Radiograph Measurement of the Posterior Tibial Slope in Normal Chinese Adults: a Retrospective Cohort Study

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Abstract

Background: Measurement of the posterior tibial slope (PTS) angle has important applications in total knee replacement surgery, high tibial osteotomy, and anterior cruciate ligament reconstruction. The aim of this study was to determine the mean PTS of knee joints in healthy Chinese adults, and to provide data to guide knee surgery in China.

Methods: A retrospective analysis was performed using 1,257 (n=1,233, 50.4% male) DR radiograph (X-ray) plain films of participants aged 25-59 years. The picture archiving and communication system (PACS) system was used for the PTS measurement. The PTS was defined as the angle between the vertical line of the tangent of the anterior tibial cortex of the proximal tibia, and the tangent line of the tibial cortex. Two imaging physicians conducted the PTS measurements independently, and both the inter- and intraclass correlation coefficients (ICCs) were estimated.

Results: The interobserver ICC was 0.91 (95% confidence interval [CI]: 0.85-0.94), and the intraobserver ICC was 0.90 (95% CI: 0.82-0.94). The mean PTS value was 7.68±3.84° (range: 0-21°). The left PTS was significantly smaller in males than in females (7.22±3.89 vs 8.05±3.60;P<0.005). Additionally, the PTS in participants aged 25-29 years was significantly larger than that in the other age groups (Left side: 8.64±3.73 vs 6.92±3.42,7.42±3.75,7.53±3.98;P< 0.001 and Right side: 8.68±3.84 vs 7.48±4.21,7.13±3.64,7.66±3.80;P=0.004). There were no significant differences in PTS between the left and right sides. The two-way ANOVA suggested that the differences in PTS between age groups were not affected by sex.

Conclusions: This study has provided valuable information regarding the normal PTS values in Chinese adults and it has provided regionalised data to guide knee surgery. Furthermore, this study demonstrated that there were significant differences in PTS based on sex and age, highlighting the need to provide individualized treatment for knee surgery.

Background

The posterior tibial slope (PTS) is the angle formed between the vertical line of the tibial anatomical axis and the tibial plateau tangent. It reflects the tilt of the tibial plateau and plays an important role in knee joint stability and biomechanics [1-4 23, 24, 46]. Measurement of the PTS angle has important applications in total knee arthroplasty (TKA), high tibial osteotomy (HTO), and anterior cruciate ligament (ACL) reconstruction surgery [3].

Changes in the tibia posterior angle can lead to a series of significant clinical symptoms. For instance, increases in the PTS will cause the sagittal line of force to shift from the front to the back of the tibia and the contact point between the tibia and the femoral condyle to move back. This will result in increased pressure on the back of the tibial plateau, and the increase in the distance between the femoral and tibial stops of the ACL will lead to an increase in the tension on the ACL, which can cause anterior and posterior instability of the knee joint and thus, increase the risk of ACL injury [1, 14, 21, 22, 32, 35]. Conversely, a decrease in the PTS will cause the sagittal force line to move forward, and the stress on the front of the tibial plateau will increase. This will reduce the distance between the femoral and tibial stops of the posterior cruciate ligament (PCL), resulting in PCL tension [17].

After TKA, if the PTS is too large, it will increase the pressure on the back of the tibial prosthesis and the wear on the back of the prosthesis. This will increase the wear on the polyethylene prosthesis during joint movement, resulting in aseptic loosening. Conversely, if the PTS decreases, the pressure will move forward, increasing the pressure on the front of the tibia, and hence the tibial prosthesis will sink [23, 26]. Additionally, the increased PTS will change the positional relationship between the tibia and the femur. Therefore, when the knee is in the flexion position, the required knee extension force is reduced [26–29].

There are several previous studies on the measurement of PTS and there are high levels of heterogeneity among their methodologies and the measurement equipment used. Furthermore, there are large differences in the PTS values based on ethnicity [4, 8, 11, 19, 20]. Moreover, there is controversy as to whether PTS is associated with sex and age in different populations [4–6]. There is a paucity of research on the PTS in the Chinese population and therefore, the average PTS value is unknown in this population. Thus, the current study aimed to determine the mean PTS of knee joints in healthy Chinese adults. Additionally, this study aimed to explore whether there was a correlation between PTS and sex, age, and the PTS side. The data from this study could help to provide guidance for knee surgery and prosthesis manufacturers.

Methods

Study design and participants

A retrospective analysis was conducted for 9,406 knee joint radiographs (X-rays) that were completed at the Affiliated Hospital of Hangzhou Normal University, Zhejiang Province, China from 2017 to 2019. After extensive consultation with anatomists and radiologists, the latest time
for the closure of human epiphysis was determined to be 25 years of age. Preliminary experiments found that the measured values of people over 60 years of age were significantly different from the rest of the group, and the individual differences were too large, so the maximum age for inclusion was determined to be 59 years of age. The inclusion criteria were as follows: (1) age 25-59 years; (2) no joint deformity; (3) no history of congenital disease, developmental deformity or related trauma, tumours, rheumatism, or inflammation; (4) X-ray film conforms to the photography standard and the image is clear. Conversely, the exclusion criteria were as follows: (1) not Chinese in ethnicity; (2) unclosed epiphyseal; (3) obvious bone degeneration or osteoarthritis of the knee joint; (4) displaced fracture around knee and/or a history of knee surgery. Based on the collection standards, 1,233 healthy subjects (1,257 knee joints) were included in the study.

Digital radiography imaging

We used GE Healthcare Definium 6000 to take pictures in lateral views of the knee joints. The images included the distal femur, knee joint space, and proximal tibia and fibula. The knee joint space was at the centre of the image, and the femoral internal and external condyles overlapped well. The patella was displayed laterally, the gap between the patella and the femur was clearly displayed, and there was no bilateral joint on the articular surface. There was little overlap between the femoral condyle and the tibial plateau articular surface. The soft tissues were also clearly displayed.

Quantitative anatomic measurements

The PTS angle was observed and measured using GE Centricity picture archiving and communication system (PACS) software. The anterior tibial cortex method was used. First, tangent line 1 was made along the anterior cortex of the upper segment of the tibia on the lateral X-ray image to represent the long axis of the tibia. Then, perpendicular line 2 was made tangent line 1. Finally, tangent line 3 of tibial plateau was made. The angles formed by lines 2 and 3 represent the tibial posterior inclination (Figure 1) [4].

Reliability analysis

The PTS angle was measured by two imaging physicians independently (physicians engaged in musculoskeletal diagnosis), and correlation analyses between and within groups were performed. To ensure interobserver reliability, measurer A measured all the data (n=1,257) and measurer B randomly selected 80 cases for independent measurement; the measurement process used a double-blind method. To ensure intraobserver reliability, after 4 weeks, measurer A randomly selected 80 cases from all the measured data for re-measurement.

Statistical analysis

SPSS software (ver. 25.0; IBM, Armonk, NY, USA) was used for statistical analysis. T-tests were used to compare the PTS angle between the different PST sides and sexes. The one-way ANOVA test was used to compare the PTS angle between the different age groups, and the two-way ANOVA test was used to investigate the interaction of the PTS angle between age and sex. The intraclass correlation coefficients (ICCs) together with their 95% confidence intervals (CIs) were used to evaluate the inter- and intraobserver correlations between the two observers; 0.75≤ICCs≤1.00 was considered to be good agreement. P-values<0.05 were considered statistically significant.

Ethics

Ethical approval was obtained from the institutional review board of the affiliated hospital of Hangzhou Normal University (Reference number: 2021(E2)-KS-074). The need for informed consent was waived due to the use of anonymized patient data and the retrospective study design.

Results

The PTS with interobserver ICCs of 0.91 (95% confidence interval [CI]: 0.85-0.94) and intraobserver ICCs of 0.90 (95% CI: 0.82-0.94) were considered to be of high inter- and intraobserver reliability.

The 1,233 subjects (50.4% males) were divided into four age groups: group A was comprised of 25-29 year old's (n=306, 24.8%), group B was comprised of 30-39 year old's (n=306, 24.8%), group C was comprised of 40-49 year old's (n=320, 26.0%), and group D was comprised of 50-59 year old's (n=301, 24.4%) (Table 1). In 637 and 620 cases of the left and right knees, the PTS was 7.64±3.77° (range: 0-20°) and 7.72±3.91 (range: 0-21°), respectively (Table 2). Independent sample t-tests showed that there was no significant difference in PTS between the left and right sides (P>0.05) (Table 2). However, the average PTS value on the left side was significantly smaller in males than in females (7.22° vs. 8.05°, P=0.005) (Table 2, Figure 2). The one-way ANOVA test showed that there were significant differences in PTS based on age grouping (left
PTS: P<0.001; right PTS: P=0.004). PTS of the 25-29 age group was significantly greater than the other age groups. The 30-39 and 40-49 year old age groups had smaller average PTS, while the 50-59 year old age group had a slightly larger mean PTS than the 30-39 and 40-49 year old age groups (Table 4, Figure 3). The two-way ANOVA test showed that the difference in PTS between the age groups was independent of sex (P>0.05) (Table 5).

| Characteristics | N(%) |
|-----------------|------|
| Sex             |      |
| Male            | 621(50.4) |
| Female          | 612(49.6) |
| Age, yrs.       |      |
| Group A(25-29)  | 306(24.8) |
| Group B(30-39)  | 306(24.8) |
| Group C(40-49)  | 320(26.0) |
| Group D(50-59)  | 301(24.4) |

Table 2
Distribution of the mean PTS (*)

| PTS(*) | N   | Mean | SD  | Range | T value | P value | Mean ± SD for all |
|--------|-----|------|-----|-------|---------|---------|------------------|
| Left side | 637 | 7.64 | 3.77 | 0-20   | -0.37   | 0.71    | 7.68±3.84 |
| Right side | 620 | 7.72 | 3.91 | 0-21   |         |         |                  |

Table 3
PTS(*) characteristics by sex

|        | Male |     |     | Female |     |     | T value | P value |
|--------|------|-----|-----|--------|-----|-----|---------|---------|
|        | N    | Mean| SD  | N      | Mean| SD  |         |         |
| Left side | 321 | 7.22| 3.89| 316    | 8.05| 3.60| -2.79   | 0.005   |
| Right side | 309 | 7.68| 3.89| 311    | 7.75| 3.93| -0.21   | 0.83    |

Table 4
PTS(*) characteristics by age groups

|        | Group A (25-29) | Group B (30-39) | Group C (40-49) | Group D (50-59) |        |        | F value | P value |
|--------|-----------------|-----------------|-----------------|-----------------|--------|--------|---------|---------|
|        | Mean (N)        | SD              | Mean (N)        | SD              | Mean (N)        | SD              |         |         |
| Left side | 8.64 (163)    | 3.73            | 6.92 (155)     | 3.42            | 7.42 (165)     | 3.75            | 7.53 (154) | 3.98 | 6.09 | < 0.001 |
| Right side | 8.68 (145)    | 3.84            | 7.48 (155)     | 4.21            | 7.13 (165)     | 3.64            | 7.66 (155) | 3.80 | 4.45 | 0.004  |
Table 5

PTS(°) characteristics by sex and age groups

| Age Group | Male | Female | F value | P value |
|-----------|------|--------|---------|---------|
|           | Sex | Age | Sex*Age |
|           | N=88 | N=76 | N=75 | N=72 | N=90 | N=79 | N=76 | N=84 |
| Left side |     |      |        |        |        |      |      |      |
| A         | 8.36±3.82 | 6.45±3.62 | 7.06±4.14 | 8.96±3.62 | 7.37±3.17 | 7.89±3.73 | 8.07±3.74 | 9.12 | 6.42 | 0.12 | 0.003 | <0.001 | 0.95 |
| B         | N=76 | N=75 | N=82 |      |
| Right side |     |      |        |        |        |      |      |      |
| A         | 8.78±3.89 | 7.25±4.42 | 7.50±3.41 | 7.32±3.70 | 8.59±3.82 | 7.72±3.99 | 6.69±3.97 | 7.95 | 1.15 | 0.007 | 4.62 | 0.94 | 0.003 |
| B         | N=79 | N=90 | N=71 | N=76 | N=75 | N=84 |

Discussion

The stability of the knee joint is composed of dynamic and static structures. The surrounding muscle tissue plays the role of providing dynamic stability, whereas the bone structure, joint capsule, and attached ligaments play the roles of providing static stability. The size directly affects the position of the sagittal force line of the lower limbs, which in turn affects the stability of the knee joint [8]. The PTS angle is defined as the angle formed by the vertical line of the tibial anatomical axis and the tibial plateau tangent [1]. There are many measurement methods for the PTS, which include X-ray, computed tomography (CT), and magnetic resonance imaging (MRI). The advantage of CT and MRI is that they can accurately measure the inner tibia and lateral posterior angle. However, their disadvantages, which include low equipment penetration, long inspection times, high costs, the need for patient cooperation, and the small scanning range, make it difficult to determine the anatomical axis of the tibia, thus requiring standard methods for interpretation. These methods are used less in clinical practice. The advantages of X-rays are the high equipment penetration rates, quick inspection times, low prices, reduced need for patient cooperation, large irradiation range, ease of ability to determine the anatomical axis of the tibia, ability of clinicians to complete the measurements independently, and ability to use them for pre- and post-evaluations. The disadvantage in using X-rays for measurement is the difficulty in distinguishing the medial and lateral plateaus of the tibia, as the lateral image requires the medial and lateral platforms to overlap [9]. Therefore, the X-ray measurement values lack consistency when compared with CT and MRI [10]. At the same time, there are many methods that can be used to obtain X-ray measurements, including: anterior tibial cortex (ATC), posterior tibial cortex (PTC), tibial proximal anatomical axis (TPAA), tibial shaft anatomical axis (TSAA), fibular proximal anatomical axis (FPAA), and fibular shaft axis (FSA) [7, 30–32]. Despite the differences between the various methods (Table 6), there is still a strong correlation between the PTS values measured using the different methods [24]. At present, the clinically most widely adopted methods are the TPAA and the ATC. The extramedullary positioning method is often used in knee surgery, during which the positioning rod is parallel to the ATC, and then the PTS is measured with reference to the positioning rod. Thus, the PTS value measured using the ATC method is often referred to in preoperative planning. The current study employed the ATC method. In order to obtain the PTS of normal adults and reduce the measurement errors, the adolescents with unclosed epiphyses and those greater than 60 years of age were excluded. This was mainly because of the diversity of epiphyseal morphology and because the formation of osteophytes will affect the determination of the tangent tibial plateau. At the same time, the knee joints with fractures, bone tumours, osteoarthritis, knee joint surgery, congenital skeletal dysplasia, and knee joint X-rays that did not meet the imaging standards were excluded [11]. In order to avoid measurement errors, Kacmaz et al. [8, 11] excluded subjects with unclosed epiphyses and bone disease when conducting PTS angle studies.
the prosthesis, narrow the knee joint space, reduce the range of flexion, and the postoperative stiffness loosening of prostheses. Conversely, a decrease in PTS will cause the sagittal force line to move forward, increase the tension on the PCL, sink thereby increasing the risk of ACL injury. Similarly, it will also increase the wear on the polyethylene prosthesis during TKA, resulting in aseptic stability after TKA. Excessive PTS will cause the tibia to move forward, the knee joint to become unstable, and the ACL to become tensioned, Relevant studies have shown that the PTS angle will affect the flexion gap, PCL tension, patellofemoral joint contact stress, and knee joint stability. In knee surgery, such as TKA and ACL reconstruction, PTS plays a vital role in preoperative decision-making and postoperative evaluation. 

| Author          | Year | Sample size | Sample | Country/region | Age | Sex          | Measurement method | Measurement principle | PTS Range | Mean ± SD |
|-----------------|------|-------------|--------|----------------|-----|--------------|--------------------|-----------------------|------------|-----------|
| The current research | 2021 | 1233        | Healthy adults | China | 25-59 | Male and Female | X-ray               | ATC                   | 0-21       | 7.68±3.84 |
| Bao et al. [7]  | 2021 | 80          | Healthy adults | China | 20-45 | Male and Female | CT                 | TPAA                  | Medial: 0.05-12.04 | Lateral: 6.78 |
| Misr et al. [19] | 2018 | 1000        | Healthy adults | Turkey | 18-92 | Male and Female | X-ray               | TPAA                  | 2.1-18.7   | 8.36±3.3  |
| Han et al. [6]  | 2016 | 535         | non-arthritis knees of adults | Korea | 20-79 | Male and Female | MRI                | TPAA                  | Medial: 6.82±1.81 | Lateral: 6.09±1.73 |
| Zhang et al. [20] | 2014 | 80          | Healthy adults | China | 20-45 | Male and Female | CT                 | TPAA                  | 8.4±3.1    | 11.5±2.8  |
| Chiu et al. [4] | 2000 | 50          | Body    | China | 17-94 | Male and Female | X-ray               | ATC                   | 5-22       | 14.7±3.7  |

| Author          | Year | Sample size | Sample | Country/region | Age | Sex          | Measurement method | Measurement principle | PTS Range | Mean ± SD |
|-----------------|------|-------------|--------|----------------|-----|--------------|--------------------|-----------------------|------------|-----------|
| Kawamura et al. [8] | 2020 | 1024        | Healthy adults | Turkey | 18-92 | Male and Female | X-ray               | TPAA                  | 2.1-18.7   | 8.36±3.3  |
| Misr et al. [19] | 2018 | 1000        | Healthy adults | Turkey | 18-50 | Male and Female | MRI                | TPAA                  | 4.9±1.9    |           |
| Han et al. [6]  | 2016 | 535         | non-arthritis knees of adults | Korea | 20-79 | Male and Female | MRI                | TPAA                  | Medial: 6.82±1.81 | Lateral: 6.09±1.73 |
| Zhang et al. [20] | 2014 | 80          | Healthy adults | China | 20-45 | Male and Female | CT                 | TPAA                  | 8.4±3.1    | 11.5±2.8  |
| Chiu et al. [4] | 2000 | 50          | Body    | China | 17-94 | Male and Female | X-ray               | ATC                   | 5-22       | 14.7±3.7  |

ATC (anterior tibial cortex), TPAA (tibial proximal anatomical axis), PTC (posterior tibial cortex)

X-ray lateral inspection: line 1 is the tangent line of the proximal tibia on the anterior cortex surface, line 2 is the perpendicular to line 1, and line 3 is the tangent line of the tibial plateau

Most of the previous studies have shown that the PTS differs based on race and region [4, 5, 6, 34-41]. Even if the same ATC measurement method is used, there are still significant differences in the measurement results (Table 6). However, in previous studies, different measurement methods were used, and there was still a strong correlation between the obtained values [13]. In this study, the mean PTS in normal adult knee joints in China was 7.68±3.84° (range: 0-21°). Chiu et al. [4] used the ATC method to measure the knee joints of 50 Chinese people (cadavers) and found that the mean PTS value was 14.7±3.7° (range: 5-22°). The findings from this study are very different from those in other studies. This is mainly because of the small sample size, and the specific age and sex composition of the included participants. In the current study, we found that the PTS was significantly related to age and sex. These findings are similar to those reported by Marouane et al. [12, 13]. Using MRI measurements, Hashemi et al. found that the PTS on both the medial and lateral sides were larger in women than in men. However, Kacmaz et al. [8] found that the PTS of men was greater than that of women in a Turkish population. Medda et al. [33] found that there was no significant correlation between the PTS and sex in studies including Indians. In this study, there were no significant differences in the PTS between the left and right sides (P>0.05), and these findings were similar to those reported by Kacmaz et al. [8, 14, 15]. In this study, the difference in the PTS between the different age groups was not affected by sex. However, the study by Sun et al. [16] found that the PTS of men 0-9 and 30-39 years of age was greater than that of women, while the results were opposite among those 40-49, 60-69, 70-79, and 80-89 years of age. People aged 0-9, 10-19, 50-59, 60-69, and 80-89 years had greater PTS on the left than on the right side.

In knee surgery, such as TKA and ACL reconstruction, PTS plays a vital role in preoperative decision-making and postoperative evaluation [17]. Relevant studies have shown that the PTS angle will affect the flexion gap, PCL tension, patellofemoral joint contact stress, and knee joint stability after TKA. Excessive PTS will cause the tibia to move forward, the knee joint to become unstable, and the ACL to become tensioned, thereby increasing the risk of ACL injury. Similarly, it will also increase the wear on the polyethylene prosthesis during TKA, resulting in aseptic loosening of prostheses. Conversely, a decrease in PTS will cause the sagittal force line to move forward, increase the tension on the PCL, sink the prosthesis, narrow the knee joint space, reduce the range of flexion, and the postoperative stiffness [18]. Therefore, the insurance of the
accuracy of the PTS measurements is the key component of knee biomechanical balance. Prosthesis manufacturers recommend a PTS angle of 3-7° during TKA. Okamoto et al. [28] believe that maintaining the PTS at approximately 5° after TKA might be best. The mean PTS angle in this study was 7.68±3.84°, which is slightly larger than the value recommended by the prosthesis manufacturer. Therefore, in the Chinese population, the prosthesis manufacturer should adjust the recommended value appropriately. Seo et al. [43] studied 768 patients who underwent TKA and found that the PTS angle (3° to -1°) was better, according to the change in PTS that was calculated by subtracting the preoperative from the postoperative PTS. These authors emphasized that patients with a larger PTS angle pre-surgery should maintain a larger PTS angle post-surgery. This will assist the degree of motion of the knee joint after surgery. Kızılgöz et al. [44] emphasized that the PTS angle measured by X-ray lateral radiographs is very important for determining the risk of ACL injury. Song et al. [22] hypothesize that PTS >10° was an independent risk factor for tibial anterior displacement and ACL injury. Smith et al. [45] believe that other factors may also be involved in ACL injury, such as ligament relaxation and hormone levels. The normal range of PTS values among healthy adult knee joints in China identified in this study will benefit the local bone and joint surgeons and provide guidance to support personalized and precise treatment.

This study was subject to several limitations. China covers a vast territory, including a large population, with various ethnic groups. Thus, our sample was likely not representative of all the individuals within the population. The PTS angle was measured using manual methods, and even if the consistency was good, it is likely there was still some measurement error. Thus, computer artificial intelligence (AI) assisted measurement is necessary in order to reduce the workload and to achieve better consistency and standardisation. Thus, future studies should include a larger sample size, and AI-assisted measurement software should be trialed.

**Conclusion**

This study measured the mean PTS value of healthy adult knee joints in China using a large population sample, and found that there were significant differences in the PTS angle of healthy Chinese adults based on sex and age. Future studies should investigate how big these differences are based on race and geographic region. The data provided in this study can provide a framework for knee surgery and prosthesis manufacturers.

**Abbreviations**

PTS, Posterior tibial slope; PACS, Picture archiving and communication system; ICCs, Intraclass correlation coefficients; CI, Confidence interval; TKA, Total knee arthroplasty; HTO, High tibial osteotomy; ACL, Anterior cruciate ligament; PCL, Posterior cruciate ligament; CT, Computed Tomography; MRI, Magnetic resonance imaging; ATC, Anterior tibial cortex; PTC, Posterior tibial cortex; TPAA, Tibial proximal anatomical axis; TSAA, Tibial shaft anatomical axis; FPAA, Fibular proximal anatomical axis; FSA, Fibular shaft axis; AI, Artificial intelligence

**Declarations**

**Ethics approval and consent to participate**

The study is carried out in accordance with relevant guidelines and regulations. Approvals for this study and report were obtained from the Medical Ethics Committee of the Affiliated Hospital of Hangzhou Normal University, in reference number 2021(E2)-KS-074. The informed consent was waived by the Medical Ethics Committee as it was a retrospective study utilizing the data and images with the patients’ identification information all removed.

**Consent for publication**

Not applicable.

**Availability of data and materials**

The datasets used in the current study are available from the corresponding author upon reasonable request and with permission of the affiliated hospital of Hangzhou Normal University. However, restrictions apply and the data are not publicly available.

**Competing interests**

The authors declare that they have no competing interests.
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Authors’ contributions

YC, JL and JPD designed the study; YC, JL, MY, MKW, TT, BYL and XLD collected the data; YC, JL, SYD, JY and JPD analyzed and interpreted the data; YC and JL wrote the main manuscript text; YC, JL, SYD and JPD ensured the accuracy of the data. YC, JL, JPD, SYD, JY, MKW, TT, GHC and XLD participated in revising the manuscript. All authors reviewed the manuscript.

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References

1. Giffin JR, Vogrin TM, Zantop T, et al. Effects of increasing tibial slope on the biomechanics of the knee. Am J Sports Med. 2004;32(2):376–82. doi: 10.1177/0363546503258880.
2. Ahmad R, Patel A, Mandalia V, et al. Posterior tibial slope: effect on, and interaction with, knee kinematics. JBJS Rev. 2016;4(4):e31-6. doi: 10.2106/JBJS.RVW.00057.
3. Bernhardson AS, DePhillipo NN, Daney BT, Kennedy MI, Aman ZS, LaPrade RF. Posterior Tibial Slope and Risk of Posterior Cruciate Ligament Injury. Am J Sports Med. 2019;47(2):312–317. doi: 10.1177/0363546518819176.
4. Chiu KY, Zhang SD, Zhang GH. Posterior slope of tibial plateau in Chinese. J Arthroplasty. 2000;15(2):224–227. doi: 10.1016/s0883-5403(00)90330-9.
5. Fan L, Xu T, Li X, Zan P, Li G. Morphologic features of the distal femur and tibia plateau in Southeastern Chinese population: a cross-sectional study. Medicine. 2017;96(46):e8524. doi: 10.1097/MD.0000000000008524.
6. Han H, Oh S, Chang CB, Kang SB. Anthropometric difference of the knee on MRI according to gender and age groups. Surg Radiol Anat. 2016;38(2):203–211. doi: 10.1007/s00276-015-1536-2.
7. Bao L, Rong S, Shi Z, Wang J, Zhang Y. Measurement of femoral posterior condylar offset and posterior tibial slope in normal knees based on 3D reconstruction. BMC Musculoskeletal Disorders. 2021;22(1):486. doi: 10.1186/s12891-021-04367-6.
8. Kacmaz IE, Topkaya Y, Basa CD, et al. Posterior tibial slope of the knee measured on X-rays in a Turkish population. Surg Radiol Anat. 2020;42(6):673–679. doi: 10.1007/s00276-020-02430-w.
9. Kessler MA, Burkhart A, Martinet V, et al. Development of a 3-dimensional method to determine the tibial slope with multislice-CT. Z Orthop Ihre Grenzgeb. 2003;141(2):143–147. doi: 10.1055/s-2003-38658.
10. Utzschneider S, Goettinger M, Weber P, et al. Development and validation of a new method for the radiologic measurement of the tibial slope. Knee Surg Sports Traumatol Arthosc. 2011;19(10):1643–1648. doi: 10.1007/s00167-011-1414-3.
11. Hashemi J, Chandrashekar N, Gill B, Beynnon B, Slaughterbeck J R, et al. The geometry of the tibial plateau and its influence on the biomechanics of the tibiofemoral joint. J Bone Joint Surg Am. 2008;90(12):2724-2734. doi: 10.2106/JBJS.G.01358.
12. Bisicchia S, Scordo GM, Prins J, Tudisco C. Do ethnicity and gender influence posterior tibial slope? J Orthop Traumatol. 2017;18(4):319–324. doi: 10.1007/s10195-017-0443-1.
13. Marouane H, Shirazi-Adl A, Adouni M, Hashemi J. Steeper posterior tibial slope markedly increases ACL force in both active gait and passive knee joint under compression. J Biomech. 2014;47(6):1353-1359. doi: 10.1016/j.jbiomech.2014.01.055.
14. Khattak MJ, Umer M, Davis ET, Habib M, Ahmed M. Lower-limb alignment and posterior tibial slope in Pakistanis: a radiographic study. J Orthop Surg (Hong Kong), 2010;18(1): 22–25. doi: 10.1177/230949901001800105.
15. AL Juhani WS, Qasim SS, Atrasheed A, AWTalawal J, ALSalman MJ. The effect of gender, age, and body mass index on the medial and lateral posterior tibial slopes: a magnetic resonance imaging study. Knee Surg Relat Res. 2021;33(1):12. doi: 10.1186/s43019-021-00095-2.
16. Sun YH, Chen LX, Jiao ZD, Wang L, Zhang RM, et al. Age-related changes of posterior tibial slope and its roles in anterior cruciate ligament injury. Int Surg. 2016;101(1-2):70–77. doi: 10.9738/INTSURG-D-15-00127.1.
17. Kang KT, Koh YG, Son J, Kwon O-R, Lee J-S, et al. A computational simulation study to determine the biomechanical influence of posterior condylar offset and tibial slope in cruciate retaining total knee arthroplasty. Bone Joint Res. 2018;7(1):69–78. doi: 10.1002/2046-3758.71.BJR-2017-0143.R1.

18. Okazaki K, Tashiro Y, Mizu-uchi H, Hamai S, Doi T, et al. Influence of the posterior tibial slope on the flexion gap in total knee arthroplasty. Knee. 2014, 21(4): 806-809. doi: 10.1016/j.knee.2014.02.019.

19. Misir A, Yildiz KI, Kizkapan TB. Wider femoral and medially narrower tibial components are required for total knee arthroplasty in Turkish patients. Knee Surg Sports Traumatol Arthrosc. 2019;27(7):2155–2166. doi: 10.1007/s00167-019-05448-9. Epub 2019 Mar 1.

20. Zhang Y, Wang J, Xiao J, Zhao L, Li Z, Htt et al. Measurement and comparison of tibial posterior slope angle in different methods based on three-dimensional reconstruction. Knee. 2014;21(3):694-698.doi: 10.1016/j.knee.2014.01.008.

21. Webb JM, Salmon LJ, Leclerc E, Pinczewski LA, Roe JP. Posterior tibial slope and further anterior cruciate ligament injuries in the anterior cruciate ligament-reconstructed patient. Am J Sports Med. 2013;41(12): 2800–2804. doi: 10.1177/0363546513503288.

22. Song GY, Zhang H, Zhang J, Liu X, Xue Z, et al. Greater static anterior tibial subluxation of the lateral compartment after an acute anterior cruciate ligament injury is associated with an increased posterior tibial slope. Am J Sports Med.2018;46(7): 1617–1623. doi: 10.1177/0363546518760580.

23. Han HS, Chang CB, Seong SC, Lee S, Lee MC. Evaluation of anatomic references for tibial sagittal alignment in total knee arthroplasty. Knee Surg Sports Traumatol Arthrosc.2008;16(4):373–377. doi: 10.1007/s00167-008-0486-1.

24. Dean RS, DePhillipo NN, Chahla J, Larson CM, LaPrade RF. Posterior Tibial Slope Measurements Using the Anatomic Axis Are Significantly Increased Compared With Those That Use the Mechanical Axis. Arthroscopy. 2021;37(1):243–249. doi: 10.1016/j.arthro.2020.09.006.

25. Kang KT, Koh YG, Son J, Kwon O-R, Lee J-S, et al. A computational simulation study to determine the biomechanical influence of posterior condylar offset and tibial slope in cruciate retaining total knee arthroplasty. Bone Joint Res.2018;7(1): 69–78. doi: 10.13002/bonejournals3578-71.BJR-2017-0143.R1.

26. Chambers AW, Wood AR, Kosmopoulos V, Sanchez HB, Wagner RA. Effect of posterior tibial slope on flexion and anterior-posterior tibial translation in posterior cruciate-reparing total knee arthroplasty. J Arthroplasty.2016; 31(1): 103–106. doi: 10.1016/j.arthro.2015.08.027.

27. Faschingbauer M, Sgroi M, Juchems M, Reichel H, Kappe T. Can the tibial slope be measured on lateral knee radiographs? Knee Surg Sports Traumatol Arthrosc.2014;22(12):3163–3167. doi: 10.1007/s00167-014-2864-1.

28. Okamoto S, Mizu-uchi H, Okazaki K, Hamai S, Nakahara H, et al. Effect of tibial posterior slope on knee kinematics, quadriceps force, and patellofemoral contact force after posterior-stabilized total knee arthroplasty. J Arthroplasty.2015;30(8): 1439–1443. doi: 10.1016/j.arth.2015.02.042.

29. Kang KT, Koh YG, Son J, Kwon O-R, Lee J-S, et al. Biomechanical effects of posterior condylar offset and posterior tibial slope on quadriceps force and joint contact forces in posterior-stabilized total knee arthroplasty. Biomed Res Int.2017;2017(2): 1-12.doi: 10.1155/2017/4908639.

30. Kim KH, Bin SI, Kim JM. The Correlation between Posterior Tibial Slope and Maximal Angle of Flexion after Total Knee Arthroplasty. Knee Surg Relat Res. 2012;24(3):158–163. doi: 10.5792/kssr.2012.24.3.158.

31. Oka S, Matsumoto T, Muratsu H, Kubo S, Matsushita T, et al. The influence of the tibial slope on intra-operative soft tissue balance in cruciate-retaining and posterior-stabilized total knee arthroplasty. Knee Surg Sports Traumatol Arthrosc. 2014;22(8):1812–1818. doi: 10.1007/s00167-014-2864-1.

32. Yoo JH, Chang CB, Shin KS, Seong SC, Kim TK. Anatomical references to assess the posterior tibial slope in total knee arthroplasty: a comparison of 5 anatomical axes. J Arthroplasty. 2008, 23(4):586–592. doi: 10.1016/j.arth.2007.05.006.

33. Medda S, Kundu R, Sengupta S, Pal AK. Anatomical variation of posterior slope of tibial plateau in adult Eastern Indian population. Indian J Orthop. 2017;51(1):69–74. doi: 10.4103/0019-5413.197545.

34. Ho WP, Cheng CK, Liao JJ. Morphometric measurements of resected surface of femurs in Chinese knees: correlation to the sizing of current femoral implants. Knee.2006;13(1):12–14.doi: 10.1016/j.knee.2005.05.002.

35. Hohmann E, Bryant A, Reaburn P, Tetsworth K. Is there a correlation between posterior tibial slope and non-contact anterior cruciate ligament injuries? Knee Surg Sports Traumatol Arthrosc.2011;19(Suppl 1):S109–S114. doi: 10.1007/s00167-011-1547-4.

36. Faschingbauer M. Editorial Commentary: Posterior Tibial Slope: The "Unknown Size" of the Knee Joint. Arthroscopy. 2021;37(1):250–251. doi: 10.1016/j.arthro.2020.10.024.

37. De Boer JJ, Blankvoort L, Kingma I, Vorster W. In vitro study of inter-individual variation in posterior slope in the knee joint. Clin Biomech (Bristol, Avon). 2009;24:488–492. doi: 10.1016/j.clinbiomech.2009.03.008.

38. Noyes FR, Goebel SX, West J. Opening wedge tibial osteotomy: the 2-triangle method to correct axial alignment and tibial slope. Am J Sports Med.2005;33(3):378–387. doi: 10.1177/0363546504269034.

39. Zeng C, Gao SG, Wei J, Yang TB, Cheng L, et al. The influence of the intercondylar notch dimensions on injury of the anterior cruciate ligament: a meta-analysis. Knee Surg Sports Traumatol Arthrosc. 2013;21(4):804–815. doi: 10.1007/s00167-012-2166-4.
40. Vaidya SV, Ranawat CS, Aroojis A, Laud NS. Anthropometric measurements to design total knee prostheses for the Indian population. J Arthroplasty. 2000;15(1):79–85. doi: 10.1016/s0883-5403(00)91285-3.

41. Kuwano T, Urabe K, Miura H, Nagamine R, Matsuda S, et al. Importance of the lateral anatomic tibial slope as a guide to the tibial cut in total knee arthroplasty in Japanese patients. J Orthop Sci. 2005;10(1):42–47. doi: 10.1007/s00776-004-0855-7.

42. Kang KT, Koh YG, Son J, Kwon OR, Lee JS, et al. Influence of increased posterior tibial slope in total knee arthroplasty on knee joint biomechanics: a computational simulation study. J Arthroplasty. 2018;33(2):572–579. doi: 10.1016/j.arth.2017.09.025.

43. Seo SS, Kim CW, Kim JH, Min YK. Clinical results associated with changes of posterior tibial slope in total knee arthroplasty. Knee Surg Relat Res. 2013;25(1):25–29. doi: 10.5792/ksrr.2013.25.1.25.

44. Kızılgöz V, Sivrioğlu AK, Ulusoy GR, Yildiz K, Aydin H, et al. Posterior tibial slope measurement on lateral knee radiographs as a risk factor of anterior cruciate ligament injury: A cross-sectional study. Radiography (Lond). 2019;25(1):33–38. doi: 10.1016/j.radi.2018.07.007.

45. Smith HC, Vacek P, Johnson RJ, Slaunwhite JR, Hashemi J, et al. Risk factors for anterior cruciate ligament injury: a review of the literature. Part 1: neuromuscular and anatomic risk. Sports Health. 2012;4(1):69–78. doi: 10.1177/1941738111428281.

46. Nagamine R, Kawasaki M, Kim KI, Sakai A, Suguro T. The posterior tibial slope is mainly created by the posterior rotation of the tibial condyles. J Orthop Surg (Hong Kong). 2020;28(3):2309499020975580. doi: 10.1177/2309499020975580.

**Figures**

![Figure 1](image_url)

**Figure 1**

The measurement method of posterior tibial slope (PTS)*

*X-ray lateral inspection: line 1 is the tangent line of the proximal tibia on the anterior cortex surface, line 2 is the perpendicular to line 1, and line 3 is the tangent line of the tibial plateau*
Figure 2

Distribution of posterior tibial slope (PTS) (°) by genders
Figure 3

Distribution of posterior tibial slope PTS (°) by genders and age groups