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Risk-factor analysis of the proximal tibia morphology for secondary ipsilateral injury after anterior cruciate ligament reconstruction

A retrospective cross-sectional study

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Abstract

Many studies have reported the risk factors associated with primary anterior cruciate ligament (ACL) injury. However, few studies have focused on the bony morphology of secondary ipsilateral injury after ACL reconstruction. This study aimed to investigate the morphological risk factors of the proximal tibia contributing to secondary ipsilateral injury after ACL reconstruction. Twenty patients who were selected from secondary ipsilateral injury after ACL reconstruction between January 2015 and May 2020 were included in the secondary injury group. They were matched in a 1:2 ratio to the control group, which underwent primary ACL reconstruction during the same period and did not experience reinjury at the minimum 2-year follow-up, based on age, gender, and body mass index. All parameters, including medial tibial posterior slope, lateral tibial posterior slope (LTPS), medial tibial plateau depth, and lateral tibial plateau height, were recorded by using magnetic resonance imaging. Binary logistic regression analysis and receiver operator characteristic curves were conducted to explore the risk factors for reinjury and determine the cutoff value for the significant parameter. The LTPS was significantly larger in the secondary injury group than in the control group (9.6 ± 1.5° to 7.0 ± 1.4°, $P < .001$), and there was no significant difference in the medial tibial posterior slope, medial tibial posterior slope, and lateral tibial plateau height between the 2 groups ($P > .05$). The LTPS was found to be an independent risk factor for secondary ipsilateral injury after ACL reconstruction (odds ratio = 3.220, 95% confidence interval = 1.904–5.446, $P < .001$). The cutoff value of the LTPS was 8.8°, with a sensitivity of 91.7% and a specificity of 81.2%. The LTPS could be a unique predictor of secondary ipsilateral injury after ACL reconstruction. Orthopedists should implement effective measurements during primary reconstruction when the LTPS is >8.8°.

Abbreviations: ACL = anterior cruciate ligament, AUC = area under the curve, BMI = body mass index, CIs = confidence intervals, DICOM = digital imaging and communications in medicine, ICCs = intraclass correlation coefficients, LTPH = lateral tibial plateau height, LTPS = lateral tibial posterior slope, MRI = magnetic resonance imaging, MTPD = medial tibial plateau depth, MTPS = medial tibial posterior slope, ORs = odds ratios, ROC = receiver operating characteristic.

Keywords: anterior cruciate ligament reconstruction, injury, morphology, risk-factor, tibia

1. Introduction

Anterior cruciate ligament (ACL) rupture is a common sport injury in the knee, affecting over 120,000 individuals annually in the United State.[1] Despite the widespread practice of arthroscopic ACL reconstruction, the incidence of revision rate is as high as 3% to 7%.[2,3] In adolescents and young adults, there is a high rate of secondary ipsilateral injury after primary ACL reconstruction.[4–6] Previous studies have identified low (<47.1) and high (>87.9) scores on the ACL-return to sport after injury scale, overweight [body mass index (BMI) > 25.4 kg/m^2], lower hamstring asymmetry (<3.3%), return to sport <9 months as risk factors for secondary ACL injury in young athletes.[7–10] Patients experiencing secondary ipsilateral injury after ACL reconstruction may suffer from a diminished health-related quality of life.[11] Exploring risk factors for secondary ipsilateral injury after ACL reconstruction holds paramount importance in preventing and treating reinjury. Many studies have shown that the primary ACL injury is significantly related to bony morphology of

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

All procedures were performed in accordance with the Declaration of Helsinki. This retrospective study was approved by the Ethical Committee of the Fengfeng General Hospital of North China Medical & Health Group (File No. 2023B05). Informed consent was obtained from all participants.

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the knee joint.[12–18] However, the correlation between proximal tibia morphology and secondary ipsilateral injury after ACL reconstruction is not clear. This study aimed to explore the morphological risk factors of the proximal tibia for secondary ipsilateral injury after ACL reconstruction using primary magnetic resonance imaging (MRI). We hypothesized that the medial tibial posterior slope (MTPS), lateral tibial posterior slope (LTPS), medial tibial plateau depth (MTPD), and lateral tibial plateau height (LTPH) are potential risk factors associated with secondary ipsilateral injury after ACL reconstruction.

2. Materials and methods

2.1. Patients

The institutional review board approved this study, and informed consent was obtained from all participants before their inclusion in the study.

Between January 2015 and May 2020, patients with secondary ipsilateral injuries after ACL reconstruction at our hospital underwent a retrospective cross-sectional review. Inclusion criteria were: patients with an acute ACL injury (undergoing the primary operation within 2 weeks after ACL injury); and patients with confirmed secondary ipsilateral injury after ACL reconstruction through MR images and arthroscopy. Exclusion criteria were: patients lacking availability of primary MR images; patients with allogeneic or artificial ligaments; patients with a significant deviation of the femoral or tibial tunnel; knee trauma potentially affecting normal bone morphology; and other conditions influencing the recognition of knee bone morphology. According to the previous study by Christensen et al,[13] the sample size was estimated using Pass software (15.0.5, NCSS, LLC, Kaysville, UT), with an 80% power and 5% alpha. The minimum required sample size were 21 patients in secondary injury group and 43 patients in control group. Following a review of the medical records, 24 patients with secondary ipsilateral injuries after ACL reconstruction were included in the secondary injury group. These patients were matched in a 1:2 ratio to control patients who were confirmed to have undergone primary ACL reconstruction in our hospital during the same period without reinjury at the minimum 2-year follow-up. The patients were matched by age, gender, and BMI from the patient pool of our hospital. Figure 1 illustrates the flowchart of patient enrollment. Table 1 presents the demographic characteristics.

2.2. Data collection and MRI evaluations

Patient-related characteristics, including age, gender, height, BMI, and ACL-related details, were collected from the patient electronic medical record.

All MRI examinations were performed using a 1.5-T scanner (Siemens, Erlangen, Germany) without the use of contrast. The measured parameters were all evaluated on MR images with the patient supine and the knees in full extension. Accurate MR images in digital imaging and communications in medicine (DICOM) format were acquired using the RadiAnt DICOM Viewer software (version 21.2 Medixant, Poznan, Poland). Both groups underwent measurements of the following MR images: MTPS, LTPS, MTPD, and LTPH.

Figure 2 shows the measurements of the parameters in the MR images. The medial and lateral tibial posterior slopes were measured following the method described by Hudek et al.[19] We drew 2 circles tangent to the proximal tibial cortex, and the line connecting the centers of the 2 circles determined the longitudinal axis of the tibia and marked it as straight line L. Then, we selected the mid-sagittal planes of the medial and lateral tibial plateaus, respectively, and took the perpendicular to the longitudinal axis of the tibia (line L) as the straight line P, and the inclusive angle between the tangent line A, which is the most superior anterior and posterior cortex edges of the medial bony plateau, and the straight line P was the MTPS. The inclusive angle between the tangent line B, which is the most superior anterior and posterior cortex edge of the lateral bony plateau, and the straight line P is the LTPS. The distance from the lowest anteroposterior point of the medial tibial plateau to the tangent line A is the MTPD.[14,20] The distance from the highest anteroposterior point of the lateral tibial plateau to the tangent line B is the LTPH.[15,21] Two experienced orthopedists, with 8 and 10 years of clinical experience, respectively, conducted the measurements on RadiAnt DICOM Viewer while being blinded to any clinical information. Each parameter was measured twice, with a minimum 2-week interval.

2.3. Statistical analysis

Statistical analysis was conducted using IBM SPSS Statistics Version 29.0.1 (SPSS, Chicago, IL). Statistical significance was set at $P < .05$. The obtained test results were reported as the mean ± standard deviation. The Kolmogorov–Smirnov normality test was used to analyze the normality of data distribution. Based on the statistical distribution, the Mann–Whitney *U* test and the independent-samples *T* test were used for comparison of all continuous variables, including age, height, BMI,

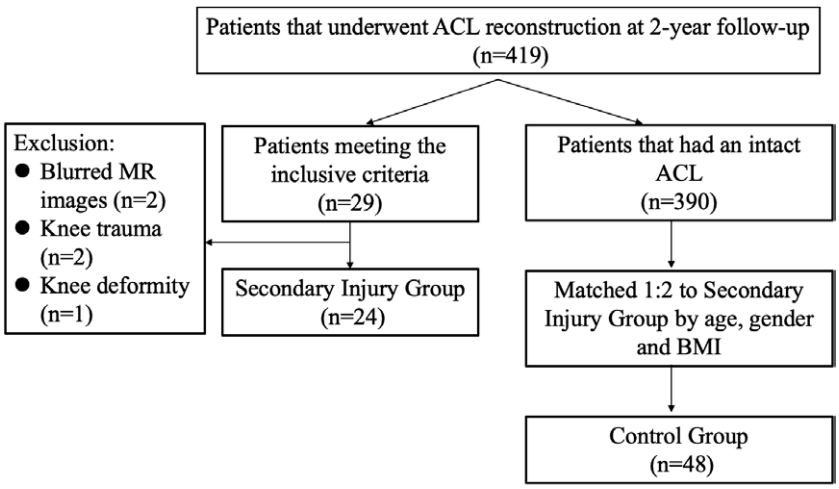

Figure 1. Flowchart of patients enrollment. ACL = anterior cruciate ligament, BMI = body mass index.

MTPS, LTPS, MTPD, and LTPH between patients in the secondary injury group and the control group. The chi-square test was used for comparison of categorical variables, including gender, between patients in the 2 groups. Relationships between secondary ipsilateral injury after ACL reconstruction and potential risk factors, including MTPS, LTPS, MTPD, and LTPH, were evaluated using binary logistic regression analysis. Odds ratios (ORs) and their 95% confidence intervals (CIs) were reported accordingly. Threshold points for each statistically significant parameter were determined by the receiver operating characteristic (ROC) curve and the area under the curve (AUC). The cutoff value was determined from the point with the maximal Youden index, representing the highest sum of sensitivity and specificity. The power of each statistically significant parameter was analyzed in Pass software (15.0.5, NCSS, LLC, Kaysville, UT). Intraobserver and interobserver reliabilities were assessed through intraclass correlation coefficients (ICCs).

3. Results

All MR parameters measured in the 2 groups are summarized in Table 2. Comparing the analysis of patients in the secondary injury group and the control groups, we observed a statistically significant difference ($P < .05$) in LTPS. The mean LTPS was 9.6 ± 1.5° for patients in the secondary injury group, which was significantly steeper than those (7.0 ± 1.4°) of patients in the control group ($P < .001$). At an $\alpha < 0.05$, the powers of the LTPS was 99%. We also found similar means for MTPS, MTPD and LTPH (4.5 ± 0.7°, 3.0 ± 0.5 mm, 5.1 ± 0.6 mm, respectively) in patients in the secondary injury group compared those (4.4 ± 0.6°, 3.0 ± 0.4 mm, 5.0 ± 0.5 mm, respectively) for patients in the control group. However, the MTPS, MTPD, and LTPH did not show statistically significant differences between the 2 groups ($P > .05$).

The binary logistic regression analysis of the factors, including MTPS, LTPS, MTPD, and LTPH, are presented in Figure 3. The LTPS was identified as an independent risk factor for secondary ipsilateral injury after ACL reconstruction (OR = 3.220, 95% CI = 1.904–5.446, $P < .001$). The ROC curve analysis of LTPS resulted in an AUC of 0.863, with a cutoff value setting at 8.8° (Youden index 0.729), yielding a sensitivity of 91.7% and a specificity of 81.2% for predicting secondary ipsilateral injury after ACL reconstruction (Fig. 4).

The parameter results within and between the groups are reliable, with ICCs values ranging between 0.752 and 0.856.

4. Discussion

The key finding of this study was the identification of LTPS as an independent risk factor for secondary ipsilateral injury after ACL reconstruction. The odds ratio (OR = 3.220, 95% CI = 1.904–5.446) and the cutoff value (8.8°) of the LTPS demonstrated that patients suffer 3.22-fold increase in secondary ipsilateral injury after primary ACL reconstruction for each 1° increase in LTPS beyond 8.8°. However, no significant differences were found in MTPS, MTPD, or LTPH between patients in the 2 groups in this study ($P > .05$). Additionally, the MTPS, MTPD, and LTPH were not risk factors for secondary ipsilateral injury after ACL reconstruction in this study ($P > .05$).

Previous studies have reported that a large posterior slope of the lateral tibia is a risk factor for primary ACL injury.[16–18] A possible explanation for this risk factor is that a the larger LTPS leads to a greater rotation tendency of the tibia and femur during knee joint movement, causing the ACL to bear greater forward pulling force and rotational shear force, which can lead to ACL injury and knee joint instability.[12] However, even if ACL reconstruction restores knee joint stability, a larger LTPS during knee joint movement increases the likelihood of anterior tibial movement, potentially resulting in secondary ipsilateral injury. Marouan et al[22] explained the correlation between increased tibial posterior slope and ACL injury from a biomechanical perspective. They reported that for every 5° increase in tibial posterior slope, the tension of the ACL will increase by 135 N. Joshua et al reported that an increased LTPS (OR = 1.2, 95% CI = 1.0–1.5, $P = .018$) is associated with an increased risk of early ACL graft failure, aligning with our findings.[13] Ye et al[18] reported that a steep lateral tibial slope measured on MRI is the best radiological predictor of ACL reconstruction failure, with

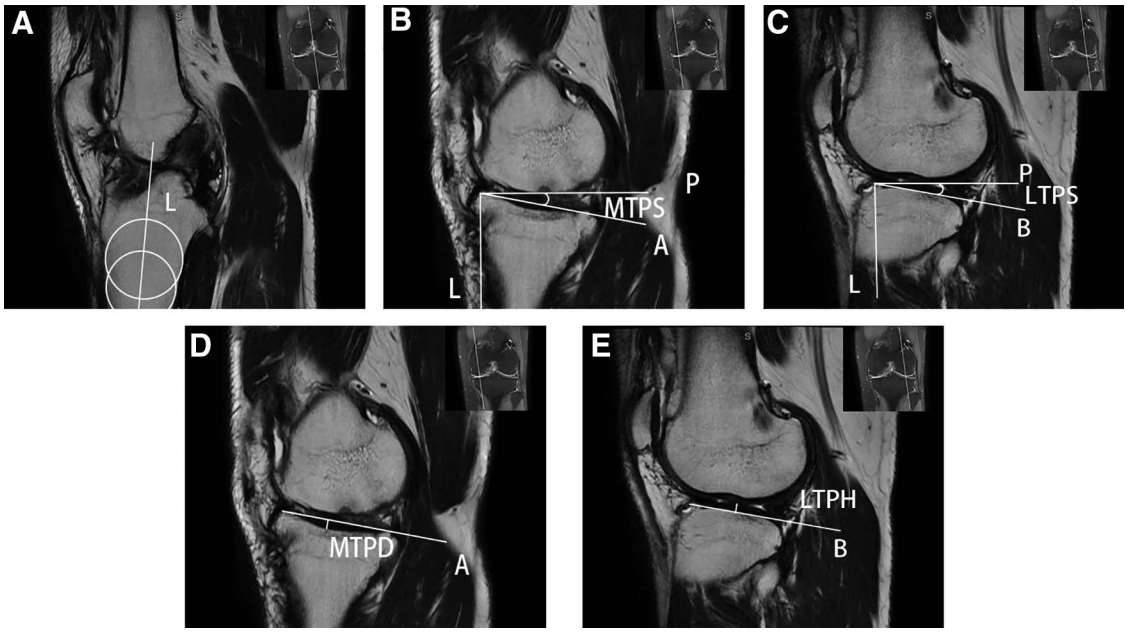

Figure 2. MRI parameters measured for evaluation of the proximal tibia morphology. (A) The way to locate the longitudinal tibial axis. (B–E) Measurements of the MTPS, LTPS, MTPD, and LTPH. LTPH = lateral tibial plateau height, LTPS = lateral tibial posterior slope, MRI = magnetic resonance imaging, MTPD = medial tibial plateau depth, MTPS = medial tibial posterior slope.

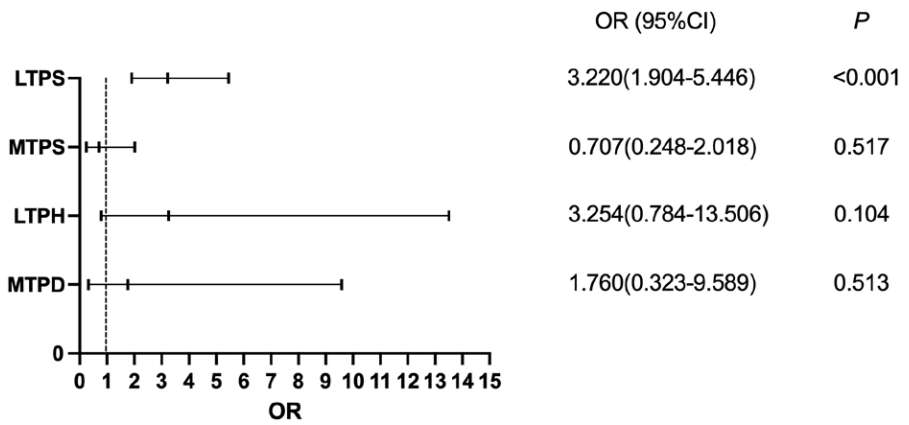

Figure 3. Binary logistic regression analysis of relationship of the factors with secondary ipsilateral injury after ACL reconstruction. ACL = anterior cruciate ligament, CI = confidence interval, LTPH = lateral tibial plateau height, LTPS = lateral tibial posterior slope, MTPD = medial tibial plateau depth, MTPS = medial tibial posterior slope, OR = odds ratio,

Table 1

Demographic characteristics of the subjects.

	Secondary injury group (n = 24)	Control group (n = 48)	*P* value
Age, yr	26.3 ± 3.9	27.4 ± 4.5	.314*
Gender, male/female	17/7	32/16	.721†
Height, cm	173.8 ± 6.0	172.8 ± 6.6	.544*
Weight, kg	74.2 ± 4.6	74.7 ± 5.7	.698*
BMI, kg/m^2	24.6 ± 1.2	25.0 ± 1.5	.204*

Data were presented as n or mean ± standard deviation. Significance was calculated using a 2-tailed.

*Two independent-samples *t* tests and

†Chi-square test.

Table 2

Comparison of each measurement between groups.

Variable	Secondary injury group (n = 24)	Control group (n = 48)	*P* value
MTPS, °	4.5 ± 0.7	4.4 ± 0.6	.976‡
LTPS, °	9.6 ± 1.5	7.0 ± 1.4	<.001‡,*
MTPD, mm	3.0 ± 0.5	3.0 ± 0.4	.687†
LTPH, mm	5.1 ± 0.6	5.0 ± 0.5	.399†

All data were presented as mean ± standard deviation. Significance was calculated using a 2-tailed.

†Two independent-samples *t* tests.

‡Mann–Whitney *U* test.

*Significant difference.

a cutoff value setting at 7.7°, yielding a sensitivity of 85.7% and specificity of 80.4%, similar to our study. Digiacomo et al[23] investigated the bony morphology of the knee in patients who experienced a secondary ipsilateral ACL injury (n = 14) compared to patients who underwent primary reconstruction but did not experience reinjury (n = 14). However, the authors found no difference in LTPS between the 2 groups. A possible explanation for the difference compared to our study is that they may not have included enough subjects, potentially introducing a selection bias. In our study, an increased LTPS emerged as a risk factor for secondary ipsilateral injury after ACL reconstruction, underscoring the significance of proximal tibia morphology in the mechanisms of ACL reinjury.

There is no consensus on the conclusion regarding whether increased MTPS is a risk factor for ACL injury.[17,24] Grassi et al reported that MTPS was a risk factor associated with primary graft failure.[17] However, Ziegler et al[24] found that there was no statistically significant difference in MTPS between the primary ACL reconstruction group and the revision group (4.7 ± 3.3° and 5.6 ± 3.8°, *P* = .1177). Kumar Panigrahi et al[16] reported that a steep MTPS was found in ACL injury subjects compared to control subjects with statistical significance (6.41 ± 2.66° to 5.95 ± 3.09°, *P* = .27), similar to our results. This study demonstrates that increased MPTS is not a risk factor for secondary injury after ACL reconstruction, although the MPTS in the secondary injury group was steeper than that in controls without statistical significance.

We did not find significant differences in MTPD and LTPH between patients in the 2 groups in this study. Hashemi et al[14] investigated MTPD in 2 groups including uninjured controls and ACL-injured cases. They found that shallow MTPD was a risk factor for ACL injuries (OR = 3.03, 95% CI = 1.78–5.26). Digiacomo et al[23] investigated MTPD among secondary ipsilateral injury after ACL reconstruction group, primary ACL reconstruction without reinjury group, and healthy controls. The authors found no difference in MTPD between all ACL patients and controls, or between the secondary ipsilateral injury after ACL reconstruction group and the primary ACL reconstruction without reinjury group (*P* > .05), similar with our results. Hodel et al reported that LTPH is a risk factor for ACL reinjury (OR = 3.75, 95% CI = 2.90–4.30),[15] however, they did not find a significant difference between the secondary injury and control groups.

This study had several limitations. First, this was a retrospective study conducted in a single center, which could introduce an inevitable selection bias. Second, parameter measurements are subject to the subjective opinions of observers; even though we obtained reliable ICCs values, the completely elimination of bias is challenging. Third, while all patients were required to adhere to standard rehabilitation guidelines in our hospital, variance in postoperative rehabilitation and the timing of return to sports may have contributed to ACL reinjury. Furthermore, the average age and the gender distribution of the participants could limit the generalizability of our results to older and female populations. Further multicenter research and a larger sample size are needed in the future to confirm these results.

5. Conclusion

This study established that an increased LTPS is linked to secondary ipsilateral injury after ACL reconstruction. LTPS is an independent risk factor for secondary ipsilateral injuries after ACL

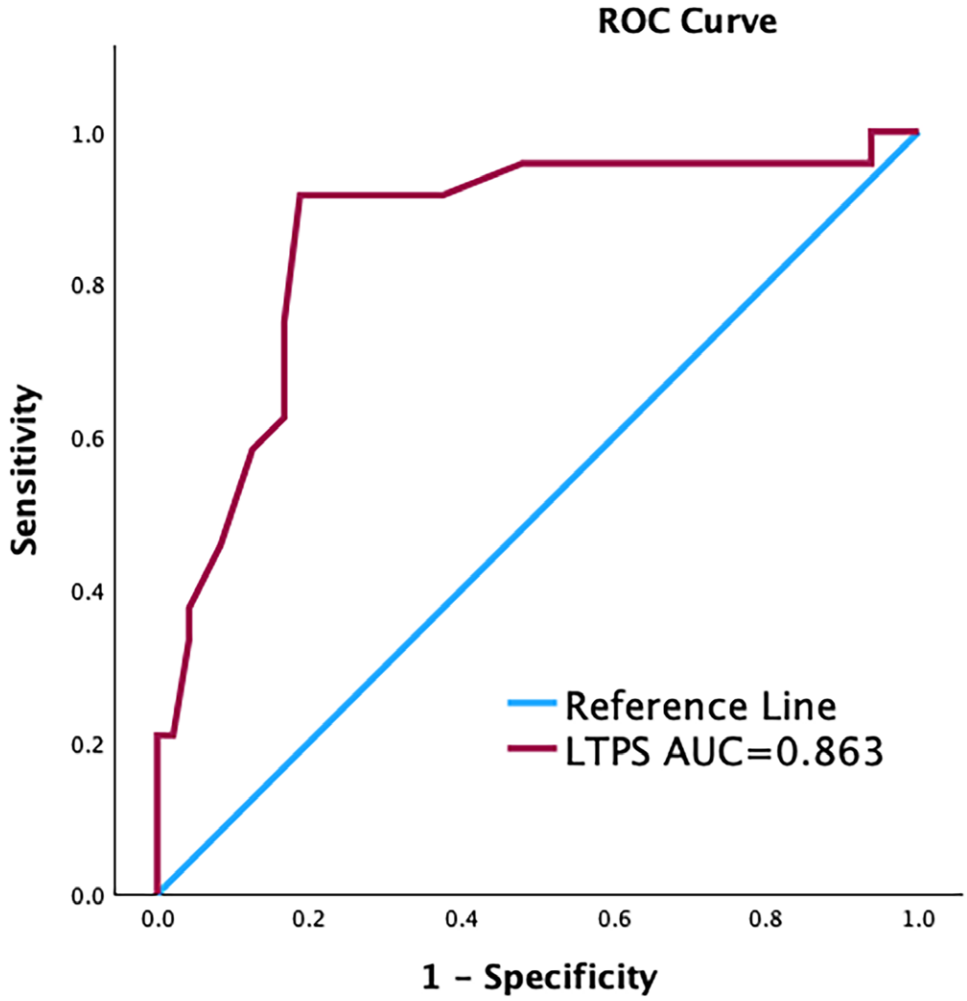

Figure 4. The receiver operating characteristic curve of lateral tibial posterior slope. AUC = area under the curve, LTPS = lateral tibial posterior slope, ROC = receiver operating characteristic.

reconstruction. Orthopedists should take effective measures in primary reconstruction when the LTPS is larger than 8.8°.

Author contributions

Conceptualization: Wei Liu, Shoujiang Han.
Data curation: Bin Wang, Zhiwei Feng.
Formal analysis: Wei Liu, He Zhang, Zhiguang Zhao.
Investigation: Wei Liu, He Zhang.
Methodology: Wei Liu, Bin Wang, Shoujiang Han.
Software: Zhiguang Zhao.
Writing – original draft: Wei Liu, Bin Wang, Zhiwei Feng, Shoujiang Han.
Writing – review & editing: Wei Liu, Bin Wang, Zhiwei Feng, Shoujiang Han.

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