Title

Comparative Analysis of Posterior Tibial Slope Measurements: Accuracy and Reliability of Radiographs and CT

Abstract

Introduction

This study aimed to evaluate the accuracy and reliability of posterior tibial slope (PTS) measurements obtained from radiographs and CT. PTS, particularly its differences in medial and lateral measurements, plays a crucial role in knee alignment, and inconsistencies in measurement techniques across different imaging modalities have raised concerns about accuracy.

Materials and Methods

This retrospective study included data from 98 Japanese patients legs and 324 Chinese patients legs. PTS was measured on long-leg and short-leg radiographs and CT. Two independent surgeons assessed the measurements, and the inter- and intra-observer reliability were evaluated. The primary outcome was the comparison of medial and lateral PTS measurements, while the secondary aim was to assess the impact of tibial length on measurement accuracy.

Discussion

The study revealed that lateral PTS was consistently smaller than medial PTS, with an average difference of 1.2° to 1.9°. Shorter leg radiographs tend to underestimate PTS compared to full-length tibial measurements. The correlation between measurements from short and long leg radiographs showed that PTS measurements were more prone to errors, which may be due to anatomical factors such as tibial bowing. Inter- and intra-observer reliability were good for medial PTS but poor to moderate for lateral PTS, especially when using radiographs.

Conclusion

For accurate measurement of both medial and lateral PTS, surgeons should consider using additional examination methods such as CT and MRI. If PTS is to be measured on radiographs, the focus should be on the medial PTS, as it tends to provide more reliable results.

Keywords:

Posterior tibial slope (PTS), knee alignment, radiographs, computed tomography (CT), medial PTS, lateral PTS, inter-observer reliability, intra-observer reliability, sagittal alignment, knee surgery

Introduction

Any joint arthroplasty procedure requires significant planning and thorough analysis of individual radiographs. This is particularly true for the knee joint as its alignment is in part dependent upon the position and integrity of ipsilateral hip and ankle joint. Numerous alignment schemes have been utilized in knee arthroplasty surgery based on radiographs. Evidence from recent studies indicate that only up to 17% of native knees have a neutral mechanical alignment (MA) i.e. a straight leg with the line joining the centre of the femoral head to the centre of the ankle goes through the centre of the intercondylar notch (1, 2). Neutral MA of the knee is defined by a mechanical hip-knee-ankle angle of $0^{\circ} \pm 3^{\circ}$ (mHKA)(1). This has spurred a growing emphasis on restoring patient-specific knee alignment, leading to the development of more complex and comprehensive knee alignment classification systems, such as the Functional Knee Phenotype classification(3), the Coronal Plane Alignment of the Knee (CPAK) classification(1), and the Coronal Extraarticular Deformity Phenotype (CEDP) classification(4). These classification systems categorize the knees into various phenotypes based upon their coronal plane disposition.

Personalized knee alignment is increasingly popular, focusing primarily on the coronal plane but often overlooking sagittal plane alignment which is primarily determined by the posterior tibial slope (PTS). Changes in the PTS affect posterior cruciate ligament (PCL) function. An increase in PTS may also lead to greater strain and overload on collateral ligaments, resulting in abnormal forces at the implant-bone interface and potential instability or excessive wear(5, 6). Conversely, reduced PTS could compromise knee stability, particularly during fixation, altering load distribution and potentially affecting the PCL's ability to provide posterior stability(5, 6). It is therefore important to assess both coronal and sagittal plane alignments, yet there is no universally agreed-upon technique to measure PTS. Typically, short leg lateral films are used in clinical practice, along with long leg anteroposterior (AP) alignment views. Short-leg films tend to underestimate the PTS(8) as they do not take into consideration the impact of sagittal tibial bow which can only be evident on long leg films or on CT scans which capture the entire lower leg(7, 8). In cases with a higher anterior bowing angle of the tibia, a short tibial shaft axis connecting mid-diaphyseal points at 6 and 10 cm below the tibial plateau as suggested by Dejour et al. (9) will underestimate the PTS. Indeed, the gold standard for assessing PTS is its measurement on computed tomography (CT) images(10). CT images allow accurate assessment of the medial as well as the lateral posterior tibial slope(11) which tend to differ with lateral being usually less than the medial PTS. In addition, length of the lower leg available for radiographic assessment can influence the accuracy of PTS measurement(12).

As CT scans and long-leg lateral films are not routinely captured, it is not known if there is an error (and if so, what is its magnitude) in the measurement of PTS when assessed using short leg films Vs long leg lateral films Vs CT scans. The primary aim of this research is to establish the accuracy and reproducibility of measuring PTS in patients on CT scans vs long leg radiographs. The secondary aim is to establish the accuracy and reproducibility of measuring PTS on long Vs short leg radiographs.

Materials and Methods

2.1. Patient enrollment

This study was retrospective analysis of prospectively collected data from two centers. The institutional review board of the ethics committee at the institution approved the study. The ethics approval number is 24-066.

The inclusion criteria included consecutive Japanese and Chinese patients who visited their respective outpatient clinic for knee-related complaints and underwent either a full-length lateral x-ray, a full-length lateral CT scan, or a long-leg standing AP x-ray.

For the Chinese patients, weight-bearing AP long-leg radiograph (APLLR) and long-leg lateral views including hip, knee, and ankle joints were available. For the Japanese patients, weight-bearing APLLR, lateral short limb radiographs and full lower limb CT were available. We excluded patients with inappropriate radiographs that could not be measured and those with lower limbs that had undergone previous surgery. To assess the impact of long and short leg radiographs and CT scans on the measurement of PTS, we produced half-size (1/2LR) and one-third-size (1/3LR) short leg radiographs from long-leg radiographs (LLR) and one-third-size short leg CT (1/3LCT) from long-leg CT (LLCT).

Radiograph measurements

We defined the medial proximal tibial joint orientation line as the tangent to the deepest point of the medial plateau concavity(13) for the measurement of medial PTS. For the measurement of lateral PTS, the lateral proximal tibial joint orientation line was defined as the line connecting the anterior and posterior edges of the lateral plateau (14). The lateral tibial central anatomical axis was defined as a line connecting the centers of two circles that are simultaneously tangent to the anterior and posterior tibial cortices. The proximal circle was positioned just distal to the tibial tuberosity, and the distal circle was positioned just proximal to the distal tibial diaphsis (15). The anatomical posterior proximal tibial angle (aPPTA) was measured as the acute angle formed between the perpendicular to the lateral tibial central anatomical axis and the proximal tibial joint orientation line. PTS was defined as 90°- aPPTA. (Fig.1) For medial PTS, medial proximal tibial joint orientation line was used whilst for lateral PTS, lateral proximal tibial joint orientation line was used.

For short-leg lateral knee joint radiographs and lateral short limb CT, the proximal lateral tibial central anatomical axis was defined as line connecting the centers of two circles that are simultaneously tangent to the anterior and posterior tibial cortices. The proximal circle was positioned just distal to the tibial tuberosity and the distal circle was positioned at one-third or one-half of the total measured length from the long leg radiographs or the long leg CT. All other measurements were identical to those described in the previous paragraph. The proximal anatomical PTS (paPTS) was defined as 90°- the anatomical proximal tibial angle to the proximal anatomical axis(paPPTA) (Fig.2)

CT measurements

Measurements on the CT scans were performed using a standard picture archiving and communication system (PACS). Multiplanar reformation (MPR) was utilized to achieve 3D alignment in all three planes, ensuring the avoidance of any rotational, varus/valgus, or flexion/extension mal-positioning(14, 16).

2.3. Data Analyses

Two independent, experienced orthopaedic surgeons conducted all the measurements independently and repeated them after a two-week interval to establish inter- and intra-observer reliability. The primary outcome was the comparison of medial and lateral PTS measurements, while the secondary aim was to assess the impact of tibial length on measurement accuracy.

Data are presented as mean values with standard deviation (SD). An a priori power analysis was performed using G*Power 3.1 (Franz Paul, Kiel, Germany) (17). To assess the normality of the data, we conducted a comprehensive evaluation using three methods: histograms, QQ plots, and tests for normality. Based on these assessments, we decided to use a paired t-test for our analysis. The sample size required for the paired t-test, targeting the primary outcome, was determined a priori, with the significance threshold of $P < 0.05$. The minimum sample size, calculated using an α error of 0.05, a β error of 0.20, and Cohen's effect size of 0.8 with an allocation ratio of 1, was 24 patients.

Group differences were evaluated using one-way analysis of variance (ANOVA) with Tukey post hoc analysis. All statistical analyses were performed using EZR software (http://www.jichi.ac.jp/saitama-sct/SaitamaHP.files/statmed.html) (18).

The necessary sample size for inter-observer and intra-observer reliability calculations was based on Zou's method, using an intraclass correlation coefficient (ICC) effect size of 0.8, a two-tailed significance level (α) of 0.05, and a power (β) of 0.8(19). Inter- and intra-observer reliability was assessed using a random two-way, single-measure ICC (ICC(2,1)) to evaluate agreement between observations (19). According to Koo and Li's guidelines(19). ICC values above 0.9 indicate excellent reproducibility, values between 0.75 and 0.9 indicate good reproducibility, and values between 0.5 and 0.75 indicate moderate reproducibility.(19).

The correlation between measurements obtained by radiographs and CT was calculated by Pearson's correlation coefficients, considering the mean values from both observers for radiographs and CT. A significance level (α) = 0.05 was adopted for all analyses.

Results

In 65 Japanese patients (98 legs), there were 65 women and 33 men, with a mean age of 57.7 ± 21.0 years. All Japanese data were based on patients with lateral short-limb radiographs, 1/3LCT derived from long-leg CT to reduce measurement errors due to lower limb length, and LCT. The mean 1/ 3LR paPTS for the medial and lateral were 9.3 ± 3.3° and 7.4 ± 3.6°(P<0.001). The mean 1/ 3LCT paPTS for medial and lateral were 9.7 ± 3.5°, 8.3 ± 3.8° (P<0.001). The mean LLCT PTS for medial and lateral were 11.5 ± 3.4°, 10.3 ± 3.4° (P<0.001). (Table.1)

The pearson correlation between medial 1/3LR and 1/3LCT paPTS were 0.84(95 % CI: 0.77 – 0.89, P < 0.001). (Fig.3) The pearson correlation between lateral 1/3LR and 1/3LCT paPTS were 0.62(95 % CI: 0.48 – 0.73, P < 0.001). (Fig.4)

Inter- and intra-observer reliability for medial 1/3LR paPTS were 0.83(95 % CI: 0.59 – 0.92, P < 0.001) and 0.80(95% CI: 0.57 – 0.88, P < 0.001). Inter- and intra-observer reliability for medial 1/3LCT paPTS were 0.94(95 % CI: 0.91 – 0.96, P < 0.001) and 0.94(95 % CI: 0.83 – 0.97, P < 0.001). Inter- and intra-observer reliability for lateral 1/3LR paPTS were 0.68(95 % CI: 0.59 – 0.75, P < 0.001) and 0.45(95 % CI: 0.13 – 0.66, P < 0.001). Inter- and intra-observer reliability for lateral 1/3LCT paPTS were 0.91(95 % CI: 0.87 – 0.94, P < 0.001) and 0.89(95 % CI: 0.79 – 0.94, P < 0.001). (Table.2)

In 200 Chinese patients (324 legs), there were 253 women and 71 men, with a mean age of 64.0 ± 9.9 years. All Chinese data were based on patients with APLLR and weight-bearing LLLR. One-way ANOVA revealed a significant difference in PTS among the three groups. The mean PTS, 1/2LR paPTS, and 1/3LR paPTS were 10.5 ± 4.6°, 9.4 ± 4.5° and 8.5 ± 4.6°, respectively; $P < 0.001$). Post hoc analysis revealed that the 1/3LR paPTS was significantly lower than both 1/2LR paPTS and PTS. The 1/3LR paPTS was also lower than 1/2LR paPTS ($p < 0.001$). Inter-observer and intra-observer reliability for PTS were 0.85(95% Confidence interval (CI): 0.50 – 0.96, P<0.001) and 0.76(95% CI: 0.65 – 0.84, P<0.001), respectively. Both ICC values indicated good reproducibility.

Discussion

In this study, we included both weight-bearing and non- weight-bearing images, as well as standing and supine position images. Previous reports have shown that the overall coronal knee alignment is influenced by the weight-bearing status(20-22). However, we haven't found any reports regarding the influence of weight-bearing positions on sagittal lower limb alignment. Unlike coronal alignment, sagittal alignment is not affected by soft tissue and is therefore considered to remain unchanged.

The findings of this study can be summarized in three key points. First, medial and lateral PTS measurements differed, with lateral PTS being slightly smaller. Second, PTS radiographic measurements were influenced by the length of tibia utilized to determine the anatomical axis. Third, we investigated the correlation and compared the intra- and inter-observer reliability of medial and lateral PTS measurement between radiographs and CT.

In this study the lateral PTS measured on radiographs and CT in Japanese patients was found to be smaller than the medial PTS, with a difference ranging from 1.2° to 1.9°.

Previous studies have begun to clarify the differences medial and lateral PTS(23, 24). Some reports have shown a difference between medial and lateral PTS(25), while others have found no significant difference(24). This discrepancy may be due to variations in race and study populations. In our study, the lateral PTS tended to be smaller, however this finding is specific to the present study and should not be generalized. The correlation between x-ray and CT in the lateral PTS, as well as the inter and intra-observer reliability, tended to be lower for medial PTS, indicating the possibility of measurement error. Caution should be exercised in interpreting these results, particularly because radiographs examinations appeared to be more prone to errors in this study.

In this study, the mean PTS, 1/2LR paPTS and 1/3LR paPTS were 10.5 ± 4.6°, 9.4 ± 4.5° and 8.5 ± 4.6° ($p < 0.001$). Measurements taken using short leg length were significantly lower than those taken with the full length of the tibia. A recent study by Ni et al(12). reported on the PTS of 200 patients who had full-length radiographs. When comparing PTS using the full and half-length tibia to determine the anatomical axis, they found a significant difference between the two measurements (full-length: 15.9°; half-length: 14.1°), with an average absolute difference of 1.8°. Furthermore, 49.5% of the half-length tibia PTS measurements showed an absolute difference of greater than 2° compared to the full-length measurements. Similarly, Garra et al(8). studied 154 patients and reported significant differences in PTS at various tibial lengths compared to the reference PTS. The number of PTS measurements with an absolute difference of greater than 2° from the reference PTS decreased as tibial length increased (overlapping: 40.3%, 10-cm: 24.0%, 15-cm: 26.0%, and half-tibia: 18.8%). The primary reason for these differences is the increased anterior tibial bowing, which leads to an underestimation of the PTS on short knee radiographs compared to the lateral mechanic axis(7). Thus, PTS varies depending on the tibial length measured in the radiographs, and caution should be exercised when interpreting data in studies that discussing the relationship between clinical outcomes and PTS in knee surgery.

Inter- and intra-observer reliability for medial PTS on both radiographs and CT were good. However, inter- and intra-observer reliability for lateral PTS measurements on both radiographs and CT were moderate, with intra-observer reliability for lateral PTS on radiographs being particularly poor. Previous studies have also demonstrated that CT and MRI have lower measurement errors and higher inter- and intra-observer reliability compared to radiographs (24, 25). While few studies have specifically reported on the inter- and intra-observer reliability for lateral PTS measurements on radiographs and CT, the results suggest that there may be a significant margin of error in lateral PTS measurements obtained from radiographs.

For accurate measurement of both medial and lateral PTS, additional examination methods such as CT and MRI are considered more reliable. However, radiographs continue to be widely used because CT and MRI are expensive, and CT involves significant radiation exposure. If we aim to measure more accurate PTS measurements on radiographs, the focus should be on medial PTS on full-leg lateral radiographs.

Limitations

This study had several limitations. First, it was a retrospective analysis using images from Chinese and Japanese patients who visited their respective outpatient hospitals for knee-related complaints. Since this study focused solely on East Asian populations and involved patients with pre-existing knee issues, further studies involving volunteers from other regions are necessary to generalize the findings. Second, the analytical methods used in the literature are not universally agreed upon, and the technique we used to measure PTS may differ from those employed in other studies. Third, only two independent surgeons assessed the alignment measurements. To improve the generalizability of our results to standard clinical practice, future studies should involve a large group of surgeons.

Conclusion

For accurate measurement of both medial and lateral PTS, surgeons should consider using additional examination methods such as CT and MRI. If PTS is to be measured on radiographs, the focus should be on the medial PTS, as it tends to provide more reliable results. While it is possible to measure lateral PTS with radiographs, it is important to account for the potential for significant measurements errors.

Figures

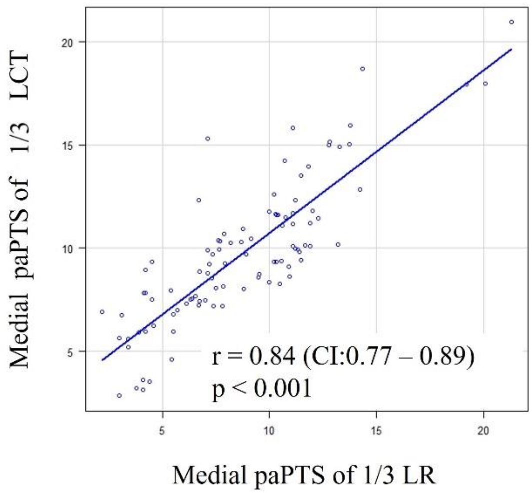
Fig.1 posterior tibial slope measurement in long limb radiographs

Proximal tibial joint orientation line. The cross marks the deepest point of the medial plateau concavity. The line is tangent to the curve at the deepest point. Measurements of anatomical posterior tibial slope.

Fig.2 proximal anatomical posterior tibial slope measurement in long limb radiographs and short limb radiographs

Proximal tibial joint orientation line. The cross marks the deepest point of the medial plateau concavity. The line is tangent to the curve at the deepest point. Measurements proximal anatomical posterior distal femoral angle and posterior tibial slope.

Fig.3 Pearson reliabilities of angles between medial paPTS of 1/3LR and 1/3LCT



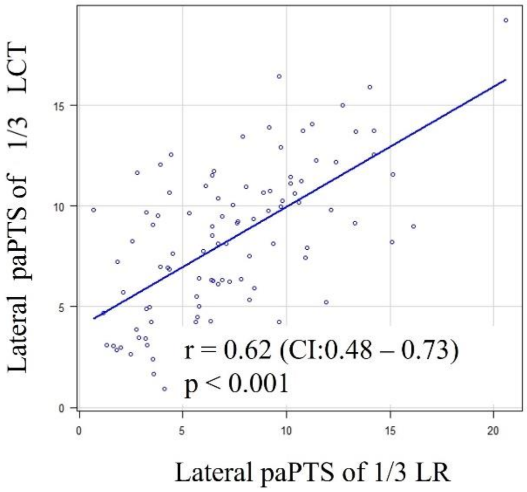
1/3LR: 1/3 size short leg radiographs

1/3LCT: 1/3 size short leg CT

CI: confidence interval

PTS: posterior tibial slope

Fig.4 Pearson reliabilities of angles between lateral paPTS of 1/3LR and 1/3LCT



1/3LR: 1/3 size short leg radiographs

1/3LCT: 1/3 size short leg CT

CI: confidence interval

PTS: posterior tibial slope

Tables

Table.1 pa PTS in Japanese patients

Japanese Patients	(pa)PTS (±SD)		
98 legs	Med	Late	p value
1 / 3 LR	9.3 ± 3.3°	7.4 ± 3.6°	0.001<
1 / 3 LCT	9.7 ± 3.5°	8.3 ± 3.8°	0.001<
LLCT	11.5 ± 3.4°	10.3 ± 3.4°	0.001<

paPTS: proximal anatomical posterior tibial slope

Med: medial, Late: lateral

SD: standard deviation

1/3LR: 1/3 size short leg radiographs

1/3LCT: 1/3 size short leg CT

LLCT: long leg CT

Table.2 Intraclass correlation coefficient

Measurement	Inter-observer reliability (CI: 95%)	p value	Intra-observer reliability (CI: 95%)	p value
MR	0.83(0.59 – 0.92)	p<0.001	0.80(0.57 – 0.88)	p<0.001
LR	0.68(0.59 – 0.75)	p<0.001	0.45(0.13 – 0.66)	p<0.001
MC	0.94(0.91 – 0.96)	p<0.001	0.94(0.83 – 0.97)	p<0.001
LC	0.91(0.87 – 0.94)	p<0.001	0.89(0.79 – 0.94)	p<0.001

CI: confidence interval

MR: Medial posterior tibial slope of radiographs

LR: Lateral posterior tibial slope of radiographs

MC: Medial posterior tibial slope of CT

LC: Lateral posterior tibial slope of CT

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