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 $7.68 \pm 3.84^\circ$ (range: $0-21^\circ$). 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; $0.75 \leq \text{ICCs} \leq 1.00$ was considered to be good agreement. $P\text{-values} < 0.05$ 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 $7.64 \pm 3.77^\circ$ (range: $0\text{-}20^\circ$) and 7.72 ± 3.91 (range: $0\text{-}21^\circ$), 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).

Table 1
Demographics of the study
participants (N=1233)

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 $\pm$ SD for all
Left side	637	7.64	3.77	0-20	-0.37	0.71	7.68 $\pm$ 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	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

FIS() characteristics by sex and age groups														
Male					Female				F value			P value		
Age	Group A	Group B	Group C	Group D	Group A	Group B	Group C	Group D	sex	age	sex*age	sex	age	sex*age
Left side	8.36	6.45±	6.85	7.06	8.96	7.37	7.89	8.07	9.12	6.42	0.12	0.003	< 0.001	0.95
	±	3.62	±	±	±	±	±	±						
	3.82		3.72	±	3.62	3.17	3.73	3.74						
	N=88	N=76	3.72	4.14	N=75	N=79	N=90	N=72						
Right side	8.78	7.25	7.50	7.32	8.59	7.72	6.69	7.95	0.007	4.62	1.15	0.94	0.003	0.33
	±	±	±	±	±	±	±	±						
	±													
	3.89	4.42	3.41	3.70	3.82	3.99	3.87	3.88						
	N=69	N=79	N=90	N=71	N=76	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.

Table 6
Comparison with previous similar research

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: -0.30-14.99	Medial: 6.78 Lateral: 6.11
Kacmaz IE et al. [8]	2020	1024	Healthy adults	Turkey	18-92	Male and Female	X-ray	TPAA	2.1–18.7	8.36±3.3
Misir 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-arthritic knees of adults	Korean	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
								ATC		11.5±2.8
								PTC		6.3±3.2
Chiu et al. [4]	2000	50	Body	China	17-94	Male and Female	X-ray	ATC	5-22	14.7±3.7
								TPAA	2-18.5	11.5±3.6
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 $\pm$ 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 $\pm$ 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 $7.68 \pm 3.84^\circ$, 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 $PTS > 10^\circ$ 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, JY, 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, JY, 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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Figures

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