

# EVALUATION OF ANATOMICAL VARIATION OF POSTERIOR TIBIAL SLOPE IN PATIENTS VISITING TERTIARY CARE HOSPITAL – AN OBSERVATIONAL STUDY

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## ABSTRACT

The posterior tibial slope (PTS) is a crucial anatomical parameter which significantly affects knee biomechanics and orthopaedic evaluation. This analysis's goal was to assess how radiographic PTS varied among persons with knee pain and how it related to anthropometric, demographic, and osteoarthritis variables. One hundred people who frequent tertiary care hospitals are the subjects of this prospective, observational research. PTS was measured using lateral knee radiographs. The relationships with age, sex, body mass index (BMI), and Kellgren–Lawrence (KL) grade were evaluated using group comparisons, correlation analysis, and multivariable linear regression. The extreme measurement was omitted from the sensitivity analysis. Mean PTS was  $13.92 \pm 2.48^\circ$ . Women had higher mean PTS than men ( $14.46 \pm 2.56^\circ$  versus  $13.13 \pm 2.16^\circ$ ;  $p = 0.006$ ). PTS correlated positively with age ( $r = 0.268$ ;  $p = 0.007$ ) and negatively with BMI ( $r = -0.343$ ;  $p < 0.001$ ). There was no considerable association between KL grade and PTS ( $p = 0.526$ ). In sensitivity analysis, age ( $B = 0.065$ ;  $p = 0.001$ ) and BMI ( $B = -0.280$ ;  $p < 0.001$ ) continued to be significant. In this symptomatic hospital population, age and BMI were independently related to radiographic PTS. Results are significant and should be replicated in a larger, more varied population.

**KEYWORDS:** Posterior Tibial Slope; Knee Radiography; Anatomical Variation; Body Mass Index; Knee Osteoarthritis.

## 1. INTRODUCTION

Posterior tibial slope (PTS) is a sagittal plane feature of the proximal tibia that refers to the angle of the posterior portion of the tibial plateau in relation to a reference axis. It adds to the tibiofemoral articulation, load transfer and balancing of forces across the knee. Variations in PTS can affect the anterior tibial translation and loading of the ligaments, especially if stabilising structures are impaired. Interactions between tibial inclination and joint kinematics in anterior cruciate ligament (ACL) deficient knees have been emphasized in previous biomechanical studies (Shu et al., 2022). Therefore, PTS is not only gaining relevance for anatomical evaluation but also for surgical planning and the understanding of knee instability.

The clinical importance of PTS is apparent in ligament reconstruction. Increased posterior inclination has been reported to be a risk for ACL graft rupture and re-injury, but this is related to other patient and surgical factors (Cruz et al., 2022). A systematic synthesis of reconstructed and native states of the ligament further highlighted the role of slope morphology in graft failure (Dean et al., 2022). Current literature reviews talk about PTS as part of the discussion when considering ACL surgery, particularly if there is ongoing instability (Mandalia et al., 2023). However, knee associations noted in injured or reconstructed knees cannot be translated to represent the typical knee slope in a larger hospital population. To be clinically useful, anatomical variation must still be described without reference to surgical results.

This is because the measurement of PTS is not equivalent in all imaging modalities. Conventional lateral radiograph can provide a convenient way to assess sagittal tibial alignment, and 3D reconstruction can provide detailed assessment of proximal tibial morphology (Bao et al., 2021). The angle measured can be significantly different depending on the tibial reference axis chosen; even if the bone itself does not change, the two different angles obtained from the anatomical and mechanical axes are not the same (Dean, DePhillipo, et al., 2021). Additional errors can be introduced when reference lines are selected on conventional radiographs if there is tibial bowing (Hees et al., 2023). Additionally, knee rotation, abduction and adduction during image acquisition can affect radiographic measurements (Bixby et al., 2023). The importance of standardised lateral positioning, clearly defined landmarks and careful comparisons between studies conducted with different protocols is revealed by these factors.

Variation in the structure also exists among and between individuals and populations. A study on the Saudi adult population shows that the value of PTS can be different across geographically specific groups (ALJuhani et al., 2020). Research using computed tomography has correlated slope with ethnicity, sex and lower limb alignment, indicating that the context of the data is important and should be taken into account in interpretation (Pangaud et al., 2020). There has also been morphometric evidence for sex and ethnic differences in South Africa (Hohmann et al., 2025). To support this, the authors of the same study suggest using PTS as a parameter for knee phenotype, in addition to the coronal alignment (Hiyama et al., 2025). This discovery is a warning against using the same reference angle in different populations that are not homogeneous.

Indian studies are of particular relevance, as there is a need for population-specific anatomical evidence for meaningful local interpretation. To assess the proximal tibial morphology by cross-sectional imaging, the morphologic parameters of normal Indian knees were determined using computed tomography assessment (Kumar & Gupta, 2022). Anatomical variation in PTS has also been reported in hospital-based research in northern Indian settings, which further suggests the need for the evaluation of the regional clinical population (Singh et al., 2023). Direct comparison of these reported values, however, is difficult due to variability in sampling, imaging modality, axis selection, and clinical presentation. Especially, healthy participants may not be a representative sample of adults seeking orthopaedic health care regarding pain in their knee. Changes in age, sex, body mass index and early radiographic degenerative changes are important variables that should be studied in an evaluated population.

These relationships may aid in interpretation of lateral knee radiographs but do not suggest that this equals causation. PTS should be assessed alongside other knee morphology features as part of knee assessment, as clinical conversation has focused on the importance of bony geometry in relation to ligament function (Dean, Larson, & Waterman, 2021). The present study thus focuses on radiographically assessed PTS among the adult population attending a tertiary health care unit and its correlations with demographic, anthropometric and radiographic characteristics.

## **OBJECTIVES:**

To find out the distribution and mean posterior tibial slope in the study population.

To evaluate the difference in the tibia slope in terms of age, sex and BMI.

To assess the correlation between Kellgren-Lawrence grade and other factors and determine the independent factors associated with the posterior tibial slope.

## **2. MATERIALS AND METHODS**

### **2.1. Study Design and Setting**

This prospective observational study was conducted at the Department of Orthopedics at Mahatma Gandhi Medical College and Research Institute (MGMCRI), which is a tertiary care teaching hospital in Puducherry, India. In this study, a cross-sectional radiographic evaluation of posterior tibial slope (PTS) was performed in adult patients with knee pain. Participants were sampled consecutively from October 2025 to March 2026. This study aimed to quantify the frequency of occurrence of PTS on standardised lateral knee radiographs and to investigate the relationship between age, sex and BMI. There were 100 eligible participants in the final analysis.

### **2.2. Study Population and Eligibility Criteria**

The study population entailed of patients of both sexes, aged 18 years and above, who attended the outpatient or inpatient Orthopaedics Department with knee pain between October 2025 and March 2026. The included patients had written informed consent, a standardised true lateral knee radiograph showing a distance among the posterior margins of the femoral condyles of less than 5 mm and adequate superimposition of the condyles. Excluded were patients who had undergone a previous operation on the index knee, knee deformities (genu varum, valgum, or recurvatum), inflammatory joint disorders, or previous fractures (acute or healed) of the distal femur, proximal tibia, patella or proximal fibula. Patients with advanced radiographic knee OA (Kellgren–Lawrence (KL) grade > 2) were also excluded. These criteria were used to ensure that a major structural defect does not have a significant effect on radiographic measurements of PTS.

### **2.3. Sample Size Determination**

A sample size was estimated based on the formula for estimating a mean from a population:

$$n = \frac{(Z_{1-\alpha/2} \times \sigma)^2}{d^2}$$

where  $\sigma$  represents the anticipated standard deviation and  $d$  denotes the required absolute precision. The mean and standard deviation of 12.76° and 2.35°, respectively, of a similar population as reported before, the significance level of 0.01 and the corresponding standard normal deviate of 2.58, and the absolute precision of 0.64° were considered. The thesis stated that 92 patients would be entered into the study, but to allow for potentially incomplete or poor-quality radiographs, the actual number of patients was raised to 100. One hundred all participants were included in the final analysis.

### **2.4. Demographic and Anthropometric Assessment**

A structured clinical proforma was used to obtain demographic and anthropometric data. Age was measured in years, and sex was reported as male or female. A stadiometer mounted on a wall was used to measure standing height to the closest 0.5 cm. To the closest 0.1 kg, measurements were taken using a digital weighing scale that had been calibrated. BMI was computed as height<sup>2</sup> (m<sup>2</sup>) divided by body weight (kg). The World Health Organization's worldwide BMI guidelines were used to classify the individuals into three groups: normal weight (BMI 18.5 to 24.9 kg/m<sup>2</sup>), overweight (BMI 25.0 to 29.9 kg/m<sup>2</sup>), and obese (BMI > 30.0 kg/m<sup>2</sup>). Four age categories were also identified: 18–29, 30–44, 45–59, and ≥60 years. Medical and surgical pasts were recorded, and criteria were considered for knee morphology eligibility and conditions that might alter knee morphology.

## 2.5. Radiographic Acquisition and Standardisation

A digital radiographic system was used to obtain standardised true lateral radiographs of the affected knee in the Department of Radiodiagnosis at MGMCRI. The participants were set up in the lateral decubitus position, the affected knee stretched at about 30° and the other knee supported behind. The X-ray beam was directed along the line of the knee joint. Radiographs that did not meet this criterion were repeated with the aim of avoiding measurement errors related to the projection. All the acceptable images were collected and stored in Digital Imaging and Communications in Medicine (DICOM) format and then evaluated managing the institutional Picture Archiving and Communication System (PACS) (MEDSYNAP).

## 2.6. Measurement of Posterior Tibial Slope

Standardised true lateral knee radiographs were used for the manual measurement of posterior tibial slope on the integrated angular measurement tools of the institutional PACS workstation. A consistent method (anterior tibial cortex) was used throughout the study group. A reference line was first drawn along the anterior cortex of the middle third of the tibial shaft and extended proximally as an anterior cortical reference line. A second line was made tangential to the proximal tibial articular surface, connecting the most anterior and posterior bony landmarks. A third line was drawn perpendicular to the anterior cortical line. This perpendicular was used to define a reference angle to the tibial plateau tangent (PTS), Posterior tibial slope was measured in degrees and recorded to the nearest 0.1°. The first measurements were taken by an assistant professor, and a second assistant professor repeated the measurements to evaluate interobserver variability.

## 2.7. Radiographic Assessment of Osteoarthritis

The radiographic severity of osteoarthritis was determined by Kellgren–Lawrence grading. Participants were judged to have grade 0 (no radiographic osteoarthritis), grade 1 (doubtful radiographic changes) or grade 2 (minimal radiographic osteoarthritis). Those patients with KL grades 3 and 4 were excluded, based on the inclusion criteria. KL grade was presented as an extra explanatory variable to explore if there was a correlation between variations in KL grade and variations in PTS, and to determine whether KL grade would have an independent effect in multivariable analysis.

## 2.8. Study Variables and Outcome Measures

The primary outcome was the measured posterior tibial slope angle (PTSA) as a continuous variable on X-ray. The main variables that explained the outcome were age, sex and BMI. BMI and age were analysed both as quantitative and as categorical variables and were divided into predefined categories. Sex was analysed as a binary categorical variable. An extra radiographic variable was considered the KL grade. The primary analysis compared the distribution of overall PTS and the secondary analysis compared the distribution of PTS between the subgroups of the demographic and anthropometric variables, between the continuous predictor variables, and between age, sex, BMI, and KL grade, respectively, with overall PTS.

## 2.9. Data Collection and Management

These clinical, anthropometric and radiographic measurements were initially recorded in standardised participant-specific data collection proformas and later recorded in the Microsoft EXCEL spreadsheet for data organisation, coding and verification. The entries in the data were compared with the clinical records to minimise transcription errors. Radiographic measurements were retrieved from the institutional PACS database and used in the analysis. Data were analysed descriptively, in comparison, by correlating and by multivariable statistics.

## 2.10. Statistical Analysis

IBM SPSS Statistics version 26 was used for the statistical analysis, and two-sided p-values of less than 0.05 were considered significant. The continuous variables were summarized using means, standard deviations, medians, interquartile ranges, and ranges, while the categorical data was described using frequencies and percentages. To verify normality, the Shapiro-Wilk test was employed. The differences in posterior tibial slope (PTS) between the male and female groups were assessed using independent-samples t-tests (with Welch's correction where appropriate) and Mann-Whitney U tests, with Cohen's d and rank-biserial correlation serving as effect sizes. Age and body mass index (BMI) relationships were examined using Pearson's and Spearman's correlations. Group differences across age, BMI and Kellgren–Lawrence (KL) grades were assessed between groups by one-way ANOVA and Kruskal–Wallis tests, respectively, with eta-squared effect sizes and Tukey's post-hoc comparisons as appropriate. Multiple linear regression was used to determine the independent relationship of age, sex, BMI, and KL grade with PTS, reporting the coefficients, 95% confidence intervals, significance levels, model diagnostics ( $R^2$ , adjusted  $R^2$ , F-statistic, Durbin-Watson statistic and variance inflation factors). Principal analyses were repeated without one extreme measurement of the PTS (25.50°), comparing the whole cohort (N = 100) with the other 99 participants (sensitivity analysis).

## 2.11. Ethical Considerations

The thesis has been approved by the Institutional Human Ethics Committee, Mahatma Gandhi Medical College and Research Institute, approval number MGMCRI/2025/01/06/IHEC/171 dated 10 April 2026. After patients were informed about the procedures and aims of the study, written informed consent was obtained. If a participant was unable to provide consent at the first time, consent was taken from a legally authorised representative, and re-consent took place whenever possible. The participant information and radiographs were administered via the institutional clinical documentation and image archiving systems.

### 3. RESULTS

#### 3.1. Baseline Demographic and Clinical Characteristics

There were 100 adult patients with knee pain included in the study. The age of the participants ranged from 18 to 73 years, and the mean age was  $45.91 \pm 12.59$  years. The majority (48.0%) were aged 45–59 years; the 30–44 age group (28.0%) was the second largest. The females accounted for 59.0%, and the males accounted for 41.0% of the study population. The mean BMI of the population was  $29.04 \pm 3.27$  kg/m<sup>2</sup>, with 52.0% of the participants being overweight, 37.0% being obese, and 11.0% being normal weight. Radiographic assessment with Kellgren–Lawrence (KL) classification showed that 22.0% had no changes, 46.0% had grade 1 changes, and 32.0% had grade 2 changes. Table 1 summarizes the baseline characteristics and demographic data in terms of anthropometric measurements and radiographs.

**Table 1. Baseline demographic, anthropometric, and radiographic characteristics of the study population (N = 100)**

| Variable                                  | Value               |
|-------------------------------------------|---------------------|
| Age (years), mean $\pm$ SD                | 45.91 $\pm$ 12.59   |
| Age (years), median (IQR)                 | 48.0 (37.0–55.25)   |
| Age range (years)                         | 18–73               |
| <b>Sex, n (%)</b>                         |                     |
| Male                                      | 41 (41.0)           |
| Female                                    | 59 (59.0)           |
| BMI (kg/m <sup>2</sup> ), mean $\pm$ SD   | 29.04 $\pm$ 3.27    |
| BMI (kg/m <sup>2</sup> ), median (IQR)    | 29.25 (27.18–31.70) |
| BMI range (kg/m <sup>2</sup> )            | 19.4–35.2           |
| <b>BMI category, n (%)</b>                |                     |
| Normal (18.5–24.9 kg/m <sup>2</sup> )     | 11 (11.0)           |
| Overweight (25.0–29.9 kg/m <sup>2</sup> ) | 52 (52.0)           |
| Obese ( $\geq 30.0$ kg/m <sup>2</sup> )   | 37 (37.0)           |
| <b>Age group, n (%)</b>                   |                     |
| 18–29 years                               | 13 (13.0)           |
| 30–44 years                               | 28 (28.0)           |
| 45–59 years                               | 48 (48.0)           |
| $\geq 60$ years                           | 11 (11.0)           |
| <b>Kellgren–Lawrence grade, n (%)</b>     |                     |
| Grade 0                                   | 22 (22.0)           |
| Grade 1                                   | 46 (46.0)           |
| Grade 2                                   | 32 (32.0)           |

**Note:** Values are presented as mean  $\pm$  standard deviation (SD), median (interquartile range [IQR]), or frequency (percentage). BMI: body mass index. Patients with KL grade greater than 2 were excluded.

#### 3.2. Distribution of Posterior Tibial Slope

PTS for the total study population was  $13.92 \pm 2.48^\circ$ , 95% confidence interval (CI):  $13.42^\circ$ – $14.41^\circ$ . The median PTS was  $13.70^\circ$  (IQR:  $12.38^\circ$ – $15.15^\circ$ ), and the observed measurements ranged from  $9.50^\circ$  to  $25.50^\circ$ . The Shapiro–Wilk test was used to assess distributional normality, and a statistically significant deviation from normality was found ( $W = 0.924$ ,  $p < 0.001$ ). One extreme measurement of  $25.50^\circ$  was included in the distribution, which was kept in the main analysis and was analysed separately in the sensitivity analysis. The overall distribution of PTS measurements is shown in Figure 1, with the mean, median and maximum observation.

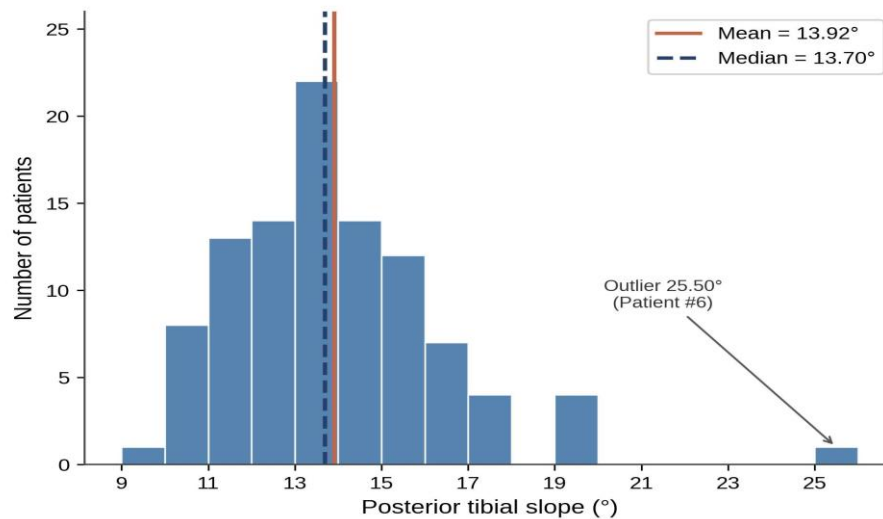


**Figure 1. Distribution of posterior tibial slope measurements among study participants (N = 100), showing the mean (13.92°), median (13.70°), and extreme observation (25.50°)**

### 3.3. Sex-Based Variation in Posterior Tibial Slope

Female participants demonstrated significantly greater mean PTS than male participants ( $14.46 \pm 2.56^\circ$  versus  $13.13 \pm 2.16^\circ$ ), corresponding to an absolute mean difference of  $1.33^\circ$  (Welch's  $t = -2.800$ ,  $p = 0.006$ ). Welch's independent-samples t-test revealed a statistically significant difference ( $t = -2.800$ ,  $p = 0.006$ ); Cohen's  $d = -0.552$  indicated that the effect of this alteration was reasonable. The non-parametric Mann-Whitney U test ( $U = 794.5$ ,  $p = 0.004$ ; rank-biserial correlation = 0.343) supported this. The variances were not significantly different among the groups based on Levene's test ( $F = 0.196$ ,  $p = 0.659$ ). The sex-specific summary of the PTS measurements is presented in Table 2, and the means and standard deviations are illustrated in Figure 2.

**Table 2. Comparison of posterior tibial slope between male and female participants**

| Parameter                       | Male (n = 41)       | Female (n = 59)     | Test statistic       | p-value |
|---------------------------------|---------------------|---------------------|----------------------|---------|
| PTS ( $^\circ$ ), mean $\pm$ SD | $13.13 \pm 2.16$    | $14.46 \pm 2.56$    | Welch's $t = -2.800$ | 0.006   |
| PTS ( $^\circ$ ), median (IQR)  | 12.98 (11.49–14.28) | 14.12 (12.99–15.62) | $U = 794.5$          | 0.004   |

**Note:** Cohen's  $d = -0.552$ ; rank-biserial correlation = 0.343. Levene's test:  $F = 0.196$ ,  $p = 0.659$ . PTS: posterior tibial slope.

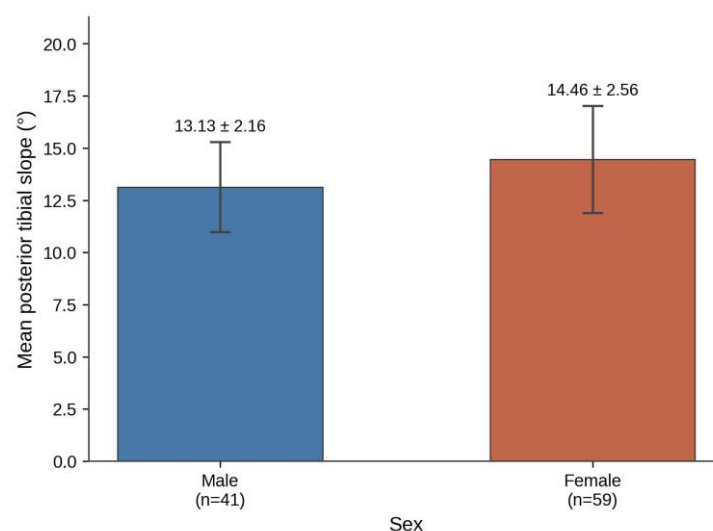


**Figure 2. Comparison of mean posterior tibial slope between male and female participants, with error bars representing standard deviations**

### 3.4. Association Between Age and Posterior Tibial Slope

The age weakly positively correlated with PTS, with Pearson's correlation coefficient of 0.268 (95% CI: 0.076–0.442,  $p = 0.007$ ) and Spearman's rank correlation coefficient of 0.233 ( $p = 0.020$ ). There was an increasing trend in Mean PTS with age going from  $12.69 \pm 2.00^\circ$  for age group 18–29 years to  $16.04 \pm 3.53^\circ$  for age group 60 years and above. One-way analysis of variance (ANOVA) discovered a important difference among age groups ( $F(3, 96) = 4.18$ ,  $p = 0.008$ ;  $\eta^2 = 0.116$ ), and this was verified by the Kruskal–Wallis test ( $H = 9.33$ ,  $p = 0.025$ ).

Significant differences were discovered by Tukey's post-hoc comparisons between the 60 years and older group and the 18–29 years ( $p = 0.005$ ) and 45–59 years ( $p = 0.038$ ) older groups, as well as between the 60 years and older group and the 30–44 years ( $p = 0.033$ ) older group. The three child age groups did not differ significantly from one another. Table 3 reports the age-stratified PTS readings, and Figure 3 illustrates the pattern of rising PTS levels with age.

**Table 3. Comparison of posterior tibial slope across age groups**

| Age group       | n  | PTS ( $^\circ$ ), mean $\pm$ SD | PTS ( $^\circ$ ), median (IQR) |
|-----------------|----|---------------------------------|--------------------------------|
| 18–29 years     | 13 | $12.69 \pm 2.00$                | 11.66 (11.09–13.95)            |
| 30–44 years     | 28 | $13.70 \pm 2.28$                | 13.27 (12.04–14.74)            |
| 45–59 years     | 48 | $13.88 \pm 2.19$                | 13.73 (12.56–14.84)            |
| $\geq 60$ years | 11 | $16.04 \pm 3.53$                | 15.67 (14.04–16.49)            |

**Note:** One-way ANOVA:  $F(3, 96) = 4.18$ ,  $p = 0.008$ ,  $\eta^2 = 0.116$ . Kruskal–Wallis test:  $H = 9.33$ ,  $p = 0.025$ . SD; IQR

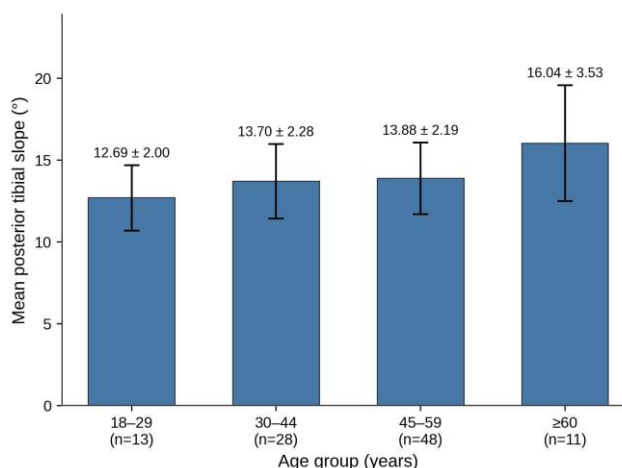


**Figure 3. Mean posterior tibial slope across four age groups, with error bars representing standard deviations**

### 3.5. Association Between Body Mass Index and Posterior Tibial Slope

There was a statistically significant inverse relationship between BMI and PTS, with weak to moderate negative correlation as indicated by Pearson's correlation coefficient ( $r = -0.343$ , 95% CI:  $-0.506$  to  $-0.158$ ,  $p < 0.001$ ) and Spearman's rank correlation ( $\rho = -0.246$ ,  $p = 0.014$ ). As shown in Figure 4, there is a general pattern of a decrease in PTS with increasing BMI, with many individuals showing little change or even increasing with BMI.

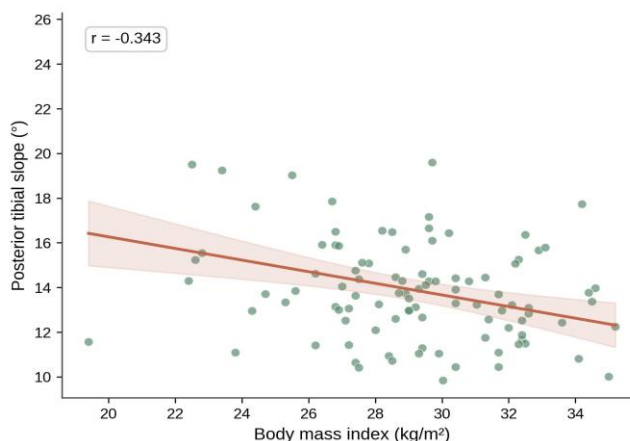


**Figure 4. Relationship between body mass index and posterior tibial slope, displaying individual observations, the fitted linear regression line, and its 95% confidence interval**

These differences in PTS between BMI groups were also highlighted by the categorical analysis. The normal weight participants had the highest mean PTS ( $16.02 \pm 4.21^\circ$ ), overweight participants ( $14.03 \pm 2.12^\circ$ ), and obese participants ( $13.13 \pm 1.90^\circ$ ). One-way ANOVA identified statistically significant between-group differences ( $F(2, 97) = 6.56, p = 0.002; \eta^2 = 0.119$ ), supported by the Kruskal–Wallis test ( $H = 7.15, p = 0.028$ ). There were substantial differences in weight status between normal weight and overweight ( $p = 0.032$ ) and between normal weight and obese ( $p = 0.002$ ) participants, but not between overweight and obese ( $p = 0.181$ ) participants as indicated by Tukey's post-hoc comparisons. The measurements stratified by BMI are summarized in Table 4 and shown in Figure 5.

**Table 4. Comparison of posterior tibial slope across body mass index categories**

| BMI category                              | n  | PTS ( $^\circ$ ), mean $\pm$ SD | PTS ( $^\circ$ ), median (IQR) |
|-------------------------------------------|----|---------------------------------|--------------------------------|
| Normal (18.5–24.9 kg/m <sup>2</sup> )     | 11 | $16.02 \pm 4.21$                | 15.23 (13.33–18.44)            |
| Overweight (25.0–29.9 kg/m <sup>2</sup> ) | 52 | $14.03 \pm 2.12$                | 13.90 (12.90–15.26)            |
| Obese ( $\geq 30.0$ kg/m <sup>2</sup> )   | 37 | $13.13 \pm 1.90$                | 13.10 (11.75–14.28)            |

**Note:** One-way ANOVA:  $F(2, 97) = 6.56, p = 0.002, \eta^2 = 0.119$ . Kruskal–Wallis test:  $H = 7.15, p = 0.028$ . BMI: body mass index; PTS: posterior tibial slope.

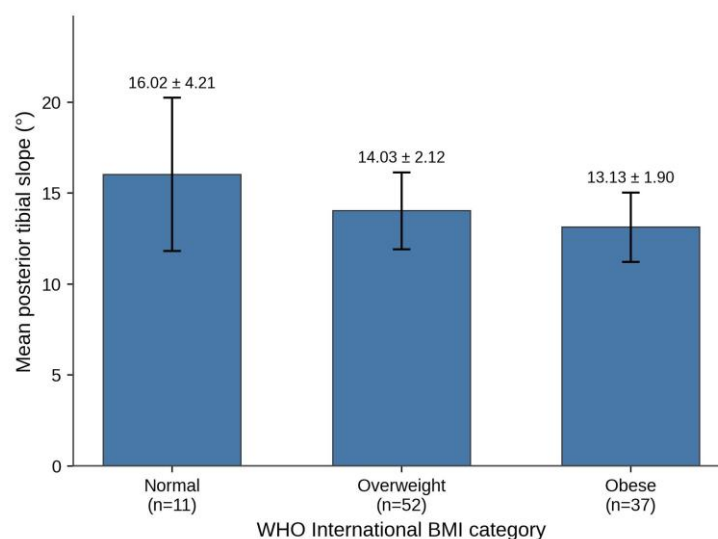


**Figure 5. Comparison of mean posterior tibial slope across normal-weight, overweight, and obese BMI categories, with error bars representing standard deviations**

### 3.6. Posterior Tibial Slope According to Osteoarthritis Severity

Posterior tibial slope did not show any statistically significant differences between Kellgren–Lawrence grades. Mean PTS measurements were  $13.52 \pm 2.38^\circ$  among participants with KL grade 0 ( $n = 22$ ),  $14.21 \pm 1.99^\circ$  among those with grade 1 ( $n = 46$ ), and  $13.77 \pm 3.13^\circ$  among those with grade 2 ( $n = 32$ ). The three groups did not vary significantly, according to a one-way ANOVA ( $F(2, 97) = 0.65, p = 0.526; \eta^2 = 0.013$ ). The Kruskal–Wallis test ( $H = 1.98, p = 0.371$ ) and Spearman's rank correlation ( $\rho = 0.009, p = 0.931$ ) supported this result. Otherwise, there was no considerable correlation between radiographic severity of OA and the level of PTS in the KL grades 0–2 group.

### 3.7. Multivariable Analysis of Factors Associated with Posterior Tibial Slope

The independent relationships of age, sex, BMI, and KL grade on PTS were investigated using multiple linear regression. The total model explained 25.7% of the observed variance in PTS ( $R^2 = 0.257$ ; adjusted  $R^2 = 0.226$ ) and was statistically significant ( $F(4, 95) = 8.23, p < 0.001$ ). Age was adjusted and was significantly positively correlated with PTS ( $B = 0.065^\circ/\text{year}$ , 95% CI: 0.028–0.101,  $p = 0.001$ ), which corresponds to an estimated difference of  $0.65^\circ/\text{decade}$ . BMI remained inversely associated with PTS ( $B = -0.280^\circ$  per kg/m<sup>2</sup>, 95% CI:  $-0.419$  to  $-0.141$ ,  $p < 0.001$ ). Male sex ( $B = -0.815^\circ, p = 0.078$ ) and KL grade ( $B = -0.094^\circ, p = 0.759$ ) were not independently correlated with PTS at the conventional level of significance. The Durbin–Watson statistic was 1.73, and the variance inflation factors were all below 1.10, suggesting good model diagnostics. Table 5 illustrates the results of the multivariable regression.

**Table 5. Multiple linear regression analysis of factors associated with posterior tibial slope (N = 100)**

| Predictor   | Unstandardised B | Standard Error (SE) | Standardised beta | t-value | p-value | 95% CI lower for B | 95% CI upper for B |
|-------------|------------------|---------------------|-------------------|---------|---------|--------------------|--------------------|
| Constant    | 19.519           | 2.014               |                   | 9.694   | <0.001  | 15.521             | 23.516             |
| Age (years) | 0.065            | 0.018               | 0.328             | 3.55    | 0.001   | 0.028              | 0.101              |

|                          |        |       |        |               |        |        |        |
|--------------------------|--------|-------|--------|---------------|--------|--------|--------|
| Sex (male)               | -0.815 | 0.458 | -0.162 | $\bar{1.779}$ | 0.078  | -1.725 | 0.095  |
| BMI (kg/m <sup>2</sup> ) | -0.28  | 0.07  | -0.368 | $\bar{3.996}$ | <0.001 | -0.419 | -0.141 |
| KL grade                 | -0.094 | 0.307 | -0.028 | $\bar{0.307}$ | 0.759  | -0.705 | 0.516  |

### 3.8. Sensitivity Analysis

A single extreme posterior tibial slope (PTS) measurement of 25.50° was tested using sensitivity analysis to evaluate its effect on the results of this study. Exclusion of this observation left 100-1 = 99 participants, who had a mean PTS that dropped from 13.92 ± 2.48° to 13.80 ± 2.20°. This difference by sex was still present in the statistical analysis ( $p = 0.011$ ). The connection between age and PTS was reduced, however ( $r = 0.197$ ,  $p = 0.051$ ); the inverse correlation between BMI and PTS did not change ( $r = -0.246$ ,  $p = 0.014$ ). In the multivariable regression, age ( $B = 0.047$ ,  $p = 0.009$ ) and BMI ( $B = -0.189$ ,  $p = 0.008$ ) were still independently correlated with PTS, whereas sex ( $p = 0.051$ ) and Kellgren–Lawrence ( $p = 0.459$ ) were not. The adjusted  $R^2$  decreased from 0.226 to 0.136. The adjusted associations of age and BMI with PTS were found to persist after excluding the extreme observation, but with reduced explanatory power of the model.

### 3.9. Case Illustration: Radiographic Assessment of Posterior Tibial Slope

A representative case was chosen to show how the posterior tibial slope (PTS) can be radiographically measured using the anterior tibial cortical reference method. The lateral knee X-ray shows the proximal tibial articular surface, the anterior tibial cortex as a reference line, and the angle measured for the determination of the PTS. The angle obtained in this portion was close to the average angle of the entire study (13.92 ± 2.48°), and the recorded angle was 14.47°. The radiograph measurement is shown in Figure 6.



**Figure 6. Representative lateral knee radiograph demonstrating measurement of posterior tibial slope (14.47°) using the anterior tibial cortical reference method**

It shows an example of how the standardised angular measurement technique was applied in this study. The anterior tibial cortex was used as the anatomical reference, and the proximal articular surface of the tibia was used as the reference for the plateau inclination. The angular relationship between the plateau tangent and the perpendicular to the cortical reference line was used to determine PTS. This case illustrates the approach used to evaluate the radiographs in the study population.

### 3.10. Summary of Results

The 100 patients included in the study had a mean posterior tibial slope (PTS) of 13.92 ± 2.48°. The scores for PTS were significantly higher in females than in males ( $p = 0.006$ ). There was a highly significant positive correlation between age and PTS ( $r = 0.268$ ,  $p = 0.007$ ) and highly significant negative correlation between BMI and PTS ( $r = -0.343$ ,  $p < 0.001$ ). There was no significant correlation with Kellgren–Lawrence grade ( $p = 0.526$ ). Age ( $B = 0.065$ ,  $p = 0.001$ ) and BMI ( $B = -0.280$ ,  $p < 0.001$ ) were found to be significant independent correlates of PTS by multivariable regression. These associations were still prominent in the sensitivity analysis and showed that age and BMI were the two most important factors related to the variation in PTS in the study population.

## 4. DISCUSSION

The present study found that the posterior tibial slope (PTS) does vary among 100 adults with knee pain and that the mean value was 13.92 ± 2.48°. Sex and radiographic grade of OA did not have independent statistically significant associations, while age and BMI did. The results do not support the use of universal reference values for symptomatic populations. Similar investigations of functional tibial phenotypes have shown that traditional categorizations of knee alignment are not fully representative of the variation of PTS (Franceschetti et al., 2026).

The mean difference of unadjusted PTS between women and men was moderate (1.33°), with women having a higher score. The adjusted sex coefficient was not significant, however, which could be a result, in part, of differences in the covariate measured. This is important to consider when comparing anatomical measurements across clinical groups. The

existing sample was predominantly female and small in size, so that effects of subgroups can only be estimated with limited accuracy. These results are not meant to set sex as an independent factor.

The group mean values of age showed a positive correlation with the scores of PTS and the highest group mean values were found in the age group of 60 years or older. The age coefficient adjusted for that was around 0.65° higher PTS per decade. However, this correlation was low, and when one extreme value was removed, the unadjusted Pearson correlation was no longer significant, but the adjusted value did remain. Investigations of the PTS in paediatric and adolescent knee disorders further highlight the importance of taking age composition and clinical context into account before making comparisons between cohorts (Yaka et al., 2024). Developmental change and/or age-related remodelling cannot be concluded from the present observations as the study was cross-sectional.

BMI (both correlation and adjusted regression analysis) showed an inverse relationship with PTS. The mean value of the normal weight group was the highest, but this group was small (n=11) and displayed fairly high levels of variation. Excluding the extreme measurement did not result in the association ending, though it did get smaller, suggesting that the extreme measurement had an impact. Importantly, previous research that included BMI with subsequent anterior cruciate ligament (ACL) injury is concerned with injury prediction, not the anatomical association which was assessed here (Fares et al., 2023). This finding, therefore, should not be interpreted as the association between an increase in BMI and a decrease in tibial slope.

There are no significant differences between Kellgren–Lawrence grades 0 to 2. This is in contrast to the overall idea that there could be a relation between tibial geometry and severity of OA, studied in an Indian clinical population (Jain et al., 2025). PTS has also been investigated in the South Indian population in combination with other markers of structural changes on the X-ray, with methodological and patient selection variations that can affect the apparent associations (Bensam et al., 2026). Longitudinal data has investigated increased medial slope in relation to meniscal extrusion and earlier onset of OA; however the measurements of the plateaus and the longitudinal outcomes cannot be directly compared with the present single radiographic angle (Ishibashi et al., 2026). The range of observed severity was further limited by excluding cases of advanced osteoarthritis.

Interpretation of these results is related to measurement considerations. In certain cases, radiographic positioning may affect the assessment of PTS, as can be seen in the case of Lateral images acquired in Abduction or Adduction Malposition (El Kayali et al., 2025). The reliability of knee parameters on radiographs is also influenced by the characteristics of the measurements with regard to slope (Lee et al., 2024). The use of the tibial reference axis and the acquisition technique (Mansour et al., 2024) should be reported in order to highlight the differences between short knee and full-length lateral radiographs. He used a specific cortical reference for measurements, but no interobserver reliability was established for his study.

The clinical implications of PTS. Slopes steeper than current ones have been considered risk factors in meniscal injury and root tears reviews (Dzidzishvili et al., 2024; Jiang et al., 2022). In studies of ACL revision failure and graft failure, slope is also considered a factor, but not a standalone surgical indication (Duerr et al., 2023a; Duerr et al., 2023b). More comprehensive studies of risk factors for ACL reconstruction reinforce the multifaceted nature of outcomes after the injury (Zhao et al., 2023). Slope is also a factor in arthroplasty research; however, this should not be directly applied to nonsurgical symptomatic adults (Jayakumar et al., 2025).

Principal limitations are the single centre recruitment, symptomatic sampling, small sub-group sizes, and potential sensitivity to an extreme measure. Due to the cross-sectional design, causal statements cannot be made. Future multicentre prospective trials with standardised imaging, repeated measurements and independently assessed reliability are required to determine if these demographic relationships are reproducible and clinically relevant.

## 5. CONCLUSION

This study found that the radiographically assessed posterior tibial slope (PTS) of 100 persons with knee discomfort in a tertiary care hospital varied significantly between individuals. The unadjusted female and male groups differed significantly, with the PTS mean value being  $13.92 \pm 2.48^\circ$ . Age and PTS were shown to be positively correlated, whereas body mass index (BMI) was negatively correlated. These relationships were both statistically significant post-adjustment for sex and Kellgren–Lawrence grade and remained in sensitivity analysis when the extreme measurement was removed. Following adjustment, however, sex was not independently correlated with PTS, nor was there any correlation with severity of OA (grades 0–2) on x-rays. The results indicate that age and BMI may be important factors to consider when evaluating lateral knee radiographs in an adult with symptoms. The small sample size, single centre recruitment, narrow range of severity of osteoarthritis and the lack of established study-specific interobserver reliability, however, limit generalisability. The cross-sectional design also does not allow causal interpretation, and some estimates are sensitive to an extreme observation, which should not be taken for granted. These associations are limited to the number of patients in these smaller multicentre studies and need to be confirmed by larger studies with well-defined standardised radiographic techniques, repeatability assessments and more clinical populations to bring more clarity to their implications for anatomical assessment and personalised orthopaedic decision-making. This evidence can in the future help to interpret more consistently across clinical settings.

## REFERENCES

1. ALJuhani, W., Qasim, S. S., & Alsaman, M. (2020). Variability of the posterior tibial slope in Saudis: a radiographic study. *Cureus*, 12(9).
2. Bao, L., Rong, S., Shi, Z., Wang, J., & Zhang, Y. (2021). Measurement of femoral posterior condylar offset and posterior tibial slope in normal knees based on 3D reconstruction. *BMC Musculoskeletal Disorders*, 22(1), 486.

3. Bensam, N. J., Pradeep, E., Vijay, A., Kumar KV, A., & Mohideen, S. (2026). Radiographic assessment of posterior tibial slope and metaphysio-diaphyseal angle as structural markers of knee osteoarthritis in South Indian adults: A cross-sectional comparative study. *Journal of Orthopaedic Surgery*, 34(1), 10225536261439404.
4. Bixby, E. C., Tedesco, L. J., Confino, J. E., Mueller, J. D., & Redler, L. H. (2023). Effects of malpositioning of the knee on radiographic measurements: the influence of adduction, abduction, and malrotation on measured tibial slope. *Orthopaedic Journal of Sports Medicine*, 11(6), 23259671231164670.
5. Cruz, C. A., Mannino, B. J., Pike, A., Thoma, D., Lindell, K., Kerbel, Y. E., ... & Bottoni, C. R. (2022). Increased posterior tibial slope is an independent risk factor of anterior cruciate ligament reconstruction graft rupture irrespective of graft choice. *Journal of ISAKOS*, 7(5), 100-104.
6. Dean, R. S., DePhillipo, N. N., & LaPrade, R. F. (2022). Posterior tibial slope in patients with torn ACL reconstruction grafts compared with primary tear or native ACL: a systematic review and meta-analysis. *Orthopaedic Journal of Sports Medicine*, 10(4), 23259671221079380.
7. Dean, R. S., DePhillipo, N. N., Chahla, J., Larson, C. M., & LaPrade, R. F. (2021a). Posterior tibial slope measurements using the anatomic axis are significantly increased compared with those that use the mechanical axis. *Arthroscopy: The Journal of Arthroscopic & Related Surgery*, 37(1), 243-249.
8. Dean, R. S., Larson, C. M., & Waterman, B. R. (2021b). Posterior tibial slope: understand bony morphology to protect knee cruciate ligament grafts. *Arthroscopy*, 37(7), 2029-2030.
9. Duerr, R. A., Ormseth, B., DiBartola, A., Geers, K., Kaeding, C. C., Siston, R., ... & Magnussen, R. A. (2023a). Association of elevated posterior tibial slope with revision anterior cruciate ligament graft failure in a matched cohort analysis. *The American Journal of Sports Medicine*, 51(1), 38-48.
10. Duerr, R., Ormseth, B., Adelstein, J., Garrone, A., DiBartola, A., Kaeding, C., ... & Magnussen, R. (2023b). Elevated posterior tibial slope is associated with anterior cruciate ligament reconstruction failures: a systematic review and meta-analysis. *Arthroscopy*, 39(5), 1299-1309.
11. Dzidzishvili, L., Allende, F., Allahabadi, S., Mowers, C. C., Cotter, E. J., & Chahla, J. (2024). Increased posterior tibial slope is associated with increased risk of meniscal root tears: a systematic review. *The American journal of sports medicine*, 52(13), 3427-3435.
12. El Kayali, M. K. D., Bürck, L. V., Fahy, S., Getgood, A., Gwinner, C., & Pichler, L. (2025). Abduction and adduction malpositioned lateral radiographs cannot be used for proper assessment of the posterior tibial slope. *Knee Surgery, Sports Traumatology, Arthroscopy*.
13. Fares, A., Horteur, C., Abou Al Ezz, M., Hardy, A., Rubens-Duval, B., Karam, K., ... & Pailhe, R. (2023). Posterior tibial slope (PTS)  $\geq 10$  degrees is a risk factor for further anterior cruciate ligament (ACL) injury; BMI is not. *European Journal of Orthopaedic Surgery & Traumatology*, 33(5), 2091-2099.
14. Franceschetti, E., Giurazza, G., Del Monaco, A., Spatuzzi, M., Campi, S., Tanzilli, A., ... & Papalia, R. (2026). Posterior tibial slope varies across functional tibial phenotypes but not CPAK categories: a radiographic analysis from the FP-UCBM Knee Study Group. *Knee Surgery, Sports Traumatology, Arthroscopy*, 34(7), 2462-2468.
15. Hees, T., Zielke, J., & Petersen, W. (2023). Effect of anterior tibial bowing on measurement of posterior tibial slope on conventional X-rays. *Archives of orthopaedic and trauma surgery*, 143(6), 2959-2964.
16. Hiyama, S., Rao, R. P., Xie, F., Takahashi, T., Shetty, V., Tandel, J., ... & Pandit, H. (2025). Posterior tibial slope is independent of coronal plane knee alignment and needs to be assessed to determine knee phenotype. *Journal of Orthopaedics*, 66, 198-203.
17. Hohmann, E., Nel, A., Zyl, R. V., Keough, N., & Mogale, N. (2025). A morphometric study of posterior tibial slope differences by sex and ethnicity in a South African population. *Surgical and Radiologic Anatomy*, 47(1), 52.
18. Ishibashi, H. K., Ishibashi, K., Ishibashi, K., Sakamoto, Y., Sasaki, E., Kimura, Y., ... & Ishibashi, Y. (2026). Steeper medial posterior tibial slope is associated with medial meniscal extrusion and early-onset knee osteoarthritis in middle-aged Japanese women: A longitudinal cohort study. *Journal of Experimental Orthopaedics*, 13(2), e70772.
19. Jain, R., Sharma, M. M., & Jain, P. (2025). Association of posterior tibial slope and Metaphysio-Diaphyseal angle with radiographic severity of knee osteoarthritis in the Indian population. *Journal of Orthopaedic Case Reports*, 15(10), 411.
20. Jayakumar, T., Hippalgaonkar, K., Savio, A., Thayer, C., & Reddy, A. G. (2025). Impact of posterior tibial slope on functional outcomes after mobile-bearing total knee arthroplasty. *Journal of Clinical Orthopaedics and Trauma*, 103296.
21. Jiang, J., Liu, Z., Wang, X., Xia, Y., & Wu, M. (2022). Increased posterior tibial slope and meniscal slope could be risk factors for meniscal injuries: a systematic review. *Arthroscopy*, 38(7), 2331-2341.
22. Kumar, P., & Gupta, A. K. (2022). Measurement of posterior tibial slope in healthy Indian population: a CT-based study. *Indian Journal of Orthopaedics*, 56(9), 1547-1553.
23. Lee, S. H., Yoo, J. H., Kwak, D. K., Kim, S. H., Chae, S. K., & Moon, H. S. (2024). The posterior tibial slope affects the measurement reliability regarding the radiographic parameter of the knee. *BMC musculoskeletal disorders*, 25(1), 202.
24. Mandalia, V., Bayley, M., Bhamber, N., Middleton, S., & Houston, J. (2023). Posterior tibial slope in anterior cruciate ligament surgery: a systematic review. *Indian Journal of Orthopaedics*, 57(9), 1376-1386.
25. Mansour III, A. A., Steward, J., Warth, R. J., Haidar, L. A., Aboulafia, A., & Lowe, W. R. (2024). Variability between full-length lateral radiographs and standard short knee radiographs when evaluating posterior tibial slope in revision ACL patients. *Orthopaedic Journal of Sports Medicine*, 12(6), 23259671241241346.
26. Pangaud, C., Laumonerie, P., Dagneaux, L., LiArno, S., Wellings, P., Faizan, A., ... & Ollivier, M. (2020). Measurement of the posterior tibial slope depends on ethnicity, sex, and lower limb alignment: a computed tomography analysis of 378 healthy participants. *Orthopaedic journal of sports medicine*, 8(1), 2325967119895258.
27. Shu, L., Abe, N., Li, S., & Sugita, N. (2022). Importance of posterior tibial slope in joint kinematics with an anterior cruciate ligament-deficient knee. *Bone & Joint Research*, 11(10), 739-750.

28. Singh, S., Chaurasia, A., Shantanu, K., Mohan, R., Chaudhary, S., Kumar, D., & Singh, A. (2023). Anatomical Variations in the Posterior Tibial Slope in the North Indian Population: A Hospital-Based Study. *Cureus*, 15(7).
29. Yaka, H., Bilge, O., Kekeç, A. F., Demiryürek, M., & Doral, M. N. (2024). Evaluation of posterior tibial slope relationship with common knee pathologies in pediatric and adolescent age groups in the Turkish population. *Journal of Pediatric Orthopaedics B*, 33(6), 531-538.
30. Zhao, D., Pan, J. K., Lin, F. Z., Luo, M. H., Liang, G. H., Zeng, L. F., ... & Liu, J. (2023). Risk factors for revision or rerupture after anterior cruciate ligament reconstruction: a systematic review and meta-analysis. *The American Journal of Sports Medicine*, 51(11), 3053-3075.