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Original article

Importance of the lateral anatomic tibial slope as a guide to the tibial cut in total knee arthroplasty in Japanese patients

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Abstract Using three-dimensional computed tomography in 50 osteoarthritic knees, we simulated at various cutting angles the tibial cut for total knee arthroplasty. Cutting angles of 0°, 3°, 5°, 7°, 9°, and 11° were used. We then calculated the anterior and posterior thicknesses, the medial-lateral widths, and the medial and lateral condylar depths of the resected tibial bone at each cutting angle. Each set of measurements was evaluated according to a comparison between the cutting angle and the anatomic posterior slopes. The cutting angles showing the smallest anterior-posterior difference at the medial and lateral plateaus were 9° and 7°, respectively. The mean anatomic posterior slopes at the medial and lateral plateaus were 9.0° and 8.1°, respectively. When the tibia was cut at the cutting angle closest to the medial anatomical posterior slope in each knee, the thickness of the lateral posterior plateaus resected from 12 knees (24%) was more than 10 mm. Among these 12 knees, the cutting angle was more than 9° in 9 knees (75%). In contrast, when the tibia was cut at the cutting angle closest to the lateral anatomical posterior slope, only one resected medial posterior plateau was more than 10 mm. The cutting angle of this case was 7°. Therefore, in consideration of the thickness of bone resection from anatomic posterior slope, we demonstrated the importance of using the lateral anatomic posterior tibial slope as a guide to the tibial cut. There was no significant difference with respect to resected bone morphology at any cutting angle.

Key words Total knee arthroplasty · Posterior tibial slope · Computed tomography · Osteoarthritis

Introduction

It is important to restore proper alignment when performing total knee arthroplasty (TKA). The posterior tibial slope after TKA affects anteroposterior stability, range of motion, and contact pressure within the femorotibial joint. An inappropriate cutting angle of the posterior tibial slope results in polyethylene wear, component loosening, and posterior cruciate ligament (PCL) strain.[4,8,11] Some total knee systems have been designed to cut the proximal tibia with a specific posterior slope, whereas others have been designed to cut the tibia perpendicular to the longitudinal axis of the tibial shaft.[6] The proper cutting angle for the posterior tibial slope is still controversial. Changes in the posterior tibial slope after TKA affect the strain on the PCL and other posterior stabilizers of the joint. For surgeons who correct the soft tissue balance before the initial bone cut, it is important that the tibial cut in the sagittal plane does not alter this balance. For surgeons who cut the bone first, it is important to note that excessive anteroposterior instability cannot be repaired by soft tissue release. Thus, to minimize the effect of the sagittal plane tibial cut on the soft tissue balance, it is desirable to minimize any alteration to the posterior tibial slope with surgery, as reflected by the extent to which differences in the thickness of the anterior and posterior portion of the resected tibia is minimized.

In this study, we evaluated the effect of the posterior tibial slope on the thickness of the resected bone and the morphology of the resected surface, which we simulated at various cutting angles of the posterior slope using three-dimensional computed tomography (3D CT). The aim of this study was to identify a reliable landmark to minimize differences in thickness between the anterior and posterior portions of resected tibia and to investigate the influence of the cutting angle of the posterior slope on the morphology of the resected surface.

Materials and methods

Subjects

We studied 50 osteoarthritic knees in 32 patients. The mean age of the patients was 71.4 years (range 58–81

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years). The population consisted of 5 knees in 3 males and 45 knees in 29 females. All patients had medial-type osteoarthritis. The mean femorotibial angle on the standing anteroposterior (AP) radiograph was 185.3° (range 180°–189°; SD 2.7°). According to the Kellgren and Lawrence classification, all knees had radiographic evidence of grade 4 osteoarthritis.

Following this study, all knees underwent high tibial osteotomy or TKA using standard procedures uninfluenced by the computerized simulation. All subjects gave informed consent for participation in this study.

Computed tomographic technique

The patients were placed supine in the scanner with their knees taped to the scanner platform in the extended position. The patellae were facing directly anteriorly. Rapid 2-mm helical CT scans at 2.5 pitch were performed using an X Vigor Real (Toshiba Medical System, Tokyo, Japan) (table speed 5 mm/s; 120 kVp; 50 mA; 512 matrix; body FOV 240 mm). The scan length was 300 mm (150 mm above and 150 mm below the joint line of the knee). A total of 121 images were retrospectively reconstructed at 2.5-mm intervals with 180° interpolation and then reformatted with 3D reconstruction (Xtension Version 2; Toshiba Medical System) to produce 3D CT images of the tibia and the distal femur. 3D CT images were reconstructed by a surface rendering technique. The threshold is 234 Hunsfield units. Once the data are acquired, the software can be used to rotate, clip, and measure the image.

Decision regarding tibia position

Initially, we evaluated the position of the PCL attachment 10 mm below the lateral tibial articular surface on the horizontal plane by magnetic resonance imaging (MRI) in five cases. We found that the center of the PCL attachment (point C) was the midpoint between the most posterolateral aspect (point A) and the most anterior aspect (point B) of the posterior intercondylar area in some cases (Fig. 1a). The 3D CT image, which was sliced at the same level as the MRI, was subsequently evaluated. We morphologically confirmed the most posterolateral aspect as point A and the most anterior aspect as point B in the 3D CT image. Therefore, this midpoint (point C) was defined as the center of the PCL attachment on 3D CT images. Also in the horizontal plane in 3D CT image, the anteroposterior axis of the tibia was defined as a line drawn from the one-third medial side of the tibial tubercle to the center of the PCL attachment (point C). Using these references, the tibia was rotated to align the anteroposterior axis parallel to the Y axis on the horizontal plane (Fig. 1b).

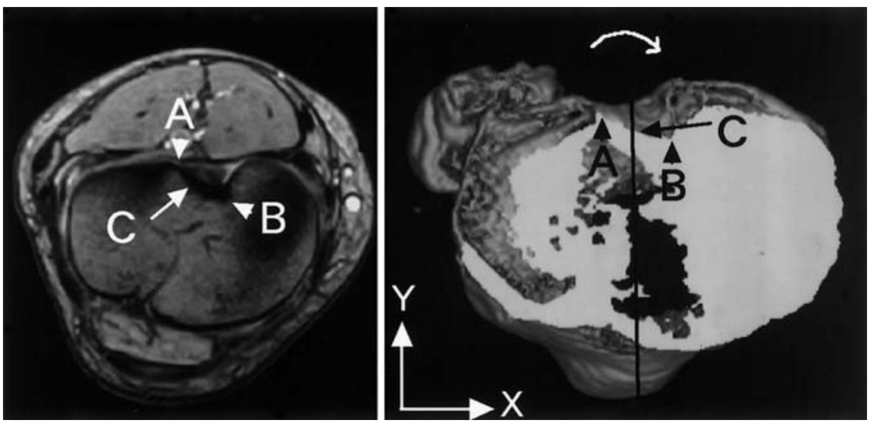
Finally, the longitudinal axis of the tibial shaft, defined as the anatomical axis of the tibial shaft on the 3D image, was aligned parallel to the Y axis on both the anteroposterior and the lateral views (Fig. 2).

Measurements

Anatomic posterior tibial slope

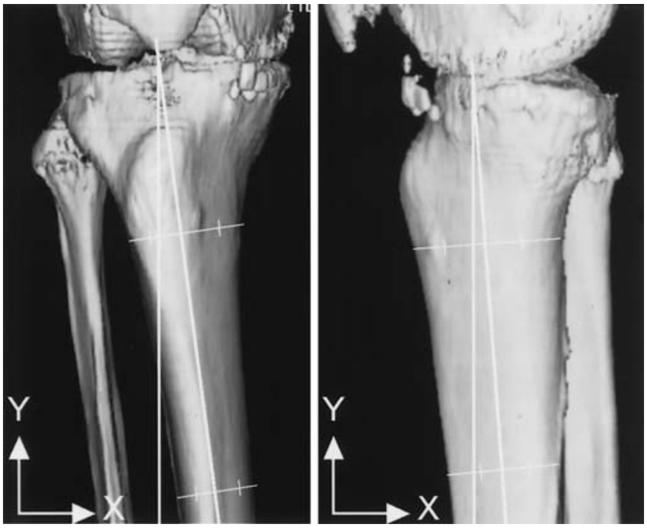
To determine the posterior slope of the medial and lateral plateau, the anterior and posterior corner of

a



b

Fig. 1. a Magnetic resonance (MR) image of the horizontal plane of the articular surface of the proximal tibia. Points *A* and *B* show the most posterolateral and the most anterior aspects of the posterior intercondylar area. Point *C* indicates the midpoint of points *A* and *B* and is the midpoint of the posterior cruciate ligament (PCL) attachment. **b** Each point in this three-dimensional (3D) image corresponds with each point in the MR image. Determination of the anteroposterior axis of the 3D computed tomography (CT) image in the horizontal plane. A line was drawn connecting the one-third medial side of the tibial tubercle and point *C*



a,b

Fig. 2. **a** Anteroposterior view of the 3D image of the distal femur and tibia. The image is rotated to align the longitudinal axis of the tibial shaft parallel to the Y axis. **b** Lateral view of the 3D model of the distal femur and tibia. The image is rotated to align the longitudinal axis of the tibial shaft parallel to the Y axis

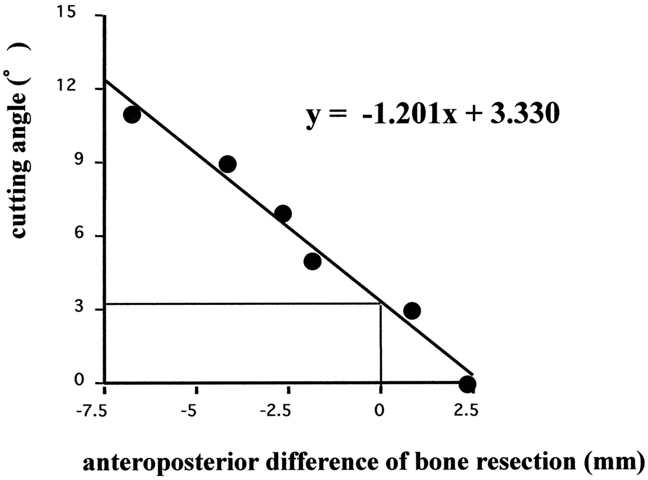
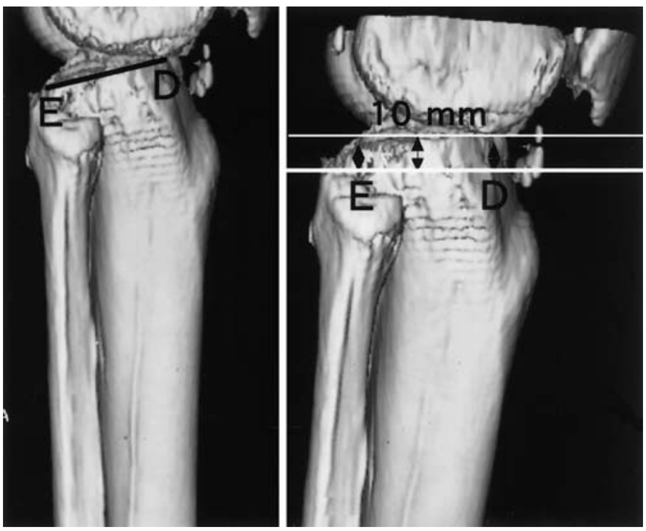


Fig. 4. Calculation of the cutting angle that yielded a 0mm anteroposterior thickness difference in the resected bone in a representative knee. A graph of the anteroposterior difference in bone resection versus the cutting angle was drawn for each knee. Then the regression line was drawn. In this case, the optimal cutting angle is 3.3°



a,b

Fig. 3. **a** Anatomic tibial posterior slope. Points *D* and *E* are the anterior and posterior corners of the lateral tibial plateau, respectively. **b** The proximal tibia was resected with a 10mm thickness. The thickness of the resected bone was measured both anteriorly and posteriorly

each plateau was located on lateral and anteroposterior views. Point D was the anterior corner of the lateral plateau, and point E is the posterior corner of the lateral plateau. The anatomic posterior tibial slope is the angle formed by the line connecting points D and E and the longitudinal axis of the tibial shaft, as shown in Fig. 3a. We measured the anatomic posterior slopes at the medial and lateral plateau in all cases.

Thickness of bone resection

Various bone-cutting theories existed on how to perform the proper TKA. In this study, the theory of the independent cut was used. The proper thickness of bone resection was determined by assuming the tibia is to be resurfaced with a 10-mm tibial component during the TKA. The level of the tibial cut was 10 mm below the midpoint between the lowest point of the lateral condyle of the femur and its corresponding point along the tibial plateau, in consideration of the cartilage width (Fig. 3b). In the simulation, the cutting angles of the posterior slope were set at 0°, 3°, 5°, 7°, 9°, and 11° relative to a perpendicular to the longitudinal axis of the tibial shaft. Then, the thickness of the bone resection in the anterior corner (D) and posterior corner (E) was measured (Fig. 3b). The anterior-posterior difference in bone resection value was defined as the anterior corner thickness minus the posterior corner thickness. We also measured the thickness of the resected bone in the medial plateau.

Calculating the cutting angle that yielded a 0mm anterior-posterior thickness difference in the resected bone

For each knee, the anterior-posterior difference in bone resection was plotted against the cutting angle. Linear regression of the data was used to generate the line of best fit; then the regression equation of the line of best fit was drawn. Figure 4 shows the graph for a representative knee. When the value of the anterior-posterior difference in bone resection was 0 on the X axis, the cutting angle was 3.3°. This cutting angle was calculated for the medial and lateral plateaus of each knee, and the mean value for all knees was obtained.

Tibial mediolateral width and medial and lateral tibial condylar depths

In each of the resected tibial surfaces, the distance between lines tangent to the most medial and lateral parts of the condyles parallel to the Y axis was defined as the tibial mediolateral width.[9]

The distances between lines tangent to the most anterior and posterior parts of the condyles parallel to the X axis were defined as the anterior and posterior tibial depths for the medial and lateral condyles (Fig. 5). Osteophytes seen surrounding the resected surface of the tibia were excluded from the measurements.

Measurements of bilateral cases

In 18 bilateral cases we compared the anatomic posterior tibial slopes of the right and left knees. The anatomic posterior slopes differed by more than 3° at the medial plateau in 9 cases and at the lateral plateau in 12 cases. The same angle of the anatomic posterior slope in both right and left knees were observed in only two cases at the medial plateau and one case at the lateral plateau.

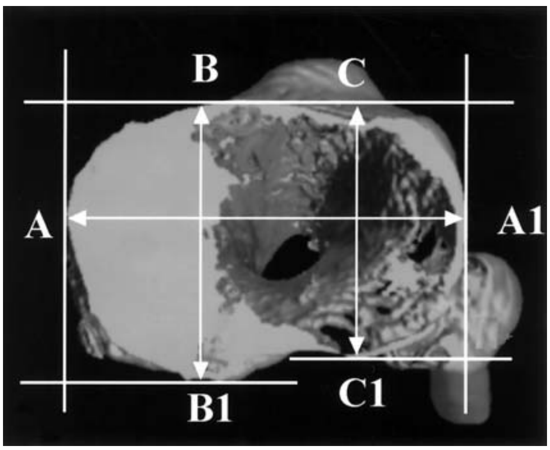


Fig. 5. 3D CT image of the resected surface of the proximal tibia. *A↔A1*, tibial mediolateral width; *B↔B1*, medial tibial condylar depth; *C↔C1*, lateral tibial condylar depth

Assessment of the reliability of measurements

3D CT images were reconstructed 10 times using the same method with the same subject, and the standard deviation (SD) and the coefficient of variation (CV) of the measurements were calculated. The thickness of the bone resection, tibial width, and condylar depth were measured at 0° posterior slope. The standard deviation of the anatomic posterior slopes were consistent within 0.1°, and the bone resection thickness, tibial width, and condylar depth measurements were consistent within 0.15 mm. The coefficients of variation were less than 2.0% for all parameters (Table 1). Each set of measurements was repeated on 10 randomly selected subjects by two independent observers. The interobserver reliability was high, as assessed by Pearson correlation coefficient (Table 1).

Statistical analysis

Data were analyzed by analysis of variance (ANOVA) with Stat View IV (Stat View; Abacus Concepts, Berkeley, CA, USA). $P < 0.01$ was considered significant.

Results

Anatomic posterior tibial slope

The mean value of the anatomic posterior tibial slope at the medial plateau was 9.0° (SD 5°), the mean value at

Table 1. Reliability of measurements

Measurement	SD	CV (%)	Correlation (*r*)
Anatomic posterior slope (degrees)			
Medial	0.05	1.3	0.84
Lateral	0.06	1.3	0.91
Thickness of bone resection (mm)			
Medial			
Anterior	0.07	1.1	0.91
Posterior	0.06	1.5	0.83
Lateral			
Anterior	0.12	1.3	0.87
Posterior	0.06	0.8	0.87
Condylar depth (mm)			
Medial	0.12	0.2	0.88
Lateral	0.14	0.3	0.94
Tibial width (mm)	0.09	0.1	0.85

the lateral plateau was 8.1° (SD 4°). Twenty-four knees (48%) at the medial plateau and 16 knees (32%) at the lateral plateau had a posterior tibial slope of more than 8°.

Thickness of bone resection

With simulated cutting of the tibia at a 0° posterior slope, the thickness of the anterior corners was greater than that of the posterior corners at both the medial and lateral plateaus in all cases. Table 2 shows that for a posterior tibial slope of 0° the mean thickness of bone resection at the medial plateau was 6.9 mm, and the mean thickness of bone resection at the lateral plateau was 4.3 mm. The resection of the proximal tibia at 9° posterior slope showed the smallest. The mean anterior-posterior difference at the medial plateau was 0.1 mm. On the other hand, the resection at 7° showed the smallest. The mean anterior-posterior difference at the lateral plateau was 0.4 mm (Table 2).

Cutting angle that yielded a 0 mm anterior-posterior thickness difference in the resected bone

The mean the cutting angles that yielded no difference in thickness between at the medial and lateral plateaus were 9.0° ± 5° (SD) and 7.2° ± 4° at the medial and lateral plateaus, respectively. A significant correlation was found between the anatomic posterior slope and this cutting angle. The regression coefficients at the medial and lateral plateaus were 0.762 and 0.553 ($P < 0.0001$), respectively.

When the tibia was cut at the cutting angle closest in value to the medial anatomical posterior slope in each knee, the thickness of the lateral posterior plateaus resected from 12 knees (24%) was more than 10 mm. In contrast, when the tibia was cut at the cutting angle closest in value to the lateral anatomical posterior slope, only one resected medial posterior plateau was more than 10 mm.

Tibial mediolateral width and medial and lateral tibial condylar depths

The tibial mediolateral width, medial tibial depth, and lateral tibial depth at each of the resected surfaces of the tibia are shown in Table 3. Various cutting angles of the posterior slope did not produce significant differences in any of these parameters.

Discussion

As far as we are aware, this is the first study to demonstrate the simulation for TKA using 3D CT. With respect to the morphological evaluation of the tibia, such as the anatomical tibial slope, thickness of the resected bone, and shape of the resected surface, we used 3D CT instead of the conventional method. We believe that 3D CT is more convenient and consistent than the conventional method using radiography and MRI. In most patients who have osteoarthritis of the knee, full extension of the knee joints is difficult. Therefore, it is difficult to obtain the correct constant anteroposterior view of the knee joint by radiography or MRI. Furthermore, the 3D CT images can be rotated without restraint after reconstruction, and the correct and constant three-dimensional axes can be determined and maintained. To design an optimal TKA procedure, morphological evaluation using 3D CT is more useful.

The mediolateral width and tibial condylar depth of resected tibial surfaces did not differ at any cutting angle of the posterior slope. This finding shows that

Table 2. Thickness of bone resection

Posterior tibial slope (degrees)	Medial plateau (mm)	Lateral plateau (mm)
0	6.9 ± 3.8	4.3 ± 2.9
3	4.7 ± 4.0	2.7 ± 2.8
5	2.9 ± 4.1	1.4 ± 2.8
7	1.4 ± 4.2	0.4 ± 2.7
9	0.1 ± 4.1	−1.0 ± 2.7
11	−1.6 ± 4.0	−2.1 ± 2.9

Values are expressed as mean ± SD

Table 3. Morphology of bone surface of the resected tibia

Posterior tibial slope (degrees)	Mediolateral width (mm)	Medial tibial depth (mm)	Lateral tibial depth (mm)
0	73.0 ± 3.7	52.3 ± 4.6	45.2 ± 3.1
3	72.8 ± 3.7	51.4 ± 3.4	44.8 ± 3.3
5	72.9 ± 3.8	51.1 ± 3.6	44.5 ± 3.2
7	72.8 ± 3.8	50.9 ± 3.5	44.3 ± 3.2
9	72.9 ± 3.9	50.7 ± 3.5	44.2 ± 3.2
11	72.7 ± 4.0	50.4 ± 3.5	44.2 ± 3.3

Values are expressed as the mean ± SD

altering the cutting angle does not require changing the size of the tibial component.

Several authors have published reports about the anatomic posterior slope of the tibial plateau. In the study of Hofmann et al.,[4] the mean posterior tibial slope on preoperative roentgenogram was 7° (SD 3°; range 2°–12°) in 23 osteoarthritic knees and 8 rheumatoid arthritic knees. Laskin and Rieger[5] stated that the normal tibial plateau has a posterior slope of 8°–10°. By MRI analysis, the mean tibial posterior slopes at the medial and lateral plateaus were 10.7° (range 5.0°–15.5°) and 7.2° (range 0°–14.5°), respectively, in 30 normal knees.[7] In cadaveric tibia, Chiu et al.[2] reported that the posterior slopes at the medial and lateral plateaus were 14.8° (range 5°–25°) and 11.8° (range 4°–23°), respectively, in 31 normal knees and 15 osteoarthritic knees. Our data show that the anatomical posterior slope in Japanese patients is similar to that in Occidentals. Posterior slopes vary widely in all studies. These data suggest that if the tibia is cut at a constant angle of the posterior slope, the anterior-to-posterior difference in the thickness of the resected bone will show a wide variation and make the correct soft tissue balancing more difficult. The proper tibial posterior slope for TKA is still controversial. When the tibia is cut perpendicular to the longitudinal axis of the tibial shaft, the anterior bone stock that remains may have reduced strength and stiffness, and it may induce anterior subsidence and failure of the tibial components.[1,4] Therefore, tibial cutting with some degree of posterior slope is desirable. We have shown that a posterior slope decreases the difference between the anterior and posterior thicknesses of the resected tibial bone. However, several studies demonstrated that a posterior tibial slope of more than than 8° led to posterior tibiofemoral subluxation, increased the polyethylene wear of the posterior part, and resulted in a lack of femoral rollback in flexion and impingement of the posterior structure.[2,3,5,10–12]

What is the best guide for determining the proper posterior slope? Our data show that when the tibia was cut at an angle close in value to the medial anatomical posterior slope in each knee, the resected thickness of the lateral posterior tibia was more than the 10mm of the prosthetic tibial component in 12 knees (24%) of the knees. Among these of 12 knees, the cutting angle was more than 9° in 9 knees (75%). In contrast, when the tibia was cut at an angle close to the lateral anatomical posterior slope, excessive resection of the medioposterior tibia occurred in only one knee (2%). The cutting angle of this case was 7°. In cases in whom the cutting angle was more than 9°, there was no need cut more than 10mm. In our study, a cutting angle close to the medial anatomical tibial slope more frequently is inclined more than 8°. When the tibia was cut at an angle close to the lateral anatomic posterior slope, the thickness of the bone resection could be reduced. Therefore, by considering of the thickness of the bone resection from the anatomic posterior slope, we demonstrated that the importance of the lateral anatomic posterior tibial slope to use as a guide to the tibial cut. However, even using the lateral anatomic slope, the cutting angle was more than 8° in 32% of the knees. If we accept the results of previous studies, we should never cut the tibia at more than 8°. The remaining anterior and posterior gaps should be corrected by soft tissue balancing. In fact, however, there were not average knees.

Knee surgeons should consider the morphological variation of the tibia among individuals. The remaining anterior and posterior gaps should be corrected by soft tissue balancing. For patients with severe varus deformity and a bone defect of the medial plateau, bone graft should be performed.

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