet Aşık[1]

[1]Department of Orthopedics and Traumatology, İstanbul University, İstanbul Faculty of Medicine, İstanbul, Türkiye
[2]Department of Orthopedics and Traumatology, Acıbadem Mehmet Ali Aydınlar University, İstanbul, Türkiye
[3]Department of Orthopedics and Traumatology, Acıbadem Maslak Hospital, İstanbul, Türkiye

ABSTRACT

Objective: Advances in arthroscopic techniques have increased the global prevalence of anterior cruciate ligament reconstruction (ACLR) surgeries. Despite this, failure rates remain high, with revision ACLR (R-ACLR) often yielding inferior outcomes compared to primary procedures. This study aimed to investigate the correlation between the technical characteristics of R-ACLR and functional outcomes.

Materials and Methods: This retrospective study analyzed 46 revision ACLRs performed at the 3rd step medical department between 2000 and 2017. Patient demographics, surgical history, and imaging findings were collected. Outcomes were assessed through physical examinations, Tegner-Lysholm Knee scales, and radiographic evaluations. Statistical analyses, including t-tests and ANOVA, were conducted using SPSS v26, with a significance level of $p<0.05$.

Results: A total of 46 procedures were analyzed. The mean follow-up duration was 77.9 months. Failure after primary ACLR occurred at a median of 45.6 months due to trauma and 25.5 months due to technical errors. The techniques included transtibial (28.2%), modified transtibial (19.6%), and anteromedial portal (52.2%). At the final follow-up, the mean Tegner-Lyshom Score was 73.5. Significant correlations were observed for graft thickness ($r=0.650$, $p=0.001$), postoperative Lachman test ($r=-0.727$, $p=0.001$), KT1000 measurement ($r=-0.581$, $p=0.001$), and femoral tunnel obliquity ($r=0.511$, $p=0.001$).

Conclusion: Revision ACLR may successfully restore knee stability, and functional outcomes are influenced by graft size, knee stability, and femoral tunnel obliquity. Understanding the causes of reduced functional scores is crucial to prevent patient dissatisfaction.

Keywords: Anterior cruciate ligament, reconstruction, revision, failure, quadrant method, functional outcomes.

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Address for correspondence:
Yiğit Umur Cırdı.
Department of Orthopedics and Traumatology, Acıbadem Mehmet Ali Aydınlar University, İstanbul, Türkiye
Phone: +90 535 354 09 99
E-mail: dryigitcirdi@gmail.com

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INTRODUCTION

Continuous advancements in arthroscopic techniques, coupled with low complication rates and increasing patient expectations, have driven a significant and consistent increase in the number of anterior cruciate ligament reconstruction (ACLR) surgeries performed worldwide.[1] Anterior cruciate ligament ruptures are typically managed surgically, particularly in athletes and physically active individuals, due to their ability to restore knee stability and facilitate a safe return to sports. However, this widespread adoption has also been accompanied by an inevitable increase in the number of cases of failed surgical interventions, recurrent ligament ruptures, and subsequent revision surgeries. The annual incidence of re-rupture following ACLR is reaching up to 23.3%, depending on patient demographics, activity levels, and the surgical techniques utilized.[2]

Primary ACLR failures are multifactorial in nature and are influenced by patient-related factors, such as younger age, high activity levels, and poor compliance with rehabilitation protocols. Technical errors, including improper tunnel placement, inadequate graft fixation, and graft size mismatch, also significantly contribute to surgical failure. Additionally, postoperative trauma, infections, and spontaneous biological graft inadequacy contribute to poor outcomes and necessitate revision surgeries. Understanding these risk factors is essential for improving surgical techniques, patient selection, and postoperative care to minimize failure rates.

Due to advancements in surgical methods, the clinical success of revision ACLR (R-ACLR) is generally considered inferior to that of primary ACLR; however, when performed correctly, revision ACLR can still achieve successful outcomes comparable to those of primary ACLR.[3–5] Several studies have highlighted that outcomes depend heavily on factors such as the timing of revision surgery, choice of graft, and correction of technical errors during the initial procedure.[6,7] These findings underscore the importance of thoroughly evaluating the factors that influence the success of R-ACLR. Proper patient counseling regarding expected functional outcomes and activity limitations is equally important to ensure that expectations are appropriately managed.

The objective of the present study was to comprehensively investigate the factors associated with outcomes in R-ACLR and the effect of surgical technique on femoral tunnel obliquity, which has become apparent with the evolution of surgical techniques, on functional scores.

MATERIALS AND METHODS

This retrospective study was conducted at the Istanbul University Department of Orthopedics and Traumatology, Medical Faculty. This study was approved by the Institutional Review Board of the Istanbul University School of Medicine (approval date: 23/12/2024, approval number 3078390) and was conducted in accordance with the principles of the Declaration of Helsinki. STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines were followed for standards including study design, setting, participants, variables, and statistical methods.

Patients who submitted to the outpatient clinic with recurrent instability as the chief complaint after ACLR surgery and who had undergone R-ACLR surgery between 2000 and 2017 were retrieved from institutional records. Patients with (1) missing functional assessment scores, (2) inadequate postoperative radiologic imaging, (3) experiencing fracture

KEY MESSAGES

- Graft Quality and Knee Stability Impact Recovery: Thicker grafts and improved knee stability, as assessed by Lachman and KT1000 tests, were significantly associated with better recovery outcomes,while higher BMI negatively affect results.
- Surgical Technique Comparison: No significant differences were found between the modified transtibial and AM portal techniques in terms of functional outcomes, but both showed superior femoral tunnel positioning compared to the traditional transtibial method.

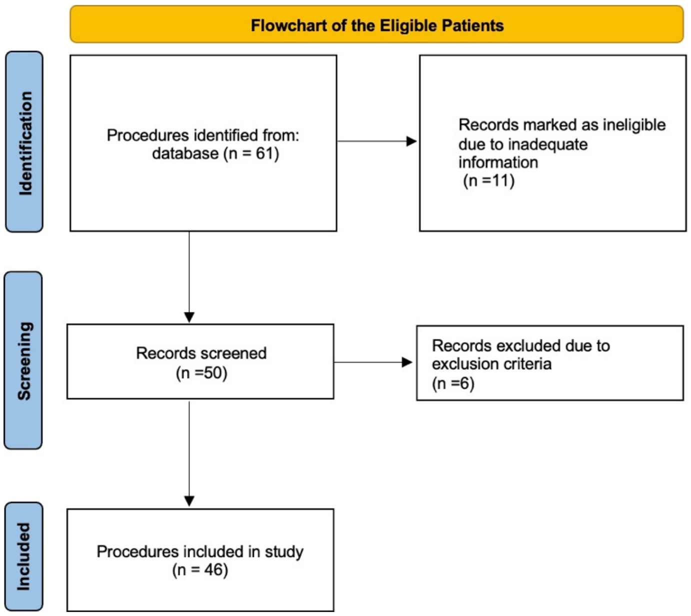

Figure 1. Flowchart of the procedures assessed for eligibility.

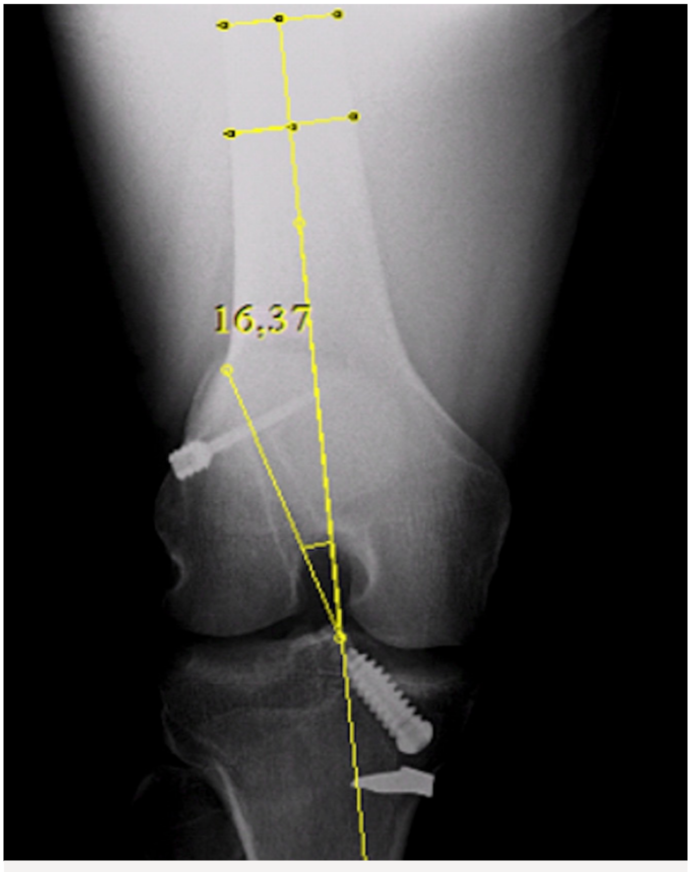

Figure 2. Assessment of femoral tunnel obliquity. The angle between the mechanical axis of the femur and femoral tunnel was measured in the coronal plane. An elevated angle denotes a more oblique tunnel.

or malignancy at the operated site, and (4) refusal to admit the last follow-up examination or out of reach were excluded from the study. All patients were contacted via their provided contact information, and functional outcome measures were collected (Fig. 1).

A total of 61 revision ACLRs were found in the database, of which 17 were excluded based on the exclusion criteria. Finally, the data from 46 individual procedures in 44 patients who were admitted to the last follow-up visit were analyzed. Patient-reported outcomes were assessed using the Tegner–Lysholm Knee Scoring Scale.[8] Knee stability was assessed using the Lachman test, pivot shift test, and KT-1000 arthrometric measurements. Plain radiography and computed tomography (CT) were performed to evaluate tunnel obliquity (Fig. 2) and quadrant methods (Fig. 3).[9] Tunnel obliquity was defined as the angle between the axis of the femoral tunnel in the coronal plane and the anatomical axis of the femur. As the angle increases, the tunnel obliquity increases.

Table 1. Demographic information of the patients who undergone revision ACL surgery and duration between the surgery and failure

Patient demographics	n (%) Mean±SD or Median (IQR)
Gender	
Male	38 (86.4%)
Female	6 (13.6%)
BMI (kg/m^2)	
Median BMI	24.0 (22.0–26.0)
Normal BMI (<25)	33 (71.7%)
Overweight (25–30)	13 (28.3%)
Time intervals associated with revision surgery	
Mean age at revision ACL reconstruction (years)	26.2±5.4
Primary reconstruction to fail duration (mean time- months)	
Due to trauma	45.6±10.2
Due to technical error	25.5±7.5
Fail to revision duration (mean time-months)	17.0±3.1

ACL: Anterior cruciate ligament; SD: Standard deviation; IQR: Interquartile range; BMI: Body mass index; n: Number.

IBM SPSS Statistics for Windows, Version 26.0 (IBM Corp., Armonk, NY, USA) was used for data analysis. The normality of data distribution was assessed using the Kolmogorov–Smirnov test. The Kruskal–Wallis test (post-hoc test: Dunn's) revealed a statistically significant difference in femoral tunnel angles among the surgical techniques. Correlation analyses were conducted using Pearson's test for normally distributed variables and Spearman's test for non-normally distributed or ordinal variables. Statistical significance was set at $p<0.05$.

RESULTS

A total of 44 patients (38 males and 6 females) were included in the study. Two patients underwent a second revision; therefore, a total of 46 procedures were analyzed. The mean age at the time of R-ACLR was 26.2 (SD: 7.2; range: 16–33) years. The mean follow-up period was 77.9 months (SD: 50.4; range: 7–206). The mean Body Mass Index (BMI) was 24 (SD: 3.8; range: 22–29) kg/m^2, 33 (75%) had a BMI <25 (normal weight), and 13 patients (29.5%) were overweight (BMI 25–30). The mechanism of failure was technical error in 29 cases (63%) and trauma in 17 (27%). The mean duration from primary ACL reconstruction to failure was 45.6 months (SD: 25.8; range: 8–90) due to trauma and 25.5 months (SD:

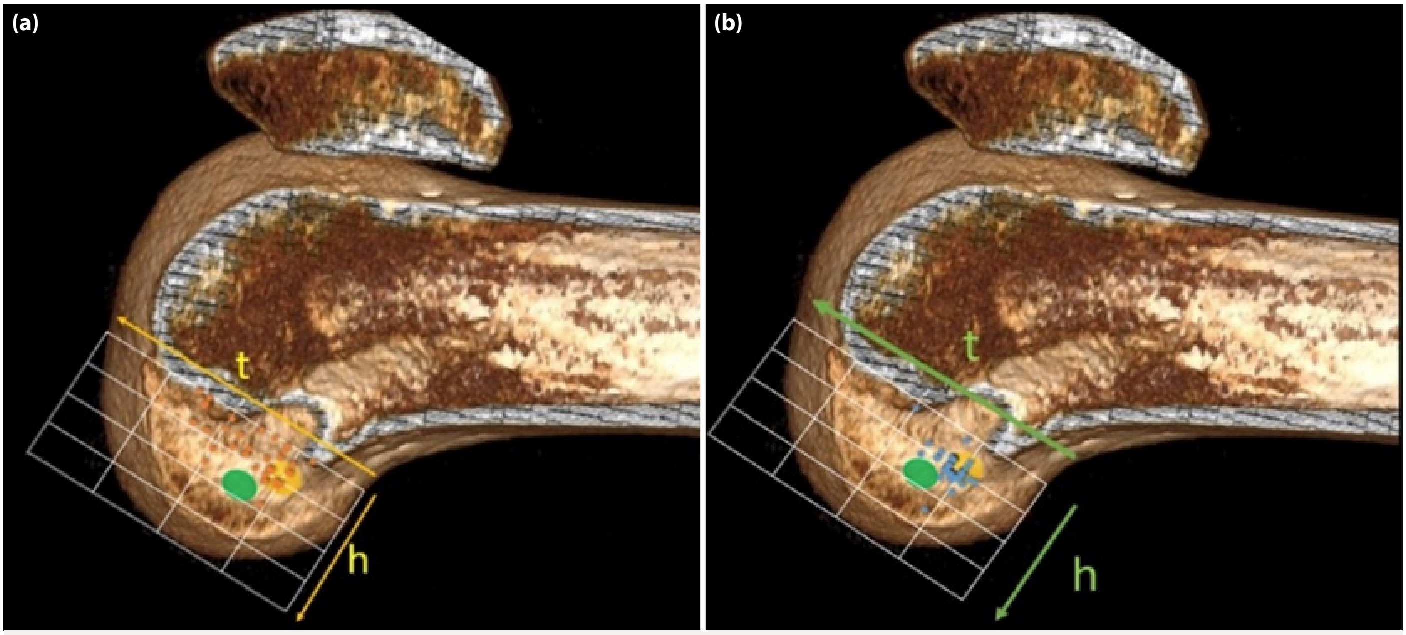

Figure 3. Analysis of the femoral tunnel orifice according to the quadrant method. Green circle: native posterolateral band origin; yellow circle: anteromedial band origin **(a)** Orange dots: Femoral tunnel opening in primary ACLR. **(b)** Blue dots: Femoral tunnel opening of revision ACLR.

8.6; range: 5–34) due to technical errors. The mean time to revision ACL reconstruction was 17.06 months (SD: 7.3; range: 3–29) after failure (Table 1).

Regarding the femoral tunnel technique used in revision procedures, 13 patients (28.2%) underwent the transtibial technique, 9 (19.6%) underwent the modified transtibial technique, and 24 (52.2%) underwent the anteromedial (AM) portal technique (Table 2). The graft types used in the revisions were as follows: five patients (10.9%) received a BPTB autograft, 39 patients (84.8%) received a hamstring autograft, one patient (2.15%) received an Achilles allograft, and one patient (2.15%) received a bone-patellar tendon-bone (BPTB) allograft (Table 2). The mean graft size was 8.1 mm, with a range of 7–10 mm. The graft diameter was as follows: 5 patients (10.9%) received grafts ≤7 mm, 30 patients (65.3%) had grafts between 7.5 and 8 mm, and 11 patients (23.8%) had grafts >8 mm (Table 2).

At the final follow-up, physical examination showed no limitation in the joint range of motion (ROM) for any patient. The Lachman test, performed on 46 patients, revealed that 61% had a score of 0, 29.3% had 1+, 4.9% had 2+, and 4.9% had 3+. For the pivot shift test, 80.5% of patients had a score of 0, 14.6% had 1+, 4.9% had 2+, and none had a score of 3+. KT-1000 arthrometric measurements showed that 68.3% of knees had a difference of <3 mm, 24.4% had 3–5 mm, and 7.3% had a difference of >5 mm.

Table 2. Technical details of the procedures in revision surgery

Revision surgery technical details	n (%)
Femoral tunnel technique	
Transtibial	13 (28.2%)
Modified transtibial	9 (19.6%)
AM portal	24 (52.2%)
Graft type	
BPTB autograft	5 (10.9%)
Hamstring autograft	39 (84.8%)
Achilles allograft	1 (2.15%)
BPTB allograft	1 (2.15%)
Graft size (mm)	
Mean±Standard deviation	8.1±0.75
≤7 mm	5 (10.9%)
7.5–8 mm	30 (65.3%)
>8 mm	11 (23.8%)

AM: Anteromedial; BPTB: Bone-patellar tendon- bone; mm: Milimeters; n: Number.

Correlation analysis of the Tegner–Lysholm Knee Scoring Scale highlighted several significant relationships between various factors and functional outcomes following R-ACL reconstruction. The strength and direction of the correlation

Table 3. Tegner–Lysholm Knee Scoring Scale correlation table (n=46)

	Correlation coefficient	p
Age	0.087	0.587
BMI	-0.546	0.001
Time between primary and revision ACLR	0.540	0.617
Graft thickness	0.650	0.001
Lachman test	-0.727	0.001
KT-1000	-0.581	0.001
Femoral tunnel obliquity	0.511	0.001

ACLR: Anterior cruciate ligament reconstruction; BMI: Body mass index.

were interpreted based on the correlation coefficient (r). A positive value indicated a direct (positive) relationship, whereas a negative value indicated an inverse (negative) relationship. The correlation was classified as very weak (r=0.00–0.19), weak (r=0.20–0.39), moderate (r=0.40–0.59), strong (r=0.60–0.79), and very strong (r=0.80–1.00). The mean last follow-up Tegner – Lysholm Score was 73.5 (SD: 8.3; range: 65–94). Notably, there was a positive correlation with graft thickness (r=0.650, p=0.001; strong correlation), indicating that thicker grafts are associated with better knee function. Furthermore, improved knee stability, as measured by the Lachman test (r=-0.727, p=0.001; strong correlation) and the KT1000 test (r=-0.581, p=0.001; moderate correlation), showed a negative correlation, suggesting that less knee instability leads to better functional outcomes. Femoral tunnel obliquity also showed a positive correlation with improved function (r=0.511, p=0.001; moderate correlation). In contrast, negative correlations were found with BMI (r=-0.546, p=0.001; moderate correlation), indicating that a higher BMI is associated with poorer knee function post-revision (Table 3).

Less oblique (more vertically oriented) tunnels were observed with the transtibial technique than with the modified transtibial and AM portal techniques (p<0.001) (Table 4). The evaluation of femoral tunnel position using the quadrant method revealed no significant differences in 't' values across the three techniques (p=0.923). Nonetheless, for 'h' values, no significant difference was observed between the modified transtibial and AM portal groups; however, a significant difference was identified between these groups and the transtibial technique (p<0.001) (Fig. 2).

DISCUSSION

This study demonstrated that graft thickness, knee stability (as assessed by the Lachman and KT1000 tests), and femoral tunnel obliquity correlated with functional outcomes. In contrast, a higher BMI negatively impacted functional outcomes. Regarding surgical techniques, no significant differences were found between the modified transtibial and AM portal methods; however, both techniques demonstrated significant improvements over the transtibial technique in terms of femoral tunnel direction and positioning. These findings emphasize the importance of graft size, knee stability, and proper femoral tunnel placement for achieving optimal outcomes after ACL revision surgery.

The success rate of primary ACLR was reported to be between 75% and 97%.[10,11] However, the criteria that indicate ACLR failure have not yet been clarified. Nevertheless, Johnson and Cohen defined failure as recurrent instability that restricts daily and sporting activities, characterized by a loss of extension of >10° or flexion contracture, and pain.[12] Failure involves graft rupture, structural deformation, and functional disability, causing instability despite the presence of an intact graft. The causes of ACLR failure are multifactorial, including technical errors, trauma, lower extremity alignment defects, and epidemiological factors.[13] Although the results of revision ACLR surgeries are not as promising as those of primary ACLR surgeries, revision surgery can still facilitate knee stability and lead to patient satisfaction.[14] Various factors affect the outcome of revision ACLR surgeries, such as age, BMI, type of injury, causes of failure, and revision surgery technique.[6,15] Surgeons who perform revision ACLR surgeries should carefully examine their patients, be aware of patient expectations, and exercise greater caution than they did during the primary ACLR surgery.

Table 4. Comparison of tunnel obliquity between groups

Technique (n)	Femoral tunnel angle (°) Median (IQR)	p		
		Trans tibial technique	Modified transtibial technique	Anteromedial portal technique
Trans tibial technique (n=13)	9.0 (7.0–11.0)	–	<0.001	–
Modified transtibial technique (n=9)	24.0 (21.0–28.0)	–	–	>0.05
Anteromedial portal technique (n=24)	31.0 (27.0–34.0)	<0.001	–	–

Since the Kruskal–Wallis test revealed a statistically significant difference in femoral tunnel angles among the surgical techniques (p < 0.05), multiple pairwise comparisons were conducted using Dunn's multiple comparison test. IQR: Interquartile range.

In this study, 38 (86.3%) patients were male and six (13.7%) were female. This proportion is higher than 57% in the MARS cohort and 66% in Rick et al.'s[16] systematic review, possibly reflecting regional differences in sex distribution and sports facilities in Türkiye.[17] The mean age in our study was 26.2 years, similar to the 26.1 years in the MARS cohort.[18] but lower than the 31.6 years in the study by Ahn et al.[19] and 30.2 years as in Grossman et al.[20] Our study found no effect of age on clinical outcomes, in contrast to the findings of Rilk et al.[21] We can attribute this situation to the fact that the functionally active group was relatively narrow in our cohort.

There is a literature void regarding the effect of BMI on R-ACLR outcomes. The debate continues about the exact effect of BMI on R-ACLR; some authors adopt it as a responsible cause, while others do not.[22,23] Consistently, Inderhaug et al.[24] reported a correlation between BMI and revision rate with ACLR with hamstring autografts. In contrast, a recent meta-analysis reported that low BMI is a risk factor for future re-rupture or revision surgery. We attribute this contradiction to the fact that the load on the graft increases as BMI increases, while activity level generally increases as BMI decreases. In our study, we reported an adverse correlation between BMI and functional scores.

Understanding the causes of ACLR failure is essential for an effective revision surgery. Factors such as technical errors, trauma, instabilities, alignment defects, and biological deficiencies contribute to failure, with infection causing graft deficiency in approximately 2% of the cases.[25] None of the patients had any infection-related deficiencies. Technical errors are the most common cause of revision ACLR, with Carson et al.[26] reporting a 52% error rate and Ahn et al.[19] a 66% error rate. Consistent with the literature, our study observed a technical error rate of 63% for all failures. The mean revision failure duration was 17.0 months, although our study showed a mean failure time of 25.5 months for technical errors and 45.6 months for trauma. In terms of reasons for failure (trauma vs. technical errors) on subjective scores, no correlation was found with Tegner-Lysholm scores ($p=0.971$). Johnson et al.[6] suggested that trauma patients have better outcomes than those with technical errors, but their study highlighted the high rate of additional injuries in trauma cases, which complicates this conclusion. They also noted that prolonged instability due to technical errors could impair the outcomes. While Battaglia et al.[27] reported a negative correlation between the interval between failure and revision and clinical outcomes, our study found no such impact on outcomes.

The direction of the femoral tunnel influences reconstruction success, with a 2 o'clock position yielding higher subjective scores.[28] In the transtibial technique, the femoral tunnel is created along the trajectory of the tibial tunnel and is, therefore, positioned vertically.[29] A recent meta-analysis reported a 15.29° difference in femoral tunnel obliquity between the anatomic and transtibial techniques.[30] Consistently, in our study, no significant difference was found between the modified transtibial and AM portal techniques in terms of coronal plane tunnel obliquity; however, both techniques created more oblique tunnel trajectories than the transtibial technique ($p<0.05$). Moreover, our study found a positive correlation between tunnel obliquity and functional scores ($r=0.511$, $p=0.001$). We attribute this to the increased tunnel obliquity, which enhances resistance to rotational forces, resulting in a more stable construction.

The quadrant method is an accurate tool for evaluating the femoral tunnel entry site.[9] The transtibial technique, owing to its non-anatomic nature, creates a tunnel placed more anteriorly. In other words, the tunnel is placed higher from the arthroscopic point of view and closer to Blumensaat's line.[31] However, the AM portal technique and modified transtibial techniques allow positioning of the tunnel relatively more posteriorly, in other words, 'lower' from an arthroscopic point of view and further from the Blumensaat line. Youm et al.[29] reported comparable 't' and 'h' values between the transtibial and AM portal techniques, as well as similar functional outcomes. In contrast, our study demonstrated higher 'h' values in the transtibial technique and other groups. However, no significant difference was observed regarding the 't' values among all techniques.

The optimal graft choice for ACLR remains unclear, and studies have shown varying graft choices. In the MARS cohort, autografts were used in 48% of revision ACLRs.[16] Carson et al.[26] preferred autografts in 34 cases and allografts in nine. In contrast, Johnson et al.[6] employed allografts in 53 cases and autografts in 20 cases, demonstrating that graft selection is based on patient requirements and that no universally ideal graft currently exists. Grassi et al.[32] found no correlation between graft type and subjective outcomes, which is similar to our findings. In our study, we used autografts in 44 cases and allografts in 2 patients, with no clinically significant difference between them. Considering the dominance of autografts in this study, it was not possible to draw a conclusion about the correlation between graft type and functional scores. Furthermore, graft thickness has been shown to affect outcomes, with thicker grafts leading to better results. A 1 mm thinning of grafts increases the failure risk by 45.7%.[33] Consistent with the literature, our study found that graft size significantly affected Tegner–Lysholm Score.

The failure rate of R-ACLR surgeries is documented to be between 2.8% and 7%, with revision procedures generally showing inferior outcomes compared with primary ACLR.[20,34,35] Consistently, Grassi et al.[36] highlighted that inferior functional scores are expected following R-ACLR compared to primary ACLR. Likewise, Kaare et al.[34] reported in their study that functional ability was affected even in cases that underwent multiple revision surgeries, but that a return to recreational sports was possible. Nonetheless, patients who have undergone multiple reconstructions still have acceptable outcomes.[5] In the current study, the Tegner–Lysholm Knee Scoring Scale yielded a mean score of 73.5 (SD: 8.3; range: 65–94). Consistent with the literature, functional activity scores were also impaired in this study; however, knee stability was sufficient. Given this, revision surgery can effectively restore knee stability, with functional outcomes affected by graft size, knee stability, and the angle of the femoral tunnel.

The limitations of this study include its single-center design and the low number of preferred allografts. Additionally, revision surgeries were performed by multiple surgeons using various techniques. However, the single-center nature of the study ensured a certain level of surgical discipline despite variations in techniques and surgeons. Furthermore, the use of different techniques provided an opportunity for technical comparison of revision surgeries, an area that is underrepresented in the literature.

CONCLUSION

In conclusion, this study provides valuable insights into the factors that influence outcomes following R-ACLR. Graft size, knee stability, and accurate femoral tunnel placement are crucial for achieving favorable clinical outcomes. The results of revision ACLR are generally less promising than those of primary ACLR; this study emphasizes that proper knee stability and successful functional scores can still be obtained following R-ACLR. The modified transtibial and AM portal techniques created more oblique tunnels than the transtibial technique did. These findings contribute to a better understanding of the factors influencing revision ACLR outcomes and provide a foundation for future research in this area.

Ethics Committee Approval: The İstanbul University Ethics Committee granted approval for this study (date: 23/12/2024, number: 3078390).

Informed Consent: Written informed consent was obtained from patients who participated in this study.

Conflict of Interest: The authors have no conflict of interest to declare.

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