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Research Article

The Posterior Tibial Slope as a Factor in Functional Outcomes and Tunnel Widening Following Revision ACL Reconstruction

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Abstract

Introduction: Anterior cruciate ligament (ACL) injuries are prevalent in sports, with revision surgeries often required due to graft failure. While several factors contribute to these failures, the role of the posterior tibial slope (PTS) in both functional outcomes and tunnel widening following ACL reconstruction has gained increasing attention. This study investigates the influence of the PTS on these outcomes in patients who underwent revision ACL reconstruction.

Methods: A retrospective cohort study was conducted with 96 patients who received revision ACL reconstructions between 2010 and 2022. Patients were categorized based on their PTS into two groups: those with a PTS greater than 10 degrees and those with a PTS less than 10 degrees. Functional outcomes were assessed using the Lysholm score, while tunnel widening was evaluated through radiographic measurements of the femoral and tibial tunnels. Statistical analysis was performed using unpaired t-tests to compare both functional outcomes and tunnel widening between the two groups.

Results: The Lysholm score in patients with a PTS greater than 10 degrees was significantly lower (mean: 79) compared to those with a PTS less than 10 degrees (mean: 89), with a p-value of <0.0001. However, no significant difference was observed in tunnel widening between the two groups across femoral and tibial measurements. The mean difference in tunnel widening was similar for both groups, suggesting that PTS has limited influence on tunnel widening after revision ACL reconstruction.

Discussion: While a steeper PTS is associated with poorer functional outcomes, particularly as measured by the Lysholm score, it does not appear to significantly affect tunnel widening in revision ACL surgeries. This suggests that the influence of PTS on functional outcomes may be more biomechanical than structural. Future research should explore the interplay between PTS and graft stability to further optimize surgical outcomes.

Keywords: *Anterior Cruciate Ligament (ACL); Posterior Tibial Slope (PTS); Medial Posterior Tibial Slope (MPTS); Patient-Reported Outcome Measures (PROMs)*

Introduction

Anterior cruciate ligament injuries are among the most common in sports traumatology, with approximately 130,000 surgical procedures performed annually in the USA and 3,000 to 10,000 revisions each [1-3]. The rupture of the ACL is a long-term health issue, often leading to knee osteoarthritis, especially when combined with a meniscal lesion [3]. Besides medical concerns, ACL ruptures incur significant costs, estimated at around $38,000 for individuals undergoing reconstruction and $88,500 for those undergoing rehabilitation [3].

Although the ACL is extensively researched, uncertainties and technical difficulties remain regarding its reconstruction. Consequently, modern ACL reconstruction continues to have failure rates of up to 13% [3].

Failures in ACL reconstruction are commonly due to multiple factors (35%), trauma (32%), technical errors (24%), and biological issues (7%) [4]. Despite this, many technical errors are avoidable, such as tunnel misplacement, fixation issues, and failure to correct malalignment and ligament injuries, which account for 53 - 79% of primary ACL graft failures [4-6]. Historically, patient-related factors were often overlooked in ACL re-tear research, but recent studies have begun focusing on neuromuscular control, age, sex, and activity levels [5]. A deeper understanding of patient-related factors can improve patient outcomes and communication. Additionally, addressing modifiable factors can help reduce re-tear rates and enhance postoperative prevention programs.

One modifiable patient-related factor is the posterior tibial slope, which is defined as the angle between a line tangent to the lateral tibial plateau and a line perpendicular to the longitudinal axis of the tibia [6].

Traditionally, a posterior tibial slope greater than 12 degrees has been used as the threshold for considering slope-modifying proximal tibial osteotomies. This benchmark is based on the study by Webb., *et al*. [7], which found that patients with a slope greater than 12 had an Odds Ratio (OR) of 5 compared to controls in a prospective randomized study. Consequently, this value has become widely accepted in the literature for determining when to perform slope-correcting proximal tibial osteotomies in cases of secondary cruciate ligament ruptures. However, other studies have reported various cut-off values ranging from 8 to 17 degrees [8-13], indicating some variation and ongoing debate in the field regarding the optimal threshold.

Dracic., *et al*. found that a group of ACL re-ruptures had a 11.29 times higher risk of having a PTS value of more than 10 compared to the above named healthy controls and as such a higher risk of secondary ACL ruptures [14].

Tunnel widening following anterior cruciate ligament (ACL) reconstructions remains a significant concern due to its potential impact on graft stability and long-term clinical outcomes. This phenomenon, characterized by the enlargement of the bone tunnels created during surgery, can compromise graft fixation and lead to suboptimal knee function and increased risk of graft failure. Despite advances in surgical techniques and graft materials, the etiology of tunnel widening is multifactorial, involving mechanical stress, biological responses, and early rehabilitation protocols. Understanding the underlying mechanisms and developing strategies to mitigate this complication are crucial for improving patient outcomes.

Recent studies have explored various factors influencing tunnel widening, including the type of graft used, fixation methods, and postoperative rehabilitation protocols. Additionally, the posterior tibial slope has been found to influence tunnel widening, potentially due to increased shear forces exerted on the graft, which can exacerbate tunnel enlargementTunnel widening following anterior cruciate ligament (ACL) reconstructions remains a significant concern due to its potential impact on graft stability and long-term clinical outcomes. This phenomenon, characterized by the enlargement of the bone tunnels created during surgery, can compromise graft fixation and lead to suboptimal knee function and increased risk of graft failure.

Despite advances in surgical techniques and graft materials, the etiology of tunnel widening is multifactorial, involving mechanical stress, biological responses, and early rehabilitation protocols. Understanding the underlying mechanisms and developing strategies to mitigate this complication are crucial for improving patient outcomes. Recent studies have explored various factors influencing tunnel widening, including the type of graft used, fixation methods, and postoperative rehabilitation protocols. Additionally, the posterior tibial slope has been found to influence tunnel widening, potentially due to increased shear forces exerted on the graft, which can exacerbate tunnel enlargement [15-18].

To our knowledge, there are no articles describing the potential influence of the PTS on the functional outcomes after revision ACL reconstruction, whereas a limited number of articles was published regarding functional outcomes after primary ACL surgery in relation to the PTS. As such we postulated the due to the biomechanical basis of PTS influence to the ACL, a higher PTS would also influence the functional outcomes of revision ACL reconstruction.

Materials and Methods

We performed a retrospective cohort study as a part of a larger single center study regarding patient related risk factors related to revision ACL reconstruction. The initial study consisted of 5000 patients from our institution, and after applying the inclusion and exclusion criteria we had a cohort of 96 patients that received revision ACL reconstruction.

We conducted an a priori analysis to determine the appropriate sample size required to support our null hypothesis using the G*Power application, which has been standardized and published in relevant databases [19,20].

We determined that a sample size of 96 patients and controls in each group would provide a 95% chance of detecting a significant result, given an ALPHA coefficient of 0.05. Additionally, any measure below a Grade of 0.3 was considered irrelevant for our study.

The following inclusion criteria were applied: We searched our institutional databases for patients who underwent primary and secondary ACL reconstructions between 2010 and 2022. We identified 5,000 patients who met our criteria, with comprehensive data and conventional radiographs available. Out of those patients 350 received revision reconstruction of the ACL whereas 256 were lost either due to failure of contact or unavailability for a follow-up examination. The minimum follow-up was 24 months with point zero being the date of the revision ACL surgery.

The following exclusion criteria were applied to our patient pool:

- Patients younger than 17 and older than 45 were excluded.
- Patients with concomitant traumatic or degenerative intraarticular pathologies, such as meniscal injuries or meniscopathies, chondral injuries, chondromalacia, osteoarthritis, collateral ligament injuries, bony or subchondral injuries, or degenerative changes, were excluded.
- Patients with patellofemoral or peripatellar pathology, injuries of the posterior cruciate ligaments, or documented previous surgeries (except for those who had primary ACL reconstruction in the group of secondary injuries) were excluded.
- Patients who underwent primary ACL reconstruction with concomitant operative treatments like meniscal repair, chondral therapy, patellofemoral therapy, ligament stabilization other than the ACL, or knee osteotomies were excluded.
- Patients with other risk factors for non-contact ACL injuries were excluded.
- Patients whose injuries were attributable to misplacement of femoral, tibial, or both drill tunnels in the primary reconstruction were excluded.

- Patients with unclear documentation about the primary or secondary injury mechanism were excluded.
- Patients whose primary reconstruction was performed outside our clinic or who had inadequate documentation of the procedure were excluded.
- Patients whose failure could be attributed to non-compliance based on their documentation were excluded.
- Patients with technically unsatisfactory standard radiographs or radiographs where the needed criteria were not obtainable (such as radiographs not performed in our institution) were excluded.
- Patients in the primary cruciate ligament injuries group whose reconstruction was less than 2 years old were not included in the study.
- In the control group, patients who did not have radiographically confirmed absence of intraarticular pathology (via both conventional radiography and MRI) were excluded.

We determined that conventional radiographs are the preferred method for assessing the posterior tibial slope due to their nature, which involves a combination of projections. Moreover, they are cost-effective compared to other diagnostic tools for obtaining this value, as discussed in the subsequent discussion session.

However, despite their advantages, we implemented stringent technical standards for the radiographs obtained. We excluded those that did not meet the following criteria:

- Satisfactory femoral or tibial orientation,
- A minimum of 15 cm of the tibial shaft visible, and
- The absence of any concomitant signs of intraarticular, subchondral, or bony injury or degenerative disorders.

Tunnel Widening was also determined using standard radiographs, we measured the diameter of the femoral and tibial tunnel 1 cm proximal and distal to the tunnel aperture in both the anteroposterior and lateral projection as described by Baumfeld., *et al*. The difference in tunnel widening was determined between postoperative radiographs and the follow-up radiographs [21].

The patients were invited to our institution and filled the functional outcomes were determined using the Lysholm score, seeing that it is highly favored and commonly employed in both clinical and research environments. Its minimal floor and ceiling effects make it valuable for monitoring both the improvement from interventions and deterioration over time. Additionally, it demonstrates strong correlations with subjective IKDC, the Cincinnati knee ligament score, and the WOMAC [21].

The statistics of the sample size determination was previously described, as the fact that we checked our obtained measures through intraclass reliability measurements [14]. Further descriptive statistics of our study population were analysed using the GraphPad and IBM SPSS programmes as well as subsequent statistical analysis.

We compared the functional outcomes between patients who had a PTS more than 10 to patients who had a PTS less than 10 both whom received revision ACL reconstruction, and objectivised those measurements using the unapaired t-test with Welch´s correction. The difference in tunnel widening between the two groups was also compared using the unpaired t-test.

Results

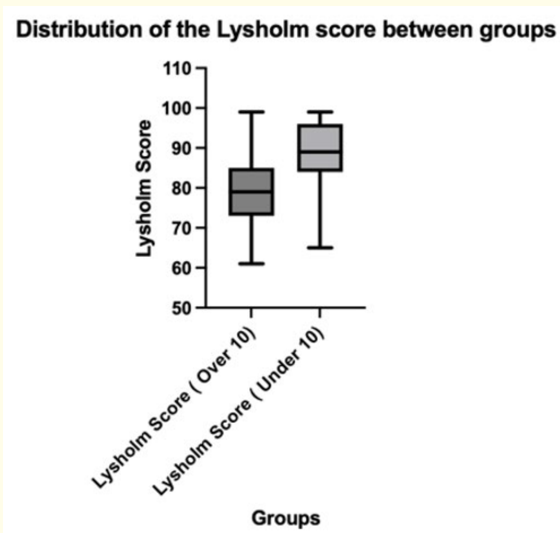
We performed a descriptive statistics analysis regarding all of our available data and found that from our 96 analysed patients 48 were female and 44 males, with 23 females and 25 males in the group of patients with a PTS of more than 10, 25 females and 19 males in the group of patients with a PTS of less than 10.

Regarding age, in the group of patients with a PTS of more than 10 the mean age was 27 (minimum 19 and maximum 39), an in the group of patients with a PTS of less than 10 the mean age was also 27 (minimum 19 and maximum 39) (Table 1).

		Age (Over 10)	Lysholm Score (Over 10)	Age (Under 10)	Lysholm Score (Under 10)
Number of values		47	47	49	49
Minimum		19	61	19	65
Maximum		39	99	39	99
Range		20	38	20	34
Mean		27	79	27	89
Std. Deviation		4.5	9.0	4.7	8.2
Std. Error of Mean		0.66	1.3	0.67	1.2
Lower 95% CI of mean		26	76	26	86
Upper 95% CI of mean		28	81	29	91

Table 1: *Shows the descriptive statistics of the study population.*

The Lysholm Score in the group with a PTS of more than 10 was 79 in average which correlates with a fair functional outcome, with a minimum of 61 and maximum of 99. In the group of patients who had a PTS less than 10 the average Lysholm score was 89 which correlates with a good functional outcome, with a minimum of 65 and maximum of 99 (Table 1 and graph 1).



Graph 1: *Shows the distribution of the Lysholm score between groups.*

A statistically significant difference was found between the groups with a p-value of <0.0001 (Table 2).

Unpaired t test with Welch's correction	
P value	<0.0001
P value summary	****
Significantly different (P < 0.05)?	Yes
One- or two-tailed P value?	Two-tailed
Welch-corrected t, df	t=5.721, df=92.20

Table 2: *Shows the results of the t test.*

Regarding the difference in tunnel widening in the group of patients with a PTS more than 10 degrees, the femoral tunnel in the AP projection had a mean difference in tunnel widening of 1.6 mm (SD 0.43) with a minimum value of 0.60 mm and maximum value of 3 mm, whereas the group of patients with a PTS less than 10 degrees showed a mean difference in tunnel widening of 1.6 mm (SD 0.45) with a minimum value of 0.70 mm and maximum value of 3.5 mm in the AP projection on the femoral side. No statistical difference was found between the mean in the compared groups (p = > 0.05) (Table 3).

In the lateral projection on the femoral side, the patients with a PTS of more than 10 degrees had a mean difference in tunnel widening of 1.7 (SD 0.38, min= 0.60 mm, max = 2.8 mm), and the patients with a PTS of less than 10 degrees had a mean difference in tunnel widening of 1.6 mm (SD 0.46, min = 0.80 mm, max = 3.4 mm). No statistical difference was found between the mean in the compared groups (p = > 0.05) (Table 3).

On the tibial side in the AP projection patients with a PTS of more than 10 degrees had a mean difference in tunnel widening of 1.8 mm (SD 0.40, min = 1.8 mm, max = 3.8), whereas patients with a PTS of less than 10 degrees had a mean in difference in tunnel widening of 2.7 mm (SD 0.35, min = 1.9 mm, max = 3.4 mm). No statistical difference was found between the mean in the compared groups (p = > 0.05) (Table 3).

In the lateral projection, the group of patients with a PTS of more than 10 degrees had a mean difference in tunnel widening of 3.1 mm (SD 0.42, min = 1.9 mm, max = 3.8 mm), in the group of patients with a PTS of less than 10 degrees the mean was 3.2 mm (SD 0.30, min = 2.4 mm, max = 3.9 mm). No statistical difference was found between the mean in the compared groups (p = > 0.05) (Table 3).

	Posterior Tibial Slope > 10 Femoral AP	Posterior Tibial Slope > 10 Femoral Lateral	Posterior Tibial Slope > 10 Tibial AP	Posterior Tibial Slope > 10 Tibial Lateral	Posterior Tibial Slope < 10 Femoral AP	Posterior Tibial Slope < 10 Femoral Lateral	Posterior Tibial Slope < 10 Tibial AP	Posterior Tibial Slope < 10 Tibial Lateral
Minimum (mm)	0.60	0.90	1.8	1.9	0.70	0.80	1.9	2.4
Maximum (mm)	3.0	2.8	3.5	3.8	3.5	3.4	3.4	3.9
Range (mm)	2.4	1.9	1.7	1.9	2.8	2.6	1.5	1.5
Mean (mm)	1.6	1.7	2.7	3.1	1.6	1.7	2.7	3.2
Standard Deviation	0.43	0.38	0.40	0.42	0.45	0.46	0.35	0.30

Table 3: *Shows the results regarding the tunnel widening.*

Discussion

We performed a retrospective cohort study with a population of 96 patients after including our extensive inclusion and exclusion criteria, with a minimum follow-up of 24 months. The sample size was determined a priori, as previously described and the patients were invited for a follow-up in the institution where the Lysholm score was determined. The patients were divided into two groups, those who had a PTS of more than 10 and those who had a PTS of less than 10. The PTS measurements were obtained beforehand as described in Dracic., *et al*. [14]. After statistical analysis, a statistically significant difference in the mean Lysholm score was found between the groups showing that in a group of patients who recieved revision ACL reconstruction who had a PTS of more than 10 the functional outcomes are signfiicantly different compared to patients who had have a PTS of less than 10.

The posterior tibial slope, or rather its cut-off value is still a controversial subject in when to perform corrective surgery.

The decision to proceed with corrective osteotomy is traditionally informed by the seminal work of Webb., *et al*. [7], who conducted a prospective study involving 200 patients over a follow-up period of 15 years, with subsequent reports published at a 20-year follow-up. Their findings suggested that a posterior tibial slope (PTS) exceeding 12 degrees yielded an odds ratio of 5 for re-rupture, after controlling for age and sex. However, it's worth noting that their data was collected from a homogeneous group without consideration of other potential risk factors, and the technical aspects of ACL injuries were not thoroughly examined. Furthermore, distinctions between non-contact and contact injuries were not made.

While many operative decisions are influenced by Webb., *et al*'s study, there remains ambiguity regarding the precise cut-off values. Song., *et al*. [8] argue for a threshold of over 13 degrees based on their findings, demonstrating improved knee stability with slope-reducing tibial osteotomy in patients with steep PTS. Similarly, Dejour., *et al*. [9] and Sonnery-Cottet., *et al*. [10] reported favorable outcomes with varying postoperative PTS values.

In contrast, Ni., *et al*. [11] utilized ROC Curve analysis to determine a PTS cut-off value of 17, despite this differing from other literature. They attributed this discrepancy to variations in imaging methodology. Comparable data from Fliho., *et al*. [19] found a PTS cut-off value of over 8, correlating with an increased risk of ACL injuries compared to healthy subjects. However, our study expands upon these findings by encompassing a larger patient cohort and a broader analysis, including both primary and secondary ACL injuries, while meticulously excluding potential confounders.

In another study, Fares., *et al*. [12] established a PTS cut-off of 10 degrees, concluding it as a risk factor for ACL injuries. However, they did not specify the methodology for determining this cut-off.

Dracic., *et al*. [14] found that in a retrospective cohort study with initial 1050 Patients in 3 groups of 350 including carefully selected healthy controls and came to the conclusion that there is possible discrepancy in reported cut-off values and our study seeing that we found a cut-off value of 10 using receiver operating characteristic curve analysis in the group of secondary ACL ruptures compared to healthy controls, consequently the studied group of secondary ACL ruptures had a 11.29 times higher risk of having a PTS value of more than 10 compared to the above named healthy controls and as such a higher risk of secondary ACL ruptures. No such difference was found the group of primary ACL subjects which were compared to healthy controls in the same study.

Hinz M., *et al*. [22] found that there was no observed link between the medial posterior tibial slope (MPTS) and functional outcomes in patients who did not experience graft failure. Despite the steepness of the MPTS, patient-reported outcome measures (PROMs) indicated satisfactory global functional outcomes of the knee, with patients reporting good clinical results and perceived stability.

Although, to our knowledge, the influence of the PTS on the functional outcomes after ACL revision reconstructions is rather limitedly researched in the field of sport orthopaedics. Mabrouk., *et al*. [23] showed that functional outcomes after deflexion osteotomies in the setting out revision ACL surgery showed improvement in the functional outcomes when compared to preoperative values but never equated to pre injury level of function.

The influence of the PTS on the functional outcomes in the field of endoprosthetics has gained more traction. As such Plancher., *et al*. [24] found that patients with postoperative posterior slope of the tibial implant >7° had significantly worse postoperative pain, without conversion to TKA, and with maintenance of high function after a medial unicompartmental knee arthroplasty. Although Miralles- Munoz., *et al*. [25] showed that no such difference exists in patients who recieved cruciate-retaining TKA.

Tunnel widening following anterior cruciate ligament (ACL) reconstruction is a multifactorial phenomenon that can adversely impact graft stability and clinical outcomes. One significant factor that has emerged in recent studies is the posterior tibial slope (PTS). The PTS refers to the angle of the tibial plateau in relation to the longitudinal axis of the tibia, and its influence on tunnel widening is primarily due to the biomechanical environment it creates. A steeper PTS can increase anterior tibial translation and shear forces on the ACL graft, which may lead to greater tunnel enlargement over time [15-18].

Studies have shown that patients with a steeper PTS are more likely to experience greater tunnel widening after ACL reconstruction. This relationship is thought to be due to the increased mechanical stress placed on the graft, leading to micro-motion within the bone tunnel and subsequent bone resorption. Morgan., *et al*. (2016) demonstrated a correlation between PTS and tunnel widening using longitudinal MRI assessments, highlighting that a higher PTS was associated with significant tunnel enlargement over a two-year period [26].

The evaluation of tunnel widening is critical for assessing the success of ACL reconstructions, and radiographic techniques play a pivotal role in this process. Radiographs are widely used due to their accessibility, cost-effectiveness, and ease of use. However, radiographs are limited in their ability to provide detailed three-dimensional assessments of the bone tunnels and the surrounding structures.

Several studies have investigated the methods for measuring tunnel widening following ACL reconstruction using various radiographic techniques [27].

Peyrache., *et al*. measured the distance between the sclerotic margins of the tibial tunnel at different levels, including the distal tunnel exit on the medial tibial cortex, the middle of the tunnel, and proximally at the joint line, also considering the tibial tunnel's position relative to Blumensaat's line [28].

L'Insalata., *et al*. assessed tunnel widening nine months postoperatively using anteroposterior and lateral views, with measurements taken using a digital caliper and compared to the diameters of the fixation screws, achieving a high intraclass correlation coefficient of 0.92 [29].

Murty., *et al*. measured tunnel size on radiographs by determining the distance between the sclerotic margins at specific points from the tibial entrance and exit, calculating the percentage of enlargement relative to the original drill size, with excellent inter- and intra-observer reliability. Baumfeld., *et al*. measured the femoral and tibial tunnel widths at the widest points and 1 cm from the apertures, with calculations in both absolute values and percentages of enlargement, demonstrating excellent inter-rater reliability [30].

Clatworthy., *et al*. evaluated tunnel widening using standardized radiographs and calculated femoral and tibial tunnel diameters at specific anatomical landmarks, choosing area measurements over width to account for the three-dimensional structure of the tunnels [31].

Fauno., *et al*. measured tunnel widths at points below the tibial plateau and above the femoral entrance on standardized radiographs, although they did not report reliability testing [15].

Nebelung., *et al*. defined six measurement points on radiographs and categorized tunnel enlargement based on deviations from the drill bit size used during surgery [32].

Kawaguchi., *et al*. compared femoral tunnel widening between different ACL reconstruction techniques by measuring the intra-articular outlet of femoral tunnels [34].

Surer., *et al*. divided the longitudinal axis of the bone tunnel into three portions and measured tunnel width at the widest part in each portion on radiographs taken immediately postoperatively and at one-year follow-up to evaluate tunnel widening over time [34].

Conclusion

In conclusion, the posterior tibial slope is a significant factor influencing tunnel widening following ACL reconstruction. Steeper slopes increase mechanical stress on the graft, contributing to greater tunnel enlargement. While radiographs are useful for routine follow-up, CT and MRI provide more detailed and accurate assessments of tunnel changes. Future research should continue to explore the interplay between biomechanical factors and imaging techniques to optimize outcomes for patients undergoing ACL reconstruction. On the other hand our study showed no difference between the mean tunnel diameter change after ACL reconstruction regarding the posterior tibial slope.

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