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Lateral posterior tibial slope correlates with tibial and femoral tunnel widening after anatomical reconstruction of anterior cruciate ligament using autologous quadrupled-hamstring tendons, A CT study

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Abstract

In the present study, we aimed to determine the risk factors predicting femoral and/or tibial tunnel widening after single-bundle anatomical anterior cruciate ligament reconstruction using hamstring autograft and to investigate the effect of tunnel widening on clinical outcomes. Forty-two patients who underwent single-bundle anterior cruciate ligament reconstruction using hamstring autograft between the dates of November 2011 and June 2020 and met the inclusion criteria of the study were retrospectively reviewed. The amount of tunnel widening was obtained by finding the difference between the measurements made by examining the oblique-coronal and oblique-sagittal reconstruction sections in the computed tomography taken one year after the surgery and the diameter of the drill bit used in the surgery. The patients were divided into two groups as those with tunnel widening (>0.5 mm) and those without tunnel widening (≤ 0.5 mm). The factors that may cause tunnel widening were evaluated separately. International Knee Documentation Committee (IKDC) subjective knee form and Tegner activity scores were used in the clinical evaluation. According to the multivariate regression analysis performed, lateral posterior tibial slope was seen to be a good predictor of femoral and tibial tunnel widening. In the receiver operating characteristic (ROC) analysis, it was determined that lateral posterior tibial slope, especially above 6°, significantly affected both femoral and tibial tunnel widening after anterior cruciate ligament reconstruction. The present study showed that increased lateral posterior tibial slope was an independent factor predicting tibial and femoral tunnel widening following single-bundle anatomical anterior cruciate ligament reconstruction using hamstring autograft, but these tunnel widenings had no significant effect on clinical outcomes.

Keywords: Tunnel widening, lateral posterior tibial slope, anterior cruciate ligament

Introduction

Bone tunnel widening can be seen in all graft types and fixation methods used in anterior cruciate ligament reconstruction (ACLR). Tunnel widening (TW) that develops after ACLR using autologous hamstring tendon grafts is caused by many etiological factors. Although the precise etiology is not known, studies are divided into two main groups as mechanical and biological factors. Mechanical factors include knee anatomy which varies with gender and from individual to individual, motion of the graft within the tunnel, fixation methods and materials, inappropriate graft placement, and accelerated rehabilitation.

In studies regarding the development and timing of TW, it has been shown that TW increases in the first three months following the surgical procedure, continues to increase at a slower pace between three months and one year, and decreases after the first year [1]. Although there is not yet a standard approach for the evaluation of TW, computed tomography (CT) is considered to be the most appropriate method for measuring tunnel width [2]. Ito and Tanaka suggested that CT assessment is an indicator showing the TW accurately. Because they noted that the tunnel does not enlarge in an oval shape everywhere and there may also be irregular widenings. For this reason, they argued that direct graphy would be insufficient [3].

CITATION
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The reason for the majority of malpractice accusations that have increased in recent years is that patients are not adequately informed before the surgery [4]. Failures arising from the anatomy and biology of the patient can be attributed to the physician by the patient. Our hypothesis in the present study is that high lateral posterior tibial slope (LPTS) resulting from patient anatomy are more effective than other surgical factors in TW seen after ACLR. The aim of our study was to determine the independent risk factors predicting tibial tunnel widening (TTW) and/or femoral tunnel widening (FTW), and to investigate the effect of TW on clinical outcomes by analyzing CT scans taken at the postoperative one-year follow-up in patients who underwent anatomical ACLR using hamstring autograft.

Material and Methods

Patients were evaluated retrospectively after approval was obtained from the Gaziosmanpaşa University Clinical Research Ethics Committee (Decision No: 21-KAEK-117, date: 29/04/2021). The study was conducted under the principles of the Declaration of Helsinki.

The patients who underwent single-bundle arthroscopic ACLR with a quadrupled hamstring tendon autograft in Tokat Gaziosmanpaşa University Faculty of Medicine Orthopedics and Traumatology Clinic between November 2011 and June 2020 were retrospectively scanned. Verbal and written informed consent was obtained from the patients who agreed to participate in the study.

The patients medical records were retrieved from our hospital automation system (ENLIL), and radiological images were collected from the picture archiving and communication system (PACS) (sectra Workstation ids7 v23.2.2.5087, ©2021 sectra ab).

The patients with a history of rheumatological and neurological disease, previous knee dislocation, tibia eminence fracture, tibia plateau fracture, multiple ligament injury, any other history of surgery in the same knee, congenital deformities, anterior cruciate ligament (ACL) revision surgery, as well as those whose medical information was not reachable, who were followed less than one year postoperatively and did not have knee CT at the last follow-up were not included in the study.

The operations were performed in a single center by two different surgeons.

No gold standard method is available in terms of detecting TW. It has been reported that the measurement of bone tunnels by roentgenography may lead to an underestimation of the true diameter of the TW [5]. CT scans have been recommended for the assessment of the size of the bone tunnels [6]; accordingly, we used CT in our study.

Despite no consensus in the literature regarding the development and timing of TW, most of the studies have indicated that the fastest development of TW occurs in the first three months after the surgical procedure, the increase continues at slower pace between three months and one year and decreases after one year [1]. Hence, the patients were evaluated by CT at one year after ACLR in our study.

LPTS measurements were performed from the preoperative magnetic resonance imaging (MRI) examinations based on the approach suggested by Hudek et al. [7] (Figure 1). By creating oblique coronal (OC) and oblique sagittal (OS) sections from CT scans, the final diameter of the section in which the tunnels were seen the widest were measured from six different points according to the method described previously in the literature [8] (Figure 2).The preoperative and postoperative International Knee Documentation Committee scale as well as pre-trauma, post-trauma and postoperative Tegner activity score were used for clinical evaluation.

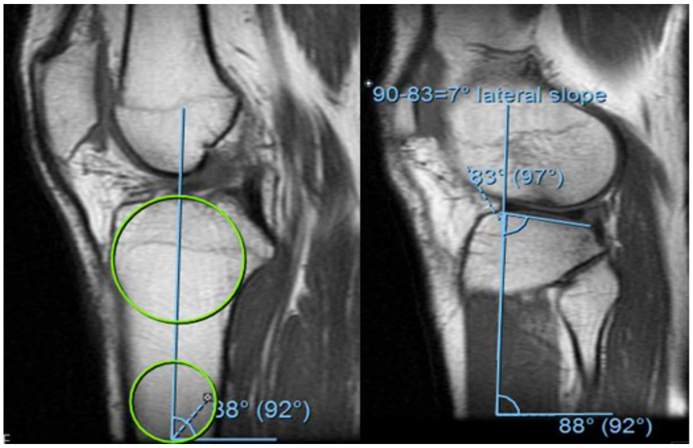

Figure 1. Measurement of LPTS in MRI

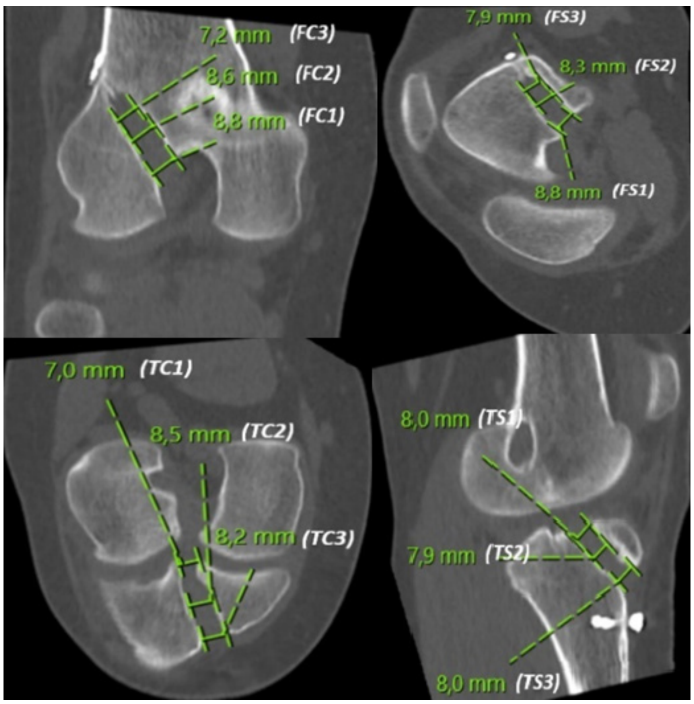

Figure 2. Measurement of tunnel diameter in CT imaging

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Radiological Evaluation

To standardize the femoral and tibial tunnel diameter measurements, they were performed from three different points by creating OC and OS sections in CT examinations using the MPR mode of the imaging system according to the method as previously described and used in the literature [8] (Figure 2).

These points are as follows;

- FC1 (The tunnel diameter at the starting point of the femoral tunnel in the OC plane)
- FC2 (The tunnel diameter at the midpoint of the femoral tunnel in the OC plane)
- FC3 (The tunnel diameter at the end point of the femoral tunnel in the OC plane)
- FS1 (The tunnel diameter at the starting point of the femoral tunnel in the OS plane)
- FS2 (The tunnel diameter at the midpoint of the femoral tunnel in the OS plane)
- FS3 (The tunnel diameter at the end point of the femoral tunnel in the OS plane)
- TC1 (The tunnel diameter at the starting point of the tibial tunnel in the OC plane)
- TC2 (The tunnel diameter at the midpoint of the tibial tunnel in the OC plane)
- TC3 (The tunnel diameter at the end point of the tibial tunnel in the OC plane)
- TS1 (The tunnel diameter at the starting point of the tibial tunnel in the OS plane)
- TS2 (The tunnel diameter at the midpoint of the tibial tunnel in the OS plane)
- TS3 (The tunnel diameter at the end point of the tibial tunnel in the OS plane)

The differences between the measured tunnel widths and the bit diameter of the drill used to open the femoral and tibial tunnel noted during the surgery were detected and recorded. According to these differences, the patients were evaluated as no widening (≤0.5 mm), borderline widening (0.5-≤2.5 mm), significant widening (2.5-≤4.5 mm), excessive widening (>4.5 mm). Afterwards, the patients were grouped as those with (>0.5 mm) and those without tunnel widening (≤0.5 mm) (Table 1).

The radiological measurements were separately performed by two different researchers (one of the researchers made two measurements one month apart).

Intraobserver and interobserver reliability was very strongly correlated with the femoral tunnel and strongly correlated with the tibial tunnel. All measurements within themselves showed a very strong relationship. There was no statistically significant difference between the measurement points in the widening zones in the tunnels.

Table 1. FTW and TTW quantity (numerical data using six different references)

using FC1 as the FTW (mm)	**0-0.5**	15	35.7%
	0.51-2.5	20	47.6%
	2.51-4.5	7	16.7%
	>4.5	0	0%
using FC2 as the FTW (mm)	**0-0.5**	20	47.6%
	0.51-2.5	15	35.7%
	2.51-4.5	6	14.3%
	>4.5	1	2.4%
using FC3 as the FTW (mm)	**0-0.5**	18	42.9%
	0.51-2.5	22	52.4%
	2.51-4.5	1	2.4%
	>4.5	1	2.4%
using FS1 as the FTW (mm)	**0-0.5**	17	40.5%
	0.51-2.5	20	47.6%
	2.51-4.5	4	9.5%
	>4.5	1	2.4%
using FS2 as the FTW (mm)	**0-0.5**	18	42.9%
	0.51-2.5	18	42.9%
	2.51-4.5	5	11.9%
	>4.5	1	2.4%
using FS3 as the FTW (mm)	**0-0.5**	21	50%
	0.51-2.5	20	47.6%
	2.51-4.5	0	0%
	>4.5	1	2.4%
using TC1 as the TTW (mm)	**0-0.5**	9	21.4
	0.51-2.5	24	57.1
	2.51-4.5	7	16.7
	>4.5	2	4.8
using TC2 as the TTW (mm)	**0-0.5**	7	16.7%
	0.51-2.5	25	59.5%
	2.51-4.5	8	19%
	>4.5	2	4.8%
using TC3 as the TTW (mm)	**0-0.5**	11	26.2%
	0.51-2.5	21	50%
	2.51-4.5	10	23.8%
	>4.5	0	0%
using TS1 as the TTW (mm)	**0-0.5**	11	26.2%
	0.51-2.5	22	52.4%
	2.51-4.5	6	14.3%
	>4.5	3	7.1%
using TS2 as the TTW (mm)	**0-0.5**	9	21.4%
	0.51-2.5	18	42.9%
	2.51-4.5	13	31%
	>4.5	2	4.8%
using TS3 as the TTW (mm)	**0-0.5**	9	21.4%
	0.51-2.5	22	52.4%
	2.51-4.5	11	26.2%
	>4.5	0	0%

Statistical Analysis

Descriptive analyses were conducted to provide information about the general characteristics of the study groups. The data for continuous variables are presented as mean±standard deviation, and the data for categorical variables are presented as n (%). In

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making comparisons between the groups in terms of the means of quantitative variables, the student t test for significance of difference between two means and one-way analysis of variance were employed. Contingency tables and chi-square tests were utilized to assess whether there existed a relationship between qualitative variables. The p-values less than 0.05 were regarded as statistically significant. The SPSS software package (IBM SPSS Statistics 19, SPSS Inc., IBM Co., Somers, NY) was used for the statistical analysis of the data.

The differences between groups in terms of sociodemographic, clinical and radiological criteria were compared using univariate analyses. Multivariate regression analysis was performed to reveal which of the preoperative demographic factors were independent risk factors for the TTW and FTW.

Results

The records of 218 patients who underwent arthroscopic ACLR with quadrupled hamstring tendon autograft between November 2011 and June 2020 were reached. 42 patients who met the inclusion criteria and had a CT scan at the last follow-up were received for evaluation.

Femoral tunnel widening was observed in 64.3% of the patients when FC1 was used in the evaluation of FTW, 52.4% when FC2 was used, 57.1% when FC3 was used, 59.4% when FS1 was used, 57.1% when FS2 was used, and 50% when FS3 was used. Tibial tunnel widening was seen in 78.6 % of the patients when TC1 was used in the evaluation of TTW, 83.3% when TC2 was used, 73.8% when TC3 was used, 73.8% when TS1 was used, 78.6% when TS2 was used, and 78.6% when TS3 was used.

Examining the distribution of the LPTS variable by gender s showed that LPTS was 9.1º±3.96 in females and 7.06º±3.81 in males.

There was no statistically significant difference between the measurement points in which we evaluated the widening in the tunnels. For this reason, to evaluate the distribution of FTW based on; the qualitative and quantitative variables (Table 2,3), IKDC and Tegner scores, the tables using FS3 as the widening variable were included since the group without enlargement (50%) and the group with enlargement (50%) showed an equal distribution at FS3.

Table 2. Distribution of FTW variable by qualitative variables using FS3

According to FS3		FTW		X^2	p
		No (n=21)	With (n=21)		
Gender	**Female**	5	5	0.000	>0.999
	Male	16	16		
Meniscal injury	**No**	8	9	1.092	0.779*
	Medial	7	5		
	Lateral	3	2		
	Medial and lateral	3	5		
Meniscal repair	**No**	8	9	0.618	0.734*
	Partial menisectomy	5	3		
	Repair	8	9		
Using FAMP	**Using**	3	7	2.100	0.147
	No	18	14		
Femoral fixation	**FCLB**	10	14	1.556	0.212
	ACLB	11	7		
Physical therapy program	**Accelerated physical therapy program**	8	10	0.389	0.553
	Normal physical therapy program	13	11		

Pearson Chi-square was built, *Fisher-Freeman-Halton was made

Table 3. Distribution of FTW variable by quantitative variable using FS3

Variables	FTW		p
	No (n=21)	With (n=21)	
Age	37.5±11.89	32.3±9.02	0.119
FTL (mm)	39.5±6.19	39.9±3.89	0.812
GPTL (mm)	30.1±4.96	29.81±4.30	0.843
LPTS (°)	6.0±4.01	9.1±3.16	0.008*
BMI (kg/m²)	27.3±1.87	25.9±2.90	0.079

Mann Whitney U. *Student T tested.

There was no statistically significant difference between the measurement points in which we evaluated the widening in the tunnels. Thus, in order to evaluate the distribution of TTW based on; the qualitative and quantitative variables (Table 4,5), IKDC and Tegner scores, since none of the measurement points showed an equal distribution in terms of the group with widening and the group without widening, the tables using TC1 as the widening variable were included in the paper, because TC1 was the one with the highest standard deviation (1.42) among all measurement points.

Table 4. Distribution of TTW variable by qualitative variables using FS3

According toTC1		TTW		X^2	p
		No (n:9)	With (n:33)		
Gender	**Female**	1	9	1.018	0.313*
	Male	8	24		
Meniscal injury	**No**	4	13	3.243	0.356**
	Medial	4	8		
	Lateral	1	4		
	Medial and lateral	0	8		
Meniscal repair	**No**	4	13	0.468	0.791**
	Partial menisectomy	1	7		
	Repair	4	13		
Using FAMP	**Using**	0	10	3.580	0.058*
	No	9	23		
Femoral fixation	**FCLB**	3	21	2.652	0.103*
	ACLB	6	12		
Physical therapy program	**Accelerated physical therapy program**	3	15	0.424	0.515*
	Normal physical therapy program	6	18		

Pearson Chi-square was built, * Fisher Exact test was performed, **Fisher-Freeman-Halton was made

Table 5. Distribution of TTW variable by quantitative variable using FS3

Variables	TTW		p
	No (n=9)	With (n=33)	
Age	30.8±6.45	36.0±11.48	0.202
FTL (mm)	39.3±9.26	39.8±3.45	0.780
GPTL (mm)	30.5±5.92	29.7±4.25	0.662
LPTS (°)	4.6±3.61	8.3±3.64	0.010*
BMI (kg/m2)	26.8±1.72	26.6±2.70	0.797

Mann Whitney U, *Student T was tested

No significant difference was detected between male and female genders in terms of FTW (Table 2).

LPTS values of the patients with FTW were higher than those of the patients without widening, and the difference was found to be statistically significant (Table 3).

The mean LPTS value of the patients whose FTW was found using FS3 was 9.1º±3.16, while that of the patients without FTW was 6º±4.01 (p=0.008) (Table 3).

When the mean of six values measured for FTW was used, the mean LPTS value was 8.62º±3.53 in the patients with FTW and 5.81º±3.94 in the patients without FTW (p=0.02).

The variables with p<0.25 in the distribution of the FTW variable based on the quantitative and qualitative variables using FS3 were determined as candidate variables for the multivariate model. Thus, the use of the far anteromedial portal (FAMP), femoral fixation system, age, body mass index (BMI) and LPTS variables were included in the multivariate regression model (Table 6).

Table 6. FTW's multiple logistical regression results using FS3

Variables	Univariant				Multi-variant			
	p	Odds ratio	95% confidence interval		p	Odds ratio	95% confidence interval	
			Lower	Upper			Lower	Upper
Using FAMP	0.157	0.333	0.073	1.527	0.158	0.215	0.026	1.816
Femoral fixation system (ALCB)	0.215	0.455	0.131	1.583	0.201	0.315	0.053	1.851
Age	0.124	0.952	0.895	1.013	0.106	0.932	0.857	1.015
BMI (kg/m²)	0.088	0.785	0.595	1.037	0.057	0.722	0.517	1.010
LPTS (°)	0.016	1.278	1.046	1.561	0.013	1.372	1.069	1.761

According to the multiple logistic regression results of FTW obtained by using FS3, when LPTS increased by one unit, the presence of FTW was 1.372 times more likely than its absence, and the statistical analysis revealed that this difference was significant (p=0.013) (Table 6).

The difference between male and female genders in terms of TTW was not statistically significant (Table 4).

It was detected that LPTS values of the group with TTW were significantly higher than those of the group without widening (Table 5).

When TC1 was used to determine TTW, the mean LPTS value of the patients with TTW (8.3º±3.64) was significantly higher thanthat of the patients without TTW (4.6º±3.61). This (p=0.01) (Table 5).

When using the mean of six values measured for TTW, the mean LPTS value was 8.37º±3.51 in the patients with TTW and 3.43º±3.21 in the patients without TTW (p=0.001).

The variables with p<0.25 in the distribution of the TTW variable based on the quantitative and qualitative variables using TC1 were determined as candidate variables for the multivariate model. Accordingly, the use of the FAMP, femoral fixation system, age, BMI, LPTS variables were included in the multivariate regression model (Table 7).

According to the multiple logistic regression results of TTW obtained by using TC1, when LPTS increased by one unit, the presence of TTW was 1.525 times more likely than its absence, and the difference was found to be statistically significant (p=0.013) (Table 7).

Table 7. TTW's multiple logistical regression results using FS3

Variables	Univariant				Multi-variant			
	p	Odds ratio	95% confidence interval		p	Odds ratio	95% confidence interval	
			Lower	Upper			Lower	Upper
Using FAMP	0.999	0.000	0.000	0.000	0.999	0.000	0.000	0.000
Femoral fixation system (ALCB)	0.115	0.286	0.060	1.355	0.159	0.209	0.024	1.847
Age	0.204	1.055	0.971	1.146	0.142	1.104	0.967	1.260
LPTS (°)	0.291	0.632	0.270	1.480	0.013	1.525	1.094	2.125

The ROC analysis performed on FTW data indicated that when LPTS≥6º, LPTS was able to predict FTW with 84% sensitivity and 50% specificity (p=0.049) (Figure 3).

In the ROC analysis conducted for TTW results, LPTS predicted TTW with 82% sensitivity, 85% specificity and with an area under the curve value of 0.8449 in the case of LPTS ≥6º (p≤0.001) (Figure 4).

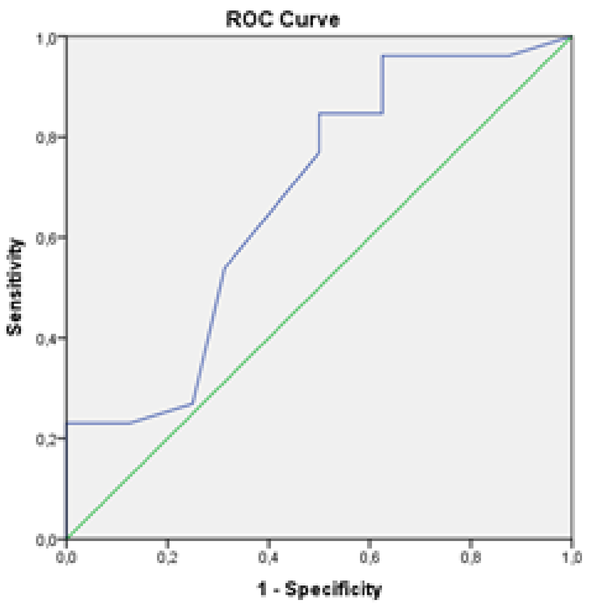

Figure 3. The ROC analysis performed on FTW data indicated that when LPTS ≥6º, LPTS was able to predict FTW with 84% sensitivity and 50% specificity (p=0.049)

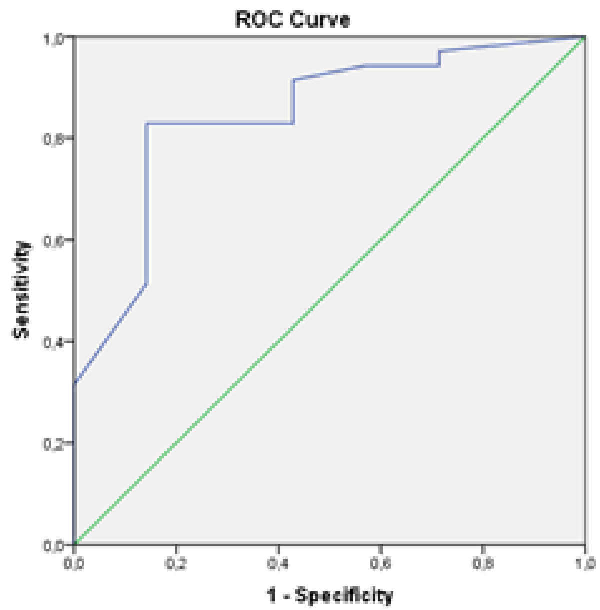

Figure 4. In the ROC analysis conducted for TTW results, LPTS predicted TTW with 82% sensitivity, 85% specificity and with an area under the curve value of 0.8449 in the case of LPTS≥6º (p≤0.001)

As seen in Table 8; when the pre- and postoperative clinical outcomes were compared, a significant improvement was observed in both groups regardless of whether the patients had FTW and TTW. It was detected that TW had no significant effect on the clinical conditions of the patients.

It was observed that the presence of TW had no significant effect on the clinic of the patients as a consequence of the evaluation of Tegner activity and IKDC evaluation results, determined in our last examination.

Table 8. Comparison of TW with preoperative and postoperative tegner scoring using FS3 and TC1

Variables	FTW		TTW	
	No median	With median	No median	With median
Pre-traumatic tegner scores	7 [6-7]	7 [7-7]	7 [4-7]	7 [7-7]
Post-traumatic tegner scores	1 [1-4]	1 [1-4]	1 [1-4]	1 [1-4]
Postop tegner scores	6 [4-7]	7 [6-7]	6 [4-7]	7 [5-7]
p	<0.001	<0.001	0.001	<0.001

The Friedman test was used

The relationships between LPTS degrees and TW are shown in Figures 5 and 6.

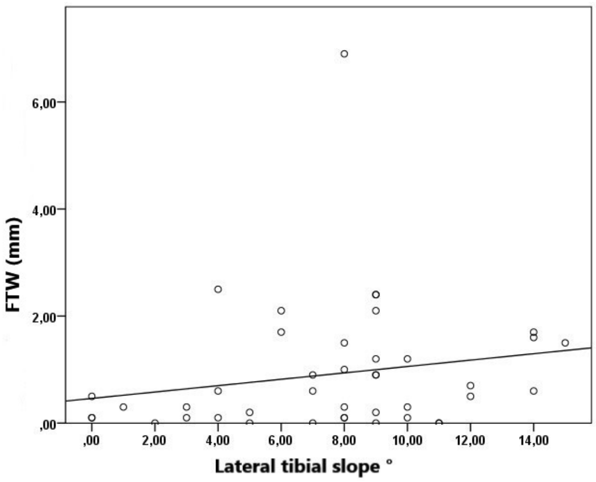

Figure 5. Scatter chart for two variables (LPTS vs. FTW positive correlation, r=0.275)

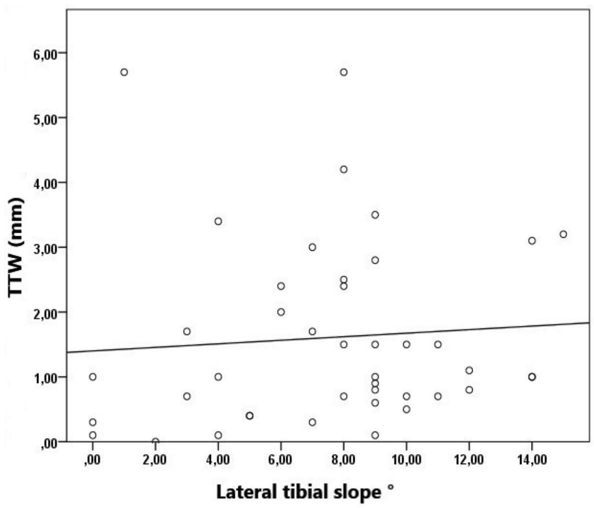

Figure 6. Scatter chart of two variables (LPTS vs. TTW positive correlation, r=0.212)

Discussion

It is considered that tunnel widening after ACLR is affected by many factors. In our study, the multivariate analysis we performed showed that LPTS is related to TW after ACLR. Besides, the cutoff value was detected to be 6° in the ROC analysis Since high LPTS values are effective in the occurrence of both TTW and FTW, the surgeon should pay more attention to LPTS in the preoperative evaluation of patients who will undergo ACLR.

Increased LPTS is also associated with increased inner rotation shearing force in the tibia, in addition to the anteroposterior instability of the knee joint [9]. There is a strong linear relationship between graft loading after ACLR and tibial slope [10]. Osteotomies applied towards increasing the posterior tibial slope increase the risk of ACL rupture by causing anterior tibial translation. An LPTS higher than 10° may lead to anterior translation of the tibia greater than 6 mm [11]. The study conducted by Yoon et al reported that, the LPTS angle being higher than 3.8° was associated with a higher failure rate in at least 10 years of follow-up after primary ACL using hamstring autografts [12]. Grassi et al. [13] emphasized that patients with LPTS values higher than 7.4° are at high risk for ACLR failure, and that LPTS should be measured by surgeons before surgery. Webb et al. [14] asserted that LPTS values of higher than 12° are highly associated with TW and consequent graft failure after ACLR. Salmon et al. [15] evaluated the long-term results of 200 patients who underwent ACLR with hamstring autograft and showed that there was eleven times more TW in patients with a tibial slope of higher than 12°. Because of all these reasons, corrective osteotomies may be required when planning ACLR for patients with increased values of LPTS. Considering the results we obtained, since LPTS of 6° or higher is linearly related to TTW and FTW, we think that the measurement of LPTS would be beneficial in terms of planning osteotomy that may be required before ACLR surgery to reduce LPTS and predicting postoperative results.

In the present study, LPTS was more commonly observed in women. Although TTW was proportionally higher in women, this difference between the sexes was not significant.

It is still unclear whether TW is associated with postoperative posterior knee laxity. We determined that the difference was not significant in terms of Tegner activity and IKDC results between the patients with TW and those without TW. We reached a conclusion that TW did not affect the clinic, which is in line with the literature [16,17].

The limitations of our study are that it is a retrospective study, two different surgeons performed the operations, and the number of patients is relatively small. However, our study has shown that it has advantages such as long follow-up period and functional results being evaluated by two independent evaluators.

Conclusion

In our study, LPTS in patients with TW was found to be significantly higher than those in patients without TW. We found the cutoff value of LPTS related to TW as 6°. An LPTS greater than 6° could predict both FTW and TTW with high sensitivity and specificity, and was positively correlated with both. We have seen that LPTS is higher in women than in men, so we recommend being more careful in terms of TW in female patients. Since the possibility of TW is high in cases with LPTS above 6°, the patient should be informed about this situation in the preoperative period. More attention should be paid to LPTS in the preoperative evaluation of patients who will undergo ACLR, and osteotomies that reduce LPTS should be included in the planning, if necessary. FTW and TTW were found to be ineffective in functional scoring in which the clinical status of patients was evaluated after surgery.

Conflict of Interests
The authors declare that there is no conflict of interest in the study.

Financial Disclosure
The authors declare that they have received no financial support for the study.

Ethical Approval
Tokat Gaziosmanpaşa University Faculty of Medicine Clinical Research Ethics Committee 21-KAEK-117, date 29/04/2021.

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