Three-Dimensional Computed Tomography Analysis of the Posterior Tibial Slope in 100 Knees

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ABSTRACT

Background: The posterior tibial slope (PTS) is an important consideration in knee arthroplasty. However, there is still no consensus for the optimal slope. The objectives of this study were (1) to reliably determine the native PTS in this population using 3-dimensional computed tomography scans and (2) to determine the normal reference range for PTS in this population.

Methods: One hundred computed tomography scans of disease-free knees were analyzed. A 3-dimensional reconstructed image of the tibia was generated and aligned to its anatomic axis in the coronal and sagittal planes. The tibia was then rotationally aligned to the tibial plateau (tibial centroid axis) and PTS was measured from best-fit planes on the surface of the proximal tibia and individually for the medial and lateral plateaus. This was then repeated with the tibia rotationally aligned to the ankle (transmalleolar axis).

Results: When rotationally aligned to the tibial plateau, the mean PTS, medial PTS, and lateral PTS were 11.2° ± 3.0 (range, 4.7°–17.7°), 11.3° ± 3.2 (range, 2.7°–19.7°), and 10.9° ± 3.7 (range, 3.5°–19.4°), respectively. When rotationally aligned to the ankle, the mean PTS, medial PTS, and lateral PTS were 11.4° ± 3.0 (range, 5.3°–19.3°), 13.9° ± 3.7 (range, 3.1°–24.4°), and 9.7° ± 3.6 (range, 0.8°–17.7°), respectively.

Conclusion: The PTS in the normal Asian knee is on average 11° (mean) with a reference range of 5°–17° (mean ± 2 standard deviation). This has implications to surgery and implant design.

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The posterior tibial slope (PTS) affects knee biomechanics and cruciate ligament tension in the normal knee [1,2]. Therefore, the natural PTS is an important consideration in the surgical treatment of the knee with osteoarthritis. In knee arthroplasty, for example, the PTS after surgery influences flexion stability [3] and range of motion [4]. In a cruciate-retaining knee design, posterior cruciate ligament tension is altered and can adversely affect femoral rollback [5,6]. Its possible role in subsidence and loosening of the tibial component has also been reported in the literature [7–9].

To date, there is little consensus on what is the optimal slope for the proximal tibial cut. Most agree that the native slope should be approximated and tibial resection slopes of 0°–7° have been common practice [10,11]. Surgeons also rely on manufacturers’ recommendation based on implant design and their interpretation of optimal slope. Generally, recommendations are based on data derived from Caucasian populations. This may not be applicable to the Asian knee; 2 recent studies suggest that Asians have a higher PTS [12,13].

Similarly, there is no universal agreement on normal range of values for the PTS because different studies use differing measurement techniques and reference axes. Furthermore, improper limb positioning gives rise to measurement errors—2-dimensional...
(D) radiographs are therefore unreliable [14,15]. A normal reference range serves as an important guide for the arthroplasty surgeon, for preoperative interpretation and intraoperative decision-making. Normative data will also be helpful in other surgeries for medial compartment osteoarthritis such as unicompartmental knee arthroplasty and proximal tibial osteotomies.

The objectives of this study were (1) to reliably measure the PTS in normal knees of Asians using 3D computed tomography (CT) scans and (2) to determine the normal reference range for PTS in this population. The PTS is a 2D measurement of an inclination projected onto the sagittal plane. Hence, rotation of the tibia conceivably affects its measurement. Therefore, our third aim was to measure the PTS with the tibia aligned to 2 rotational axes: the tibial plateau and the ankle.

**Materials and Methods**

We analyzed CT scans of 100 knees from 100 individuals who were of age ≥18 years using a 3D analysis software, Mimics, version 14.0 (Materialise Inc, Leuven, Belgium). Ethics approval was obtained from the medical research ethics committee of our institution before commencement of the study. The knees had no radiologic evidence of osteoarthritis, and these patients had CT angiograms of the limbs for vascular disease or injury. Our population is multiethnic and consists of descendants from various regions of Asia. Indian descendants (South Asia), Chinese descendants (East Asia), and the Malays (Southeast Asia) made up 38%, 25%, and 37% of the study population, respectively.

**Aligning the Tibia**

For reliable measurement with good reproducibility, a standard frame of reference was established before measurement. Essentially, the tibia was aligned in a constant and prescribed manner by defining datum axes. This is akin to limb positioning before radiographic measurements. However, in measurements based on 3D CT, limb positioning at the time of the scan acquisition is inconsequential. This is because the tibia can be subsequently aligned to the standard frame of reference by virtually orientating the tibia within the software environment.

In the coronal and sagittal planes, the 3D reconstructed tibia was aligned to its anatomic axis (TAAx). This was achieved by defining the center of the ankle and the center of the proximal tibia, its axis being a line which connected these 2 points.

The center of the ankle was located by a best-fit sphere algorithm to the combined articular surface of the tibial plafond and the inner surfaces of the medial and lateral malleoli of the ankle (Fig. 1). The center of the upper tibia was localized by first, generating a locus of centerpoints to the endosteal medullary tube of the upper tibia (a 6-cm segment distal to the tibial tubercle, Fig. 2A). This was projected proximally to the surface of the tibial plateau of the knee as a single point which defined the center of the proximal tibia (Fig. 2B).
Once the tibia was aligned in this fashion (Fig. 2C), the tibia was then aligned rotationally as follows. Initially, the tibia was rotationally aligned to the tibial plateau using the tibial centroid axis (TCAx) and PTS measurement was made. Then, the tibia was rotationally aligned to the ankle using the transmalleolar axis (tmAx) and slope measurement was repeated.

The TCAx was introduced by Leong et al [16] to provide a reliable reference for rotational orientation of the tibial plateau. In our study, the medial and lateral surfaces of the tibial plateau were first marked using a virtual brush and the respective centroids calculated by the software. The TCAx is a line connecting these 2 centroids (Fig. 3A). The 3D reconstructed tibia which has already been

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**Fig. 3.** (A) Tibial centroid axis (TCAx); (B) Rotationally aligned to the TCAx.

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**Fig. 4.** Rotational alignment to the ankle. (A) Transmalleolar axis (tmAx). A virtual brush first marked the inner surfaces of both malleoli. A best-fit line connecting these 2 point clouds was determined by the software (line a). (B) A plane perpendicular to this line, and made to pass through the center of the ankle was constructed (plane b). (C) Next, a second plane which passed through the center of the ankle and perpendicular to the axis of the tibia was constructed (plane c). (D) The confluence of these 2 planes is a line (line d) which is perpendicular to the tmAx. Once aligned, line d points directly anterior.
the tibia, a line perpendicular to its TCAx is pointing directly anterior. This is akin to the joint arthroplasty surgeon placing the tibia with the ankle facing directly forward (anteriorly) and then adjusting the inclination of his saw to achieve posterior slope alignment in the coronal and sagittal planes was then rotationally aligned to the ankle. In the software that we used, this is achieved with a few steps, the details of which are given in Figure 4.

Measurements

PTS was measured as the angle between the tibial slope and a line perpendicular to the anatomic axis of the tibia. The tangent of the tibial slope was derived from planes which were created by best-fit algorithm to the combined marked surfaces of the medial and lateral tibial plateaus (Fig. 5A). The medial and lateral PTSSs (MPTS and LPTS) were also individually derived using the same method from individually marked surfaces of the tibial plateau (Fig. 5B).

Statistical Analyses

A coauthor repeated the entire process from alignment to measurement in 30 subjects. Intraclass correlation coefficient (ICC) was applied to measure interobserver agreement for PTS. Data were tested for normality using the Kolmogorov-Smirnov test. Subsequently, comparisons between variables of both data sets were made using hypothesis testing with the appropriate tests: independent t test, paired t test, or 1-way analysis of variance. Pearson correlation coefficient (r) was used to examine the relationship between variables. All analyses were performed using SPSS (version 21; IBM, Chicago, IL). Statistical significance was defined as \( P < .05 \).

Results

One hundred knees from 100 individuals (52 men and 48 women) were used in this study. The mean age was 54 years (range, 18-81 years). When rotationally aligned to the tibial plateau (TCAx), the mean PTS, MPTS, and LPTS were 11.2° ± 3.0 (mean ± standard deviation), 11.3° ± 3.2, and 10.9° ± 3.7, respectively. When aligned to the ankle (tmAx), the mean PTS, MPTS, and LPTS were 11.4° ± 3.0, 13.9° ± 3.7, and 9.7° ± 3.6, respectively. Detailed results are given in Table 1.

Since the mean PTS for the 2 different rotational alignments did not differ, the PTS for our study can therefore be expressed as 11° ± 3.0. When rotationally aligned to the tibial plateau (TCAx), the MPTS was equal to the LPTS, a mean difference of 0.4° ± 3.1 was not significant (\( P = .2 \)). When aligned to the ankle (tmAx), the MPTS was 4.1° ± 3.8 more than the LPTS (\( P = .001 \)). The MPTS had a stronger correlation with PTS (Pearson coefficient \( r = 0.9 [TCAx], P = .001; r = 0.9 [tmAx], P = .001 \)) than the LPTS (\( r = 0.8 [TCAx], P = .001; r = 0.7 [tmAx], P = .001 \)). The PTS, MPTS, and LPTS were variable in our study population (Fig. 6).

There was no correlation found between all the slope measurements and age. No statistically significant difference was observed for gender and ethnicity for all these variables. The mean difference between measurements when aligned to the TCAx and tmAx is shown in Table 2. These differences were statistically significant but small, and there was good correlation between the measurements (Fig. 7).

Table 1

<table>
<thead>
<tr>
<th>Rotational Alignment</th>
<th>Tibial Centroid Axis</th>
<th>Transmalleolar Axis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PTS</td>
<td>MPTS</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>11.2° ± 3.0</td>
<td>11.3° ± 3.2</td>
</tr>
<tr>
<td>Range</td>
<td>(4.7°–17.7°)</td>
<td>(2.7°–19.7°)</td>
</tr>
<tr>
<td>Male (n = 52)</td>
<td>10.7° ± 3.1</td>
<td>10.9° ± 3.1</td>
</tr>
<tr>
<td>Female (n = 48)</td>
<td>11.8° ± 2.9</td>
<td>11.8° ± 3.3</td>
</tr>
<tr>
<td>Indian (n = 38)</td>
<td>11.0° ± 2.9</td>
<td>10.7° ± 3.1</td>
</tr>
<tr>
<td>Malay (n = 37)</td>
<td>12.0° ± 3.0</td>
<td>12.3° ± 2.9</td>
</tr>
<tr>
<td>Chinese (n = 25)</td>
<td>10.5° ± 3.2</td>
<td>10.8° ± 3.6</td>
</tr>
<tr>
<td></td>
<td>11.4° ± 3.0</td>
<td>13.9° ± 3.7</td>
</tr>
<tr>
<td></td>
<td>(5.3°–19.3°)</td>
<td>(3.1°–24.4°)</td>
</tr>
<tr>
<td></td>
<td>11.0° ± 2.9</td>
<td>13.4° ± 3.3</td>
</tr>
<tr>
<td></td>
<td>11.8° ± 3.0</td>
<td>14.4° ± 4.1</td>
</tr>
<tr>
<td></td>
<td>11.0° ± 2.8</td>
<td>13.3° ± 3.7</td>
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<tr>
<td></td>
<td>12.0° ± 3.1</td>
<td>14.7° ± 3.5</td>
</tr>
<tr>
<td></td>
<td>11.2° ± 3.1</td>
<td>13.9° ± 3.9</td>
</tr>
</tbody>
</table>

Values for gender and ethnicity are presented as mean ± SD.

LPTS, lateral posterior tibial slope; MPTS, medial posterior tibial slope; PTS, posterior tibial slope; SD, standard deviation.
All the interobserver repeated measurements for PTS were within 2°. The ICC for measurements using both axes were 0.93 suggesting excellent agreement.

Discussion

To optimize outcome, it is important to consider the PTS when performing knee surgery. Changes in PTS after arthroplasty affect knee biomechanics [1,2] and clinical parameters such as range of motion [3,4,17]. Asians are thought to have a higher PTS [12,13] than their Western counterparts. However, there is a paucity of reliable data for this conception. Studies have been performed to ascertain the PTS in both Asians and Caucasians, but these were largely in arthritic knees and performed using radiographs. Generalization of the normal PTS based on measurements made on arthritic knees is inaccurate because arthritic knees have more slope than normal knees and are more variable [12]. In addition, radiographs are less reliable for this purpose [15,18].

In our study, in addition to rotationally aligning to the TCAx, we also remeasured the slope after aligning the tibia with the ankle facing forward to study its effect on PTS measurement. This is because surgeons intuitively align the tibia rotationally using the foot and ankle pointing anteriorly during surgery. The circle method [26] and the centroid method [16] are less practical for surgery as best-fit circles and centroids are not so easily determined manually without image analysis. The tibial tubercle as a reference for rotation has been shown to be unreliable [26].

A widely accepted value for normal PTS is 7° [9,14]. From our study, we found that the PTS in our population was 11°, and this is higher than the Caucasian population [14,23,27]. This is in agreement with several studies performed on Asian populations [12,13]. However, our results did not concur with Yue et al [23], who reference for rotational alignment of the tibia on CT is the method by Cobb et al [26], which involves forming a line that connects 2 best-fit circles of the outer perimeter of the medial and lateral tibial plateaus. Although it is a reliable frame of reference, this method is not without its difficulties. The medial and lateral tibial plateaus are rarely circular and osteophytes often distort its perimeter. Leong et al [16], belonging to the same research group, later developed another rotational axis (TCAx, described earlier) and compared it with the method published by Cobb et al [26]. Validated against the Cobb method, it had a mean difference of 1° ± 2, and the TCAx had an interobserver ICC of 0.94. In our study, in addition to rotationally aligning to the TCAx, we also remeasured the slope after aligning the tibia with the ankle facing forward to study its effect on PTS measurement. This is because surgeons intuitively align the tibia rotationally using the foot and ankle pointing anteriorly during surgery. The circle method [26] and the centroid method [16] are less practical for surgery as best-fit circles and centroids are not so easily determined manually without image analysis. The tibial tubercle as a reference for rotation has been shown to be unreliable [26].

Table 2

<table>
<thead>
<tr>
<th>Mean Difference Between Measurements When Aligned to TCAx and tmAx.</th>
<th>Mean Difference (TCAx, tmAx)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTS</td>
<td>0.2° ± 0.8</td>
<td>.021</td>
</tr>
<tr>
<td>MPTS</td>
<td>2.5° ± 1.3</td>
<td>.001</td>
</tr>
<tr>
<td>LPTS</td>
<td>1.2° ± 1.7</td>
<td>.001</td>
</tr>
</tbody>
</table>

LPTS, lateral posterior tibial slope; MPTS, medial posterior tibial slope; PTS, posterior tibial slope; TCAx, tibial centroid axis; tmAx, transmalleolar axis.
Table 3: Comparison of PTS, MPTS, and LPTS of This Study and Other Published Works.

<table>
<thead>
<tr>
<th>Population</th>
<th>Sample size</th>
<th>Average age (y)</th>
<th>Imaging modality</th>
<th>PTS</th>
<th>MPTS</th>
<th>LPTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asian</td>
<td>100</td>
<td>54</td>
<td>CT, MRI</td>
<td>11.2</td>
<td>11.3</td>
<td>10.9</td>
</tr>
<tr>
<td>Caucasian</td>
<td>37</td>
<td>45</td>
<td>Radiographs</td>
<td>11.2</td>
<td>11.3</td>
<td>10.9</td>
</tr>
<tr>
<td>Asian</td>
<td>35</td>
<td>45</td>
<td>No</td>
<td>11.2</td>
<td>11.3</td>
<td>10.9</td>
</tr>
<tr>
<td>Asian</td>
<td>35</td>
<td>45</td>
<td>Radiographs</td>
<td>11.2</td>
<td>11.3</td>
<td>10.9</td>
</tr>
<tr>
<td>Asian</td>
<td>35</td>
<td>45</td>
<td>Radiographs</td>
<td>11.2</td>
<td>11.3</td>
<td>10.9</td>
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<tr>
<td>Asian</td>
<td>35</td>
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<td>11.2</td>
<td>11.3</td>
<td>10.9</td>
</tr>
</tbody>
</table>

It is interesting and unexpected to find that despite measuring the PTS based on 2 different rotational alignments, the paired values did not differ much, and are not clinically significant, although statistically significant. The MPTS measured with both axes had a larger difference when compared with the LPTS (Table 2). This could be explained by the fact that the tibial plateau also has a varus inclination [31], and so when the tibia is aligned to the ankle, the medial plateau resolved to the sagittal plane has a larger slope. The LPTS has a mean difference of only 1° when measured with both alignment axes. Intraoperatively, it may then be prudent to use the LPTS as a guide for the tibial cut because rotation appears to have little effect on it even though the MPTS correlated slightly stronger to the PTS. In practice, osteoarthritis initially affects the medial compartment more commonly, and thus, making the tibial cut closer to the LPTS may be more appropriate [32].

The prevalence of flexion gap tightness after cruciate-retaining knee arthroplasty has been reported to be 21.1%, and insufficient tibial slope had been identified as a significant independent risk factor [33]. Singh et al [34], in another study, reported that if the slope change was >2°, the odds ratio of having a postoperative flexion angle <100° was 17.6 and suggested recreating the anatomic tibial slope to improve maximum flexion after posterior-stabilized knee arthroplasty. Restoring the original slope has also been suggested by other authors as making the cut parallel to stronger subchondral bone reduces subsidence and loosening [7,9,35]. Currently, the optimal slope for the prosthetic knee is not known, although a 0°–7° cut is routinely recommended [10,11]. If recommendations based on Western populations are to be followed, an Asian patient may have a slope which is less than that of the original knee after arthroplasty, resulting in a knee that is tight in flexion, owing to increased tension in the posterior cruciate ligament and collaterals as well as other factors [33,34,36]. For the Asian patient, limitation in flexion would cause difficulty with activities such as kneeling or squatting [37,38]. It is thus important to develop implants and techniques which take into account that the Asian proximal tibia has a relatively higher posterior slope, although within the population this is variable.

There is relevance to the findings of our study which define the native slope of the tibia in a population. Conceptually, it provides some direction on the question of what magnitude should the PTS be cut during knee arthroplasty. Recently, attention has focused on mechanical vs kinematic alignment with regard to the coronal orientation of the tibia. The sagittal orientation, that is, the posterior slope is less topical and presumably less contentious even though there is no universal agreement. Should the patient’s natural slope be emulated (minus slope inbuilt into the bearing) by referencing to areas of less disease involvement or should a fixed slope be aimed for and should this be based on the normal population average? It is our opinion that, provided the natural slope of the tibia is not excessive, it is intuitive that the prosthetic tibial slope be made to approximate this native slope as this is the slope in which the ligaments have been accustomed to. If the native slope is considered excessive, then a more conservative slope is preferred. This is subjective, though, and our work does give data reference range for the population to help make this
judgment. Our study may also shed light on a possible reason for flexion tightness when a knee is prepared according to recommended resection angles especially with a cruciate-retaining design.

**Limitations**

A more rigorous comparison between Asian and Western PTS would require a comparative study or studies using the same methodology. Emulating the native slope, although it may give better soft-tissue balance in flexion, could result in an increased flexion angle of the knee in cruciate ligament sacrificing total knee arthroplasty. Knee Surg Relat Res 2013;25:54–9.

**Conclusion**

The PTS in the Asian knee is 11° (mean) with a reference range (mean ± 2 standard deviation) of 5°–17° (Fig. 8). A high variability in these measurements suggests that restoration of PTS should be individualized. This large study provides reliable and accurate normative data for researchers and surgeons to reference.

**Acknowledgments**

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**References**


