The tibial crest as a practical useful landmark in total knee arthroplasty

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ABSTRACT

Background: The middle one-third of the tibial crest in the coronal plane and the fibula in the sagittal plane are known as landmarks for extramedullary guides in total knee arthroplasty (TKA). However, there are few foundational anatomic studies about them. We conducted this study to confirm whether these landmarks are reliable.

Methods: We evaluated 100 Japanese knees using 3D imaging software. We examined our data for correlations between the angle of deviation from the mechanical axis and patient-specific factors (i.e. hip-knee-ankle angle, tibial length, tibial bowing, and tibial torsion) to determine whether there are any individual factors affecting their reliability.

Results: The mean angles between each of the axes defined by the fibula and the tibial crest with the mechanical axis were 2.9°±0.6° of valgus and 0.7°±0.9° of varus in the coronal plane and 2.2°±0.8° of posterior and 3.6°±1.0° of anterior inclination in the sagittal plane. The middle one-third of the tibial crest (TCL) was revealed as a useful landmark, especially in female patients, who possess TCLs that were within 3° of the tibial mechanical axis in the coronal plane. There were no patient-specific factors strongly affecting reliability of these landmarks.

Conclusions: We can use these landmarks even if the patient has tibial bowing or severe varus deformity. Although not considering soft tissue thickness, our study demonstrated that the tibial crest in the coronal and sagittal planes could be useful guidelines in performing TKAs.

Level of evidence: II

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1. Introduction

Total knee arthroplasty (TKA) survivorship depends upon proper alignment of the limb and prosthesis. Several studies have correlated poor outcomes with coronal malalignment of the components [2,11,14]. Proper sagittal alignment is also important, as the tibial slope affects anteroposterior stability, range of motion, and contact pressure within the tibiofemoral joint [3,5,9,20].

Intramedullary systems have been considered superior to extramedullary systems for making the femoral cut and arriving at an accurate and reproducible placement of the component [4,7,12,18,19]. However, for tibial alignment, there is still controversy as to whether intramedullary systems or extramedullary systems are more reliable. Although numerous bone and soft tissue landmarks have been advocated [6,16,17], it is not easy to align an extramedullary guide to the mechanical axis primarily due to the difficulty in finding the ankle center. Furthermore, most of those landmarks are readily affected by the position of the ankle joint [15]. The middle one-third of the tibial crest in the coronal plane and the fibula in the sagittal plane are known as landmarks to provide an extramedullary guide in TKA [8,13]. However, they seem to lack sufficient scientific foundational anatomic studies. In actual practice, the landmark expressed by a line connecting the two points on the tibial crest 10 cm and 20 cm distal to the knee joint line is easier to use than the landmark expressed by the middle one-third of the tibial crest. The points on the tibial crest 10 cm and 20 cm distal from the knee joint line approximate the proximal one-third and distal one-third of the tibia, respectively, in Japanese patients. We also wondered if the tibial crest in the sagittal plane and the fibula in the coronal plane could be reliable landmarks for alignment of the tibia.

We therefore conducted this study to determine (1) whether the anterior crest (a line connecting the two points on the tibial crest 10 cm and 20 cm distal to the knee joint line) and the fibula are reliable in coronal and sagittal alignment of the tibia and (2) whether there are any individual factors affecting their reliability.

2. Materials and methods

Our study investigated 100 knees in 89 consecutive patients scheduled for TKA. The population consisted of 85 knees in 75 females...
and 15 knees in 14 males. None of our patients had evidence of trauma, infection, tumour, or any congenital disorder. The mean age of all patients was 70.8 years (range 39 years to 88 years). Our study group included 76 patients with osteoarthritis (86 knees) and 13 patients with rheumatoid arthritis (14 knees). We performed preoperative high-resolution CT scans of all the affected lower limbs, including the whole tibia and fibula with a 16-detector CT unit (Toshiba Medical, Japan) in the helical mode in a 512×512 matrix, setting slice thickness at 1 mm as part of a routine exam for TKA. We used CT-based preoperative TKA planning software (ZedKnee® LEXI Co., Ltd., Tokyo, Japan) to determine the tibial mechanical axis (MA) and perform measurements of the accuracy of the tibial crest line and fibula for alignment. To our regret, we do not have full-length weight-bearing AP radiographs in about half of the patients. Therefore we used non-weight bearing CT data to measure the hip-knee-ankle angle using this software. We defined the tibial MA as a straight line from the center of the appropriate-size LCS® Complete™ (Johnson & Johnson, DePuy, Warsaw, IN, USA) tibial component without posterior slope to the center of the distal tibial plafond. The center of the distal tibial plafond was automatically calculated by the software with the aid of three peripherally defined points approximating the plafond to a circle (Fig. 1) The anteroposterior axis of the tibia was defined as a straight line connecting the mid-posterior cruciate ligament (PCL) attachment with the anterior edge of the patellar tendon attachment; the tibial crest line (TCL) as the line connecting the two points on the tibial crest 10 cm and 20 cm distal to the knee joint line (Fig. 2); the fibular line in the coronal plane (FLc) as a tangential line connecting the most prominent parts of the fibular head with the lateral malleolus; and the fibular line in the sagittal plane (FLs) as a line from the center of the fibular head to the center of the lateral malleolus (Fig. 3A and B). We measured the angle between the TCL and MA (TCL-MA angle) in both the coronal and sagittal planes; the angle between the FLc and the coronal MA (FLc-MA angle); and the angle between the FLs and the sagittal MA (FLs-MA angle). Preoperative TKA planning automatically measures the angle by dotting the reference points for the respective lines on reconstruction CT images. To test intra- and inter-observer reliability, each set of measurements was repeated three times on 10 randomly selected subjects by two of the authors (T.T. and T.L.).

We examined our data for correlations between the angle of deviation from the MA and patient-specific factors (i.e. hip-knee-ankle angle, tibial length, tibial bowing, and tibial torsion). Tibial length was measured from the proximal end (eminentia intercondylaris) to the ankle joint. Tibial bowing was determined by the angle between the lines drawn from the midpoint of the diaphysis at the apex of the bow to the center of the tibial component and to the center of the tibial plafond using the digital reconstruction radiography mode of the software (a positive value indicated laterally convex bowing). We detected the apex of the bow in this image as the most prominent cortex laterally or medially compared to the mechanical axis of the tibia, and defined the midpoint of the diaphysis by circle approximation in the axial plane (Fig. 4). We defined tibial torsion as the angle between the line perpendicular to the anteroposterior axis of the tibia and the transmalleolar axis (a positive value indicated outward rotation). The transmalleolar axis is the

Fig. 1. The definition of the mechanical axis (MA) of the tibia. (A) The mechanical axis of the tibia was defined by connecting the points between the center of the proximal tibia and the center of the distal tibia. (B) Proximal tibial center. (C) The center of the distal tibial plafond was automatically calculated by the software with the aid of three peripherally defined points approximating the plafond to a circle.
line joining the tips of the malleoli, estimated from the medial and lateral perspectives.

Intra- and inter-observer measurement reliabilities were assessed using intra-class correlation coefficients (ICC). We used the Mann–Whitney test or the Student’s t-test to compare the differences in angles for men and women after normality tests using Chi-square were performed for each data set. We used Pearson’s correlation coefficients to correlate the angle of deviation from MA with patient-specific factors. A p-value of less than 0.05 was considered significant.

This study was approved by our Institutional Review Board.

3. Results

Measurement reliability was excellent for the angle between the MA and the other reference axes (ICC 0.94–0.99; Table 1). In the coronal plane, the mean TCL-MA angle was 0.7°±0.9° of varus (range 1.7° of valgus to 3.8° of varus) and the percentage of subjects in which TCL was within 3° of the mechanical axis was 98% (100% in female patients) (Fig. 5). The mean FLc-MA angle was 2.9°±0.6° of valgus (range 4.3° of valgus to 1.6° of valgus). Fig. 6 shows all knees possessed an FLc within 2° of the mechanical axis when the FLc is used as an extramedullary guide with 3° of varus.

In the sagittal plane, the mean TCL-MA angle was 3.6°±1.0° of anterior inclination (range 1.3° to 6.1° of anterior inclination). Eighty-seven percent of the knees possessed a TCL with 0° to 3° of posterior slope of the proximal tibial cut when TCL was used as an extramedullary guide with 5° of posterior inclination (Fig. 7). The mean FLs-MA angle was 2.2°±0.8° of posterior inclination (range 0.4° to 4.3° of posterior inclination). Eighty-five percent of the knees had an FLs with 0° to 3° of posterior slope when a cut of the proximal tibia perpendicular to the FLs was performed (Fig. 8).

We found significant differences between male and female subjects in the TCL-MA angle in the coronal plane (male 1.6°±1.0° of varus vs female 0.6°±0.9° of varus, p<0.001) and in the sagittal plane (male 3.1°±1.0° of anterior inclination vs female 3.7°±1.0° of anterior inclination, p<0.005). For fibular lines, there were no significant differences between men and women.

4. Discussion

A line connecting the two points on the tibial crest 10 cm and 20 cm distal to the knee joint line was revealed as a reliable landmark of the proximal tibial cut in total knee arthroplasty, especially in female patients, who were within 3° of the tibial mechanical axis in the coronal plane. It can also be a useful landmark in the sagittal plane. Surgeons can achieve 0° to 3° of posterior slope of the proximal tibial cut in 87% of cases without taking into consideration the soft tissue thickness if they pre-angle the proximal tibial cutting jig in 5° of posterior inclination using points 10 cm and 20 cm distal to the knee joint on the tibial crest as indicators. Using one-third of the tibial crest as a landmark for the proximal tibial cut in the sagittal plane was as reliable as using the fibula. There were no patient-specific factors strongly affecting reliability of these landmarks (Table 2). We can use these landmarks even if the patient has tibial bowing or severe varus deformity.

Theoretically, when the fibula is used as an extramedullary guide with 3° of varus, surgeons can place the proximal tibial cutting guide within 2° of the mechanical axis of the tibia in all cases if an alignment confirmation device can be pre-angled 3° in varus from...
the fibula. In actual surgery, the patella shifts laterally making it difficult to detect the fibular head clearly. In addition, the surgeon cannot see the contour of the fibula directly from the anterior view. Therefore the fibula seems to be less useful than the tibial crest.

To our knowledge, there are few studies discussing the efficacy of the anterior crest or fibula using 3D evaluation. Fukagawa et al. [8] recommended using the line connecting the medial one-third of the patellar tendon attachment and the distal one-fourth of the anterior border of the tibia. It is difficult to determine these points in practical use because the patellar tendon shifts laterally during surgery, and the distal part of the tibia becomes more round, making it difficult to detect the anterior crest clearly. Fukagawa et al. reported that a line connecting the proximal and distal one-third of the anterior border of the tibia was parallel to the mechanical axis, but demonstrated wider variations among individuals. However, they did not discuss what caused this. They also suggested that surgeons can achieve 3° of tibial posterior slope with only a small error when the axis connecting the medial one-third of the patellar tendon attachment and the distal one-fourth of the anterior border is used as an extramedullary guide with 6° of posterior inclination. They cautioned that gender should be considered in using this axis because male subjects (n = 15) had larger anterior inclinations than females (n = 86). Our results in the current study were nearly the same as theirs and demonstrated that there are no patient-specific factors that strongly affect the reliability of the landmarks. However, men had more varus and less anterior inclination than women, which differed from the previous study. This may be due to the small sample of male patients in both reports. Further study to elucidate gender differences is warranted.

Han et al. [10] reported the anterior tibial cortex and fibular shaft axis as landmarks for sagittal tibial alignment. They defined the anterior tibial cortex (ATC) as the line tangential to the anterior cortex 7 cm below the tibial plateau and 7 cm above the plafond, and the fibular shaft axis (FSA) as the line connecting the center of the fibular neck and lateral crest of the distal fibula. The mean angle between ATC and the mechanical axis was $2.2^\circ \pm 0.92^\circ$ of anterior

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![Fig. 3](image)

**Fig. 3.** (A) Fibular line in the coronal plane (FLc). (B) Fibular line in the sagittal plane (FLs).
inclination and the mean angle between FSA and the mechanical axis was 2.1° ± 0.98° of posterior inclination. The angle between the fibula and the mechanical axis in the present study (2.2° ± 0.8° of posterior inclination) is very similar to their results. The reason why our coronal TCL-MA angle (3.6° ± 1.0° of anterior inclination) was larger than the angle between ATC and sagittal MA was mainly because the connecting points of ATC were too proximal and too distal.

Although we have to consider the soft tissue, there is a chance to improve the accuracy of the tibial alignment by using the anterior tibial crest. The anterior tibial crest is the area which has the least soft tissue, and is an easily palpable and visible landmark. Furthermore, by making the mark on the tibial anterior crest 10 cm and 20 cm distal from the knee joint line, the accuracy of our position for cutting will improve and will reduce the number of outliers, especially in female patients.

Our study has several limitations. First, there is no consensus regarding the definitions of tibial MA and the anteroposterior axis of the tibia. We defined tibial MA as the straight line from the center of the tibial component to the center of the distal tibial plafond, and anteroposterior axis as Akagi’s line [1]. If the definition of these two axes changed, the results would also change. Second, anatomical features of the tibia can vary with the ethnic origin of patients. Because all subjects in this study were ethnically Japanese, our findings might be difficult to directly extrapolate to a patient population of a different ethnic origin. Although further investigation including Caucasian subjects should be performed, we believe the findings from this study can be applied directly to the Chinese population because the average height of Japanese women is almost equal to that of the Chinese [21]. Third, further studies are needed to prove the accuracy of the anterior tibial crest in the sagittal plane taking into consideration the soft tissue. As the anterior tibial crest may not be palpable in some individuals, such as patients with high BMIs, special care must be taken to align extra-medullary guides correctly for such patients. None of the soft tissue and bony landmarks which have been reported are reliable in these patients.

In conclusion, our study demonstrated that the anterior tibial crest in the coronal and sagittal planes could be a useful guideline in performing TKAs.

**Conflict of interest**

The authors have no conflict of interest.
Fig. 6. Angle between the fibular line and the mechanical axis in the coronal plane (FLc-MA angle; a positive value indicated varus of the predicted tibial alignment).

Fig. 7. Angle between the tibial crest line and the mechanical axis in the sagittal plane (sagittal TCL-MA angle; a positive value indicated anterior inclination of the predicted tibial alignment).

Fig. 8. Angle between the fibular line and the mechanical axis in the sagittal plane (FLs-MA angle; a positive value indicated posterior inclination of the predicted tibial alignment).
Tibial hip-knee-ankle angle: a positive value indicated varus.

Tibial torsion: a positive value indicated outward rotation.

Table 2

<table>
<thead>
<tr>
<th>All knees</th>
<th>Male patients</th>
<th>Female patients</th>
<th>Correlations between each of four angles and the factor (r value)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n = 100)</td>
<td>(n = 15)</td>
<td>TCL-MA</td>
</tr>
<tr>
<td>Hip-knee-ankle angle</td>
<td>8.2° ± 6.6°</td>
<td>9.3° ± 4.9°</td>
<td>80° ± 6.9°</td>
</tr>
<tr>
<td>(−9°–24.7°)</td>
<td>(−9°–22.2°)</td>
<td>(−9°–24.7°)</td>
<td></td>
</tr>
<tr>
<td>Tibial length</td>
<td>313 ± 17 mm</td>
<td>328 ± 18 mm</td>
<td>311 ± 15 mm</td>
</tr>
<tr>
<td>(272–363 mm)</td>
<td>(297–356 mm)</td>
<td>(272–363 mm)</td>
<td></td>
</tr>
<tr>
<td>Tibial bowing</td>
<td>0.1° ± 1.7°</td>
<td>0.2° ± 1.2°</td>
<td>0.0° ± 1.7°</td>
</tr>
<tr>
<td>(−4.7°–6.6°)</td>
<td>(−4.7°–6.6°)</td>
<td>(−1.7°–6.2°)</td>
<td></td>
</tr>
<tr>
<td>Tibial torsion</td>
<td>13.2° ± 8.1°</td>
<td>13.2° ± 8.0°</td>
<td>13.3° ± 7.9°</td>
</tr>
<tr>
<td>(−11°–32°)</td>
<td>(−0.7°–30°)</td>
<td>(−11°–32°)</td>
<td></td>
</tr>
</tbody>
</table>

TCL: tibial crest line, MA: mechanical axis, FLc: fibular line in the coronal plane, FLs: fibular line in the sagittal plane. N.S.: not statistically significant.

Tibial torsion: a positive value indicated outward rotation.

Although we identified a moderate positive correlation between tibial length and coronal TCL-MA angle (r = 0.43, p = 0.001) and a moderate negative correlation between tibial torsion and FLs-MA angle (r = −0.41, p < 0.001), other correlations were weak.

References