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Graft position in arthroscopic anterior cruciate ligament reconstruction: anteromedial versus transtibial technique

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Abstract
Introduction When treating anterior cruciate ligament (ACL) injuries, the position of the ACL graft plays a key role in regaining postoperative knee function and physiologic kinematics. In this study, we aimed to compare graft angle, graft position in tibial tunnel, and tibial and femoral tunnel positions in patients operated with anteromedial (AM) and transtibial (TT) methods to those of contralateral healthy knees.
Materials and methods Forty-eight patients who underwent arthroscopic ACL reconstruction with ipsilateral hamstring tendon autograft were included. Of these, 23 and 25 were treated by AM and TT techniques, respectively. MRI was performed at 18.4 and 19.7 months postoperatively in AM and TT groups. Graft angles, graft positions in the tibial tunnel and alignment of tibial and femoral tunnels were noted and compared in these two groups. The sagittal graft insertion tibia midpoint distance (SGON) has been used for evaluation of graft position in tunnel.
Results Sagittal ACL graft angles in operated and healthy knees of AM patients were 57.78° and 46.80° ($p < 0.01$). With respect to TT patients, ACL graft angle was 58.87° and 70.04° on sagittal and frontal planes in operated knees versus 47.38° and 61.82° in healthy knees ($p < 0.001$). ACL graft angle was significantly different between the groups on both sagittal and frontal planes ($p < 0.001$). Sagittal graft insertion tibia midpoint distance ratio was 0.51 and 0.48 % in the operated and healthy knees of AM group ($p < 0.001$) and 0.51 and 0.48 % in TT group ($p < 0.001$). Sagittal tibial tunnel midpoint distance ratio did not differ from sagittal graft insertion tibia midpoint distance of healthy knees in either group. Femoral tunnel clock position was better in AM [right knee 10:19 o'clock-face position (310° ± 4°); left knee 1:40 (50° ± 3°)] compared with TT group [right knee 10:48 (324° ± 5°); left knee 1:04 (32° ± 4°)]. With respect to the sagittal plane, the anterior–posterior position of femoral tunnel was better in AM patients. Lysholm scores and range of motion of operated knees in the AM and TT groups showed no significant difference ($p > 0.05$).
Conclusions Precise reconstruction on sagittal plane cannot be obtained with either AM or TT technique. However, AM technique is superior to TT technique in terms of anatomical graft positioning. Posterior-placed grafts in tibial tunnel prevent ACL reconstruction, although tibial tunnel is drilled on sagittal plane.

Keywords Anterior cruciate ligament reconstruction · Anteromedial technique · Lysholm scoring · Single-bundle ACL reconstruction · Tibial tunnel

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Introduction

The position of the anterior cruciate ligament (ACL) graft plays a key role in regaining knee function and physiologic kinematics postoperatively [1, 2]. Negative effects of sagittal and frontal plane vertical ACL graft angles have been reported on functional outcomes [3–6]. Both the anteroposterior and rotational stabilities of horizontal grafts were found to be superior to those of vertical grafts [1, 7–9]. Anatomically placed tunnels seemed to restore normal knee kinematics better in cadaveric and clinical studies [10]. Transtibial (TT) and anteromedial (AM) techniques, postoperative tunnel positions and graft angles in ACL reconstruction surgery have been studied in the relevant literature [3, 11, 12]. Their results indicated that ACL grafts are mostly vertical because of the direct relationship between tibial tunnel placement and femoral tunnel position [3].

In recent years, the AM technique has been used to drill the femoral tunnel. Researchers found that horizontally drilled femoral tunnel graft angles are more horizontal when using the AM technique compared to the TT technique [3]. Comparative studies have also reported that the ACL graft angle cannot be fully restored to that observed in healthy knees, regardless of technique [3, 7]. Although several studies have focused on femoral tunnel position, few studies regarding tibial tunnel and graft placement have been reported [4].

The aim of the current study was to compare ACL graft angles, graft placement, and tibial and femoral tunnel positions in knees that were reconstructed using AM and TT techniques and to evaluate the outcome by means of comparing the ACL angles of healthy knees.

Patients and methods

Study groups and design

One hundred and sixteen knees of 58 patients who underwent arthroscopic ACL reconstruction by ipsilateral hamstring tendon graft were examined retrospectively. All surgical procedures were performed by two surgeons [one senior author with more than 15 years of experience with AM technique (MM) and one assistant professor with more than 6 years of experience with TT technique (OG)] using the AM or TT technique between February 2012 and May 2013. Surgical technique (AM or TT) has been chosen depending on surgeons' preference. Of the 58 patients, 28 were operated with the AM technique (AM group), whereas the remaining 30 patients underwent surgery with the TT technique (TT group).

Inclusion criteria were negative Lachman test, negative or +1 positive pivot shift test, and ACL surgery with single-bundle hamstring autograft using the TT or AM technique. Exclusion criteria consisted of previous ACL revision surgery, patients whose measurements could not be taken due to a failed magnetic resonance imaging (MRI) of the ACL graft, patients younger than 18 years and older than 50 years of age, presence of arthrosis signs and symptoms, and bilateral ACL rupture. This study was approved by the Institutional Ethics Committee and conducted in accordance with the latest version of the Helsinki Declaration. All patients were informed of the study and they signed a written informed consent form.

A total of 10 patients were excluded from this study: five patients whose measurements could not be taken, three patients who exhibited osteoarthropathy symptoms and findings and two patients who experienced bilateral ACL injuries. Of the remaining 48 patients, 23 were operated with AAM technique and the remaining 25 with TT technique. A postoperative control MRI was obtained after a mean of 18.4 ± 2.7 months (range 15–24 months) and 19.7 ± 3.6 months (range 15–27 months) for the AM and TT groups, respectively.

Surgical technique

Regardless of the technique, the tibial tunnel was opened with the help of a tibial guide adjusted to 55°. The extra-articular starting point was 1 cm medial to the tuberositas tibiae and 2 cm proximal to the upper rim of the pes anserinus. The intra-articular tibial tunnel was opened to the center of the natural insertion point of the ACL [13]. For the TT technique, femoral tunnels were opened at the 10:30 o'clock position on the right knee and at the 1:30 o'clock position on the left knee. The flexion angle of the knee was approximately 120°–130°, and an intact side of 2 mm was left at the posterior wall. For the AM technique, the anteromedial portal insertion point was defined as 1 cm inferior and medial to the classical anteromedial portal (patellar tendon lateral rim and 0.5–1 cm superior to the joint). With the help of the AM portal, the knee was taken to 130° flexion, and the femoral tunnel was opened to the center of the ACL footprint [14]. Femoral tunnel graft fixation was obtained using an endobutton (Smith & Nephew Endoscopy, Andover, MA, USA) in both techniques. Tibial tunnel fixation was performed with a bioabsorbable grooved screw (Smith & Nephew Endoscopy, Andover, MA, USA), which was placed in the anterior portion of the tibial tunnel using a stapler.

MRI and evaluation

MRI was taken only once for each patient after the operation. MRI was evaluated by three orthopedic surgeons (MHC, AS, and SM) who were blinded to patient groups. All imaging studies were conducted on a 1.5-Tesla MRI device (Sigma HDXT, General Electric, Chicago, IL, USA). A proton-weighted T2 fat-sat-weighted TR2220 TE 20 device was used to take continuous 2.5-mm sections of

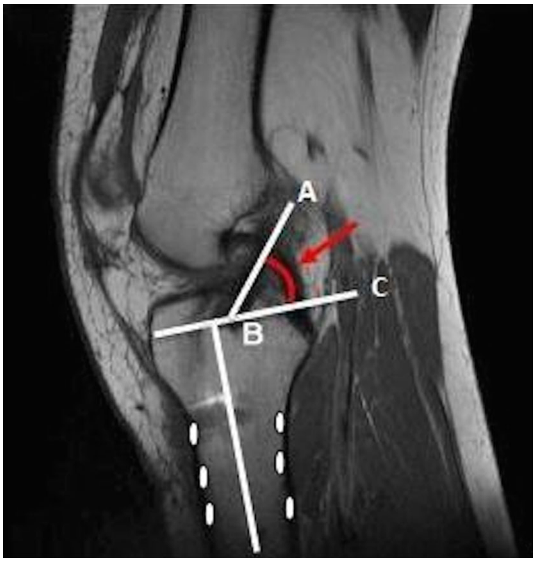

Fig. 1 The sagittal ACL graft angle was described as the angle between the midline of the sagittal plane anterior cruciate ligament graft (*AB*) and the reference *line* perpendicular to the tibial shaft (*BC*). The tibial shaft is parallel to long axis of tibia, and it is the descending line drawn by combining middle points of tibial anteroposterior cortex at visible three levels (*white oval spots*)

Fig. 2 The frontal ACL graft angle was described as the angle between the midline of the frontal plane anterior cruciate ligament graft (*AB*) and the *line* on the tibial plateau (BC)

the sagittal and frontal planes. Axial plane sections were 3.5 mm thick and non-continuous with 1-mm intervals. All MRI scans of operated and healthy knees were performed when the knees were fully extended and at 15° external rotation [11]. Each measurement was taken at the sagittal and frontal planes where the ACL was clearly visible. The picture archiving and communication system (PACS, General Electric, Chicago, IL, US) was used to measure distances and angles and to calculate measurement points. Sagittal and frontal ACL angles were also measured. The sagittal ACL graft angle (SAGA) was described as the angle between the midline of the sagittal plane ACL graft and a reference line perpendicular to the tibial shaft (Fig. 1); this was measured on the midsagittal MRI section. The tibial shaft is parallel to the long axis of tibia. It was the line drawn by combining middle points of tibial anteroposterior cortex at visible three levels (Fig. 1) [11]. The frontal ACL graft angle (FAGA) was described as the angle between the midline of the frontal plane ACL graft and the line on the tibial plateau (Fig. 2).

The location of the tibial tunnel was defined using the method described by Odensten and Gillquist [15]. The ACL tibial tunnel location was measured on both the sagittal and frontal planes. On the frontal plane, the distance of the femoral tunnel midpoint (FTON) was calculated by extending the tibial tunnel central axis to the point at which the tibial plateau and the mediolateral lines crossed. The distance from this crossing point to the tibial medial joint rim was multiplied by 100 and divided by the entire length of the mediolateral tibia, which resulted in a percent value of the mediolateral location (Fig. 3). The sagittal tibial tunnel midpoint distance (STON) was calculated only in operated knees by extending the tibial tunnel central axis to the crossing point of the tibial plateau anteroposterior line. The distance from this crossing point to the tibial anterior joint rim was multiplied by 100 and divided by the anteroposterior length, which resulted in a percent value of the anteroposterior location (Fig. 4).

The sagittal graft insertion tibia midpoint distance (SGON) which is related to graft position in tibial tunnel directly was also measured. The distance between the midline of the sagittal plane ACL graft and the anteroposterior line of the tibial plateau was calculated. The distance between this crossing point and the anterior end of the line was multiplied by 100 and divided by the entire length, which gave a percent value of the anteroposterior location (Fig. 4). The femoral tunnel clock position (FTCP) was measured on an axial-cut MRI scan by use of a modified method described by Rue et al. [16]. The 10:30 o'clock value for the right knee (or 1:30 for the left knee) was assumed to be the targeted femoral tunnel clock position (Fig. 5). The anterior–posterior position of the femoral tunnel (APFT) was measured on a sagittal-cut MRI scan by the modified Bernard method [17].

Comparisons were made between operated and intact knees (within-group comparisons for the same patients), between operated knees of the two study groups (inter-group comparisons), and between the measuring physicians.

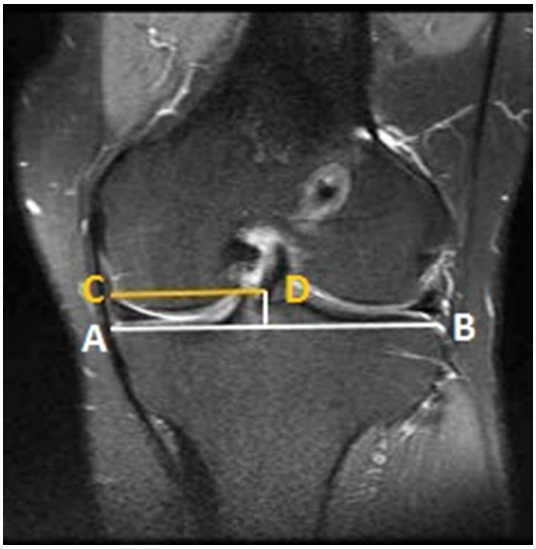

Fig. 3 The tibial tunnel midpoint was calculated by dividing the distance from the medial edge of the tibia to the center of the tibial tunnel (*CD*) by the width of the articular surface of the tibial plateau (*AB*) and multiplying the result by 100

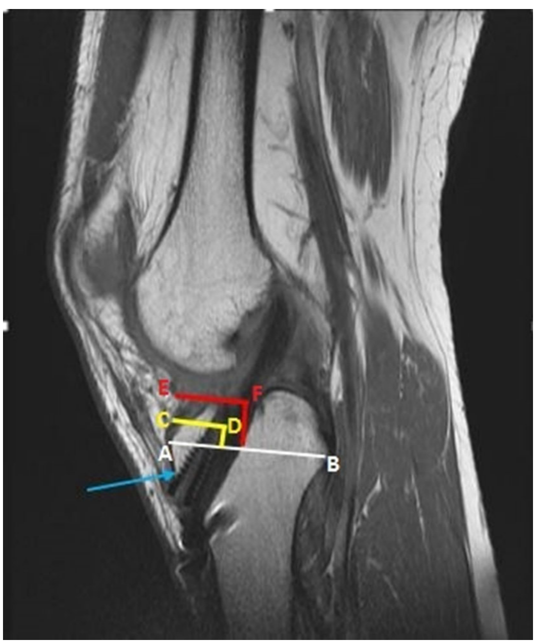

Fig. 4 The sagittal graft insertion tibia midpoint distance was calculated by dividing the distance from the anterior edge of the tibial plateau to the midline of the graft (*EF*) by the distance between the anteroposterior edges of the tibial plateau (*AB*) and multiplying the result by 100. The sagittal tibial tunnel midpoint distance was calculated by dividing the distance from the anterior edge of the tibial plateau to the center of the tibial tunnel (*CD*) by the distance between the anterior–posterior edges of the tibial plateau (*AB*) and multiplying the result by 100. The *blue arrow* denotes the anteriorly placed absorbable screw in the tibial tunnel

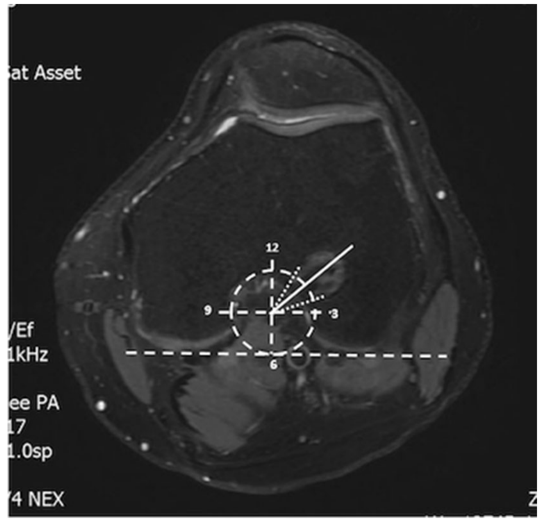

Fig. 5 Femoral tunnel clock position measurement on the axial-cut MRI scan of the right knee

Functional scores

The functional outcome comparison was performed using the range of motion and the Lysholm scoring system, which measures patient activity of daily living on an 8-level scale to produce an overall score on a point scale of 0–100 [14], to compare operated and intact knees in the AM and TT groups at the postoperative follow-up visit. Lysholm scoring was completed by an independent investigator (SC).

Inter-observer variability

Sagittal graft angle, frontal graft angle, sagittal graft insertion tibia midpoint distance, distance of the frontal tibial tunnel midpoint, sagittal tibial tunnel midpoint distance, femoral tunnel clock position, and anterior–posterior position of the femoral tunnel values have been compared between observers in the AAM and TT groups.

Statistical analysis

Comparisons among the measurements performed by three orthopedic surgeons were conducted using one-way analysis of variance (ANOVA) and post hoc Bonferroni tests. Mean differences between study groups were compared using the Wilcoxon test. A comparison of functional outcomes assessed by the Lysholm system was performed using the Mann–Whitney *U* test. All statistical significance levels were adjusted to 95 % confidence intervals, and statistical level of significance was set to $p < 0.05$.

Results

Patients in the AM and TT groups were of similar age and gender profile (mean age 30.9 ± 3.7 years and 31.4 ± 4.1 years; male/female ratio 22/1 and 25/0 in the AM and TT groups, respectively; $p > 0.05$ for both). The operated knee was right-sided in 13 of 23 knees in AM patients and in 16 of 25 knees in TT patients ($p < 0.05$).

Inter-observer variability

There was no significant inter-observer difference in either operated or healthy knees between AM and TT groups ($p > 0.05$ for all variables, Table 1). Similarly, a comparison of the two surgeons who performed the operations demonstrated no significant differences in the number of surgeries or postoperative SAGA, FAGA, STON, SGON, right and left FTCP, or APFT values ($p = 0.109$, $p = 0.214$, $p = 0.301$, $p = 0.238$, $p = 0.438$, $p = 0.342$, and $p = 0.214$, respectively).

Comparison of operated and intact knees

In both the AM and TT groups, SAGA and SGON values were significantly higher in operated knees than contralateral control knees in all measurements taken by three observers ($p < 0.01$ for all variables, Table 1). FAGA, on the other hand, was significantly higher in operated knees than control knees in TT patients, but not in AM patients ($p < 0.01$ for all variables, Table 1). The same results were obtained when the measurements by three observers were averaged; SAGA and SGON values were significantly higher in operated knees in both the AM and TT groups, while FAGA was higher in operated knees in TT patients only (Table 2). Also, the STON values of operated knees were similar to the SGON values of healthy knees in both study groups (Table 3).

Comparison of AAM and TT techniques

A significant difference between the AM and TT groups was revealed with respect to FAGA and SAGA values, but not for those of STON, FTON or SGON (Table 4). FTCP was significantly better in the AM group [right knee 10:19 o'clock-face position (310° ± 4°); left knee 1:40 o'clock-face position (50° ± 3°)] than in the TT group [right knee 10:48 o'clock-face position (324° ± 5°); left knee 1:04 o'clock-face position (32° ± 4°)] (Table 4). APFT was also significantly better in the AM group than in the TT group (70.47 ± 1.26 and 68.67 ± 1.30, respectively; $p < 0.001$) (Table 4). However, there was no significant difference between healthy knees of AM and TT groups in any variable (all $p > 0.05$).

Functional outcomes

Comparison of Lysholm functional scores between groups revealed a significant difference between operated and healthy knees in both the AM and TT groups ($p = 0.03$) (Fig. 6). However, Lysholm scores of operated knees in the AM and TT groups showed no significant difference ($p = 0.07$). Furthermore, Lysholm scores of healthy knees in the AM and TT groups were also comparable ($p = 0.101$). There was no significant difference between AM and TT groups in terms of range of motion (139° ± 8.2° and 138° ± 7.6°, respectively, $p > 0.05$); in other words, tunnel location had no influence on the range of motion of operated knee joints. Postoperative range of motion values also did not show any significant difference between operated and intact knee joints in either AM or TT groups ($p > 0.05$ for both).

Discussion

The most remarkable finding of the present study was that even though TT is more anatomical than AM, the graft is posteriorly placed within the tibial tunnel with TT technique due to anterior location of screw. Thus, AM technique is superior to TT technique in terms of anatomical graft positioning.

MRI is a common radiologic method for ACL imaging. Its sensitivity and specificity in demonstrating ACL pathologies are reported to be 90–94 % and 95–100 %, respectively [18]. A previous study reported that a 1.5-Tesla standard MRI can detect the ACL single-bundle image in the sagittal and coronal planes in 62 % of patients assessed, and can detect the double-bundle image in 38 % of patients [19]. Therefore, we included patients who underwent single-bundle imaging. Various studies have used different techniques to measure tibial tunnel placement and sagittal/frontal plane angles of the reconstructed graft and the intact ACL [3, 11, 12, 20, 21].

Poor clinical outcomes were reported with frontal plane vertical grafts and continuous pivot shift [3, 30]. Some studies reported higher frontal graft angle values in TT grafts compared to AM grafts and healthy knees (i.e., the more horizontal placement may be due to the more lateral placement of the graft with respect to the anatomical insertion point) [3, 11]. In our study, the graft of the TT group in the frontal plane was more vertical than that of both the AM group and healthy knee group. In both techniques, tibial insertion midpoints of the grafts in the frontal plane showed no difference from healthy knees, indicating that the tibial tunnel was drilled in an anatomical location on the frontal plane. In contrast, a

Table 1 Comparison of sagittal graft angle, frontal graft angle, sagittal graft insertion tibia midpoint distance, distance of the frontal tibial tunnel midpoint, sagittal tibial tunnel midpoint distance, femoral tunnel clock position, and anterior–posterior position of the femoral tunnel values between observers, as well as operated and control knees, in the AM and TT groups

	AAM group ($n = 23$)			TT group ($n = 25$)		
	Operated knees	Control knees	*p* value (operated vs. control knees)	Operated knees	Control knees	*p* value (operated vs. control knees)
Sagittal graft angle (°)						
Observer#A	53.22 ± 1.73	46.08 ± 2.28	<0.01	58.21 ± 4.85	46.23 ± 4.86	<0.01
Observer#B	54.46 ± 1.92	47.52 ± 2.38	<0.01	60.99 ± 4.50	49.24 ± 4.18	<0.01
Observer#H	53.65 ± 3.47	46.79 ± 3.07	<0.01	57.42 ± 4.58	46.66 ± 4.68	<0.01
p (between observers)	0.243	0.179		0.21	0.49	
Frontal graft angle (°)						
Observer#1	62.37 ± 1.94	62.12 ± 2.07	0.19	70.51 ± 1.87	62.49 ± 3.79	<0.01
Observer#2	61.09 ± 3.66	61.67 ± 4.19	0.91	69.39 ± 2.80	61.57 ± 3.73	<0.01
Observer#3	61.21 ± 2.97	60.50 ± 4.04	0.22	70.20 ± 4.31	61.40 ± 4.08	<0.01
p (between observers)	0.269	0.288		0.437	0.568	
Sagittal graft insertion tibia midpoint distance (%)						
Observer#1	0.52 ± 0.01	0.49 ± 0.01	<0.01	0.51 ± 0.01	0.49 ± 0.02	0.001
Observer#2	0.51 ± 0.02	0.48 ± 0.03	<0.01	0.52 ± 0.01	0.49 ± 0.02	<0.01
Observer#3	0.52 ± 0.03	0.49 ± 0.02	<0.01	0.52 ± 0.02	0.49 ± 0.02	<0.01
p (between observers)	0.741	0.216		0.255	0.136	
Frontal tibial tunnel midpoint distance (%)						
Observer#1	0.48 ± 0.02	0.48 ± 0.02	0.79	0.48 ± 0.02	0.48 ± 0.03	0.371
Observer#2	0.48 ± 0.02	0.48 ± 0.02	1	0.48 ± 0.02	0.48 ± 0.02	0.089
Observer#3	0.49 ± 0.02	0.48 ± 0.02	0.34	0.49 ± 0.02	0.49 ± 0.03	0.358
p (between observers)	0.155	0.562		0.043	0.104	
Sagittal tibial tunnel midpoint distance (%)						
Observer#1	0.50 ± 0.01	NA	–	0.50 ± 0.02	NA	–
Observer#2	0.48 ± 0.02	NA	–	0.49 ± 0.02	NA	–
Observer#3	0.49 ± 0.02	NA	–	0.49 ± 0.02	NA	–
p (between observers)	0.48	–		0.167	–	
Femoral tunnel clock position (right knee)						
Observer#1	10.22 (311° ± 4°)	NA	–	10.47 (323.5° ± 4°)	NA	–
Observer#2	10.19 (310° ± 5°)	NA	–	10.49 (324.5° ± 6°)	NA	–
Observer#3	10.16 (308° ± 3°)	NA	–	10.47 (323.5° ± 5°)	NA	–
p (between observers)	0.264	–	–	0.654	–	
Femoral tunnel clock position (left knee)						
Observer#1	1.44 (52° ± 2°)	NA	–	1.05 (32.5° ± 5°)	NA	–
Observer#2	1.29 (45° ± 3°)	NA	–	1.04 (32° ± 3°)	NA	–
Observer#3	1.44 (52° ± 4°)	NA	–	1.03 (31.5° ± 4°)	NA	–
p (between observers)	0.462	–		0.255	–	
Anterior–posterior position of the femoral tunnel (%)						
Observer#1	69.11 ± 1.08	NA	–	70.60 ± 1.80	NA	–
Observer#2	68.48 ± 1.92	NA	–	70.62 ± 1.52	NA	–
Observer#3	68.42 ± 1.68	NA	–	70.20 ± 1.37	NA	–
p (between observers)	0.274	–		0.561	–	

AAM anatomical anteromedial, *TT* transtibial, *NA* not applicable

more vertical location of the graft on the frontal plane in the TT group resulted from a lack of anatomic location of the femoral tunnel. However, the indifference between operated and healthy knees on the frontal plane in the AM group suggests that both femoral and tibial tunnels were drilled in anatomic locations.

Table 2 Comparison of sagittal graft angle, frontal graft angle, sagittal graft insertion tibia midpoint distance and distance of the frontal tibial tunnel midpoint values between operated and healthy knees of AAM and TT groups

	AAM Group ($n = 23$)			TT Group ($n = 25$)		
	Operated knees	Control knees	p value	Operated knees	Control knees	p value
Sagittal graft angle (°)	57.78	46.80	<0.001	58.87	47.38	<0.001
Frontal graft angle (°)	61.56	61.43	0.235	70.04	61.82	<0.001
Sagittal graft insertion tibia midpoint distance (%)	0.51	0.48	<0.001	0.51	0.48	<0.001
Frontal tibial tunnel midpoint distance (%)	0.49	0.48	0.409	0.49	0.48	0.156

Data are presented as the mean measurements from three observers

AAM anatomical anteromedial, *TT* transtibial

Table 3 Comparison of sagittal tibial tunnel midpoint distance values in operated knees and sagittal graft insertion tibia midpoint distance values in healthy knees in both groups

	Sagittal tibial tunnel midpoint distance (%) in operated knees	Sagittal graft insertion tibia midpoint distance (%) in control knees	p value
AAM Group ($n = 23$)	0.49 ± 0.01	0.49 ± 0.02	0.675
TT Group ($n = 25$)	0.49 ± 0.01	0.49 ± 0.01	0.934

AAM anatomical anteromedial, *TT* transtibial

Table 4 Comparison of sagittal graft angle, frontal graft angle, sagittal graft insertion tibia midpoint distance, sagittal tibial tunnel midpoint distance, distance of the frontal tibial tunnel midpoint, femoral tunnel clock position, and anterior–posterior position of the femoral tunnel values of operated knees among the study groups

	AAM group ($n = 23$)	TT group ($n = 25$)	p value
Sagittal graft angle (°)	57.78 ± 1.87	58.87 ± 4.33	<0.001
Frontal graft angle (°)	61.56 ± 2.07	70.04 ± 2.32	<0.001
Sagittal graft insertion tibia midpoint distance (%)	0.51 ± 0.02	0.52 ± 0.01	0.602
Sagittal tibial tunnel midpoint distance (%)	0.49 ± 0.01	0.49 ± 0.01	0.572
Frontal tibial tunnel midpoint distance (%)	0.49 ± 0.01	0.49 ± 0.01	0.150
Femoral tunnel clock position in clock-face position (angle)			
Right knee	10:19 (310° ± 4°)	10:48 (324° ± 5°)	0.001
Left knee	1:40 (50° ± 3°)	1:04 (32° ± 4°)	0.007
Anterior–posterior position of the femoral tunnel (%)	70.47 ± 1.26	68.67 ± 1.30	<0.001

AAM anatomical anteromedial, *TT* transtibial

Although the central axis of the tibial tunnel overlapped with the natural ACL insertion point, the graft location was more vertical on both sagittal and frontal planes in TT patients, but only on the sagittal plane in AM patients. The ACL graft was determined to be more horizontal than in the TT technique in both planes. The reason for the vertical location of the ACL graft in the TT group in both planes is the non-anatomic location of the femoral tunnel. However, the vertical location of the ACL graft on the sagittal plane in the AM group suggests only a posterior placement of the graft within the tibial tunnel, which was drilled in an anatomic location [22]. Therefore, the location of the drill channel is more anatomic in AM technique than TT technique.

Sagittal graft angle and sagittal graft insertion tibia midpoint distance values were higher in TT patients than in those with healthy knees [11, 31]. This could be explained by a more posterior tibial insertion point of the graft with respect to the natural ACL. Another study reported higher sagittal graft angle values in AM and TT grafts than in healthy knees [3]. We found that in the sagittal plane, ACL grafts operated by the AM technique were more vertical than those of healthy knees, but less vertical than grafts operated by the TT technique (i.e., TT provided more vertical grafts). The location of the tibial tunnel was anatomic on the frontal and sagittal planes with both techniques. However, higher frontal and sagittal graft angles

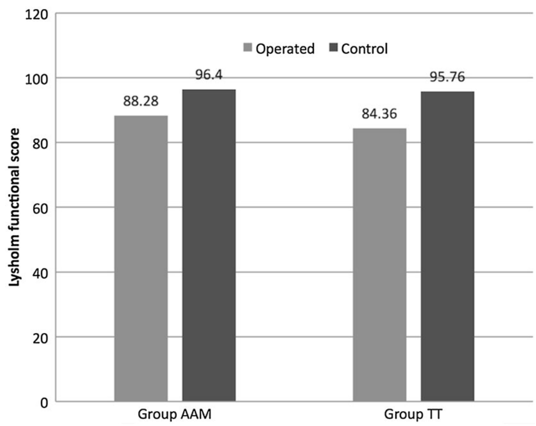

Fig. 6 Lysholm functional scores of operated and contralateral healthy knees in the transtibial (TT) and anteromedial (AM) groups

relative to healthy knees suggest that both ACL tibial insertion point and femoral tunnel were not anatomic in the TT group. On the other hand, anatomical graft angle on the frontal plane with a higher angle on the sagittal plane in the AM group indicates that the femoral tunnel was drilled in an anatomic location on the frontal plane, while the sagittal insertion point of the graft was located more posteriorly than the anatomical insertion point with the AM technique. Posterior graft placement with the AM technique also explains the anteriorly placed screw within the tibial tunnel despite its anatomic location (Fig. 4).

The importance of natural ACL angles in sagittal and frontal planes and femoral and tibial footprints in ACL reconstruction surgery has been demonstrated previously [23]. To prevent excess stretching and loosening of the reconstructed graft, anatomical placement of both the sagittal and coronal angles, as well as the tunnel, is important. Cadaveric and in vivo studies have shown that ACL reconstruction points should be close to the natural ligament insertion points, which positively affect knee kinematics and clinical outcomes [8, 24–27]. Our finding of an insignificant difference between the sagittal tibial tunnel midpoint distance of operated knees and the sagittal graft insertion tibia midpoint distance of healthy knees in both the AM and TT groups indicates drilling of the tibial tunnel on the sagittal plane.

Obtaining an ideal femoral tunnel placement with the TT technique is difficult, because the tibial tunnel should be opened before the femoral tunnel. The tibial tunnel should be opened anteriorly and in a horizontal plane [10, 28]. A more vertical graft has been reported to result from anterior placement of the femoral tunnel [12]. Comparative studies have shown that a posterior femoral tunnel obtained with the AM technique can lead to a more horizontal graft in the sagittal plane than with the TT technique [1, 6, 29]. These results suggest that the difference in frontal graft angle values stems from the femoral tunnel. Indeed, previous studies have reported that the femoral tunnel angle of the frontal plane in the AM technique was significantly more horizontal compared to the TT technique [1, 3]. Similarly, we found that both femoral tunnel clock position and anterior–posterior position of the femoral tunnel were significantly better in the AM group than the TT group, indicating a more anatomic location of the femoral tunnel with the AM technique.

More vertical ACL grafts lead to significantly worse pivot shift, KT-1000 measurement and Lysholm scores compared to horizontal grafts [12, 32, 33]. In our study, the functional outcomes of operated knees were significantly worse than those of healthy knees. However, no statistically significant difference was detected in the functional results, i.e., range of motion and Lysholm scores of the AM and TT groups.

In the relevant literature, the femoral tunnel exit in outside-in technique was located more anterior and proximal; femoral graft bending angle of AMB in outside-in technique was greater than that in transportal technique [34]. Femoral tunnel length was found to be a clue for intraoperative evaluation of the femoral tunnel position [35]. Lee et al. postulated that conventional transtibial drilling technique used during double-bundle ACL reconstruction does not reproduce correct tunnel locations, and this problem may be associated with the bony geometry of the medial wall of the lateral femoral condyle or the bone bridge between the two tibial tunnels [36]. The main limitations of this study were its retrospective nature and small sample size. In addition, MRI is not as sensitive as three-dimensional computed tomography in evaluating bone tunnels, which can result in improved visualization. However, MRI was chosen to prevent radiation exposure. Moreover, we assumed that the ACL is a single-bundle ligament; but in fact, it is a double-bundle ligament. Furthermore, ACL femoral insertion point in healthy knees could not be evaluated. In addition, in spite of evidence on the relation between tunnel position and stability [12, 32], we did not evaluate the location of the tunnel in relation to any stability tests, i.e., KT-1000. However, all of the patients had negative Lachman test. It should also be noted that surgical technique (AM or TT) that has been chosen depending on surgeons' preference might produce a bias in our study, which is compensated by the fact that each surgeon only performs one singular procedure. Finally, absence of control values for functional scores and MRI should be mentioned as a limitation of this study design.

In conclusion, precise anatomic reconstruction was not obtained on the sagittal plane using either of the techniques, and functional results of the AM and TT reconstruction techniques were similar. Posterior placement of the graft in the tibial tunnel is important for ACL reconstruction, although the tibial tunnel has an anatomical position on the sagittal plane. In other words, even though TT is more anatomical than AM, the graft is posteriorly placed within the tibial tunnel with TT technique due to anterior location of screw. Thus, the most remarkable conclusion of the present study is that AM technique is superior to TT technique in terms of anatomical graft positioning. Future studies will highlight the importance of the position of ACL reconstruction grafts in the tibial tunnel, as well as that of anatomical tibial tunnel placement.

Compliance with ethical standards

Conflicts of interest The authors declare no conflicts of interest.

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