The Offset of the Tibial Shaft from the Tibial Plateau in Chinese People

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J Bone Joint Surg Am. 2010;92:1981-1987. doi:10.2106/JBJS.I.00969

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Background: Long-stem tibial components are available for complex primary and revision total knee arthroplasties. Most of the stems' designs are based on anatomic data from Western populations. We conducted a morphologic study to determine the relationship of the tibial shaft to the tibial plateau in Chinese people.

Methods: We included knees from fifty Chinese individuals (twenty-five females and twenty-five males) in this study. On magnetic resonance imaging scans of the tibial plateau and the proximal part of the tibial shaft of each lower limb, the distance between the axis of the tibial shaft and the center of the tibial plateau was measured and was defined as the offset of the tibial shaft from the tibial plateau at three resection levels: the first just distal to the subchondral bone of the medial tibial plateau, the second 5 mm distal to it, and the third 10 mm distal to it. The dimensions of the tibial plateau were measured as well.

Results: At the first, second, and third resection levels, the mean tibial shaft offsets (and standard deviations) from the center of the tibial plateau were, respectively, 7.23 ± 2.44 mm (3.40 ± 1.94 mm of mediolateral offset and 6.22 ± 2.05 mm of anteroposterior offset), 6.33 ± 2.26 mm (3.14 ± 2.04 mm of mediolateral offset and 5.24 ± 1.96 mm of anteroposterior offset), and 4.75 ± 2.07 mm (2.68 ± 1.91 mm of mediolateral offset and 3.46 ± 2.03 mm of anteroposterior offset). At each resection level, the mean offset in the male group was significantly larger than that in the female group.

Conclusions: There is a large variation in the offset of the tibial shaft from the tibial plateau in Chinese people. The axis of the tibial shaft is located anterolateral to the center of the tibial plateau in this population.

Clinical Relevance: The use of an anterolaterally offset tibial keel or stem seems more suitable for Chinese patients undergoing primary or revision total knee arthroplasty.

Many factors determine the success of a primary or revision total knee arthroplasty. Component position, good fixation, and osseous coverage have been shown to be important for the long-term survival of these prostheses.

For good fixation and implant stability, a tibial component with a stem extension may be needed in knees with extensive proximal tibial bone loss and in revision total knee arthroplasty[1-3]. A long stem provides more efficient stress transfer from the proximal tibial joint line to the tibial diaphysis, with stress bypassing the metaphysis in patients who have undergone revision knee arthroplasty[4-6]. Long stems can also be used in total knee arthroplasties performed for the treatment of nonunion after a high tibial osteotomy or a tibial fracture in patients with arthritic knees[7,8].

However, if a tibial component with a long central stem is used, the tibial tray may not be centered on the tibial plateau because the axis of the tibial shaft does not always match the center of the tibial plateau. Many authors have noted the problems of poor coverage of the proximal part of the tibia and overhang of the tibial tray caused by such a mismatch[9-11]. In an anatomic study of ten tibial specimens, Hicks et al. found a high degree of variability in the location of the tibial shaft axis at the site of the resection of the proximal part of the tibia[9]. Therefore, a tibial component with an offset stem is needed to accommodate the anatomic features of the proximal part of the tibia and to obtain maximal coverage of the tibial plateau with minimal overhang.

Most modern designs of offset stems have been based on anatomic studies of Western populations. However, the ana-

Disclosure: The authors did not receive any outside funding or grants in support of their research for or preparation of this work. Neither they nor a member of their immediate families received payments or other benefits or a commitment or agreement to provide such benefits from a commercial entity.

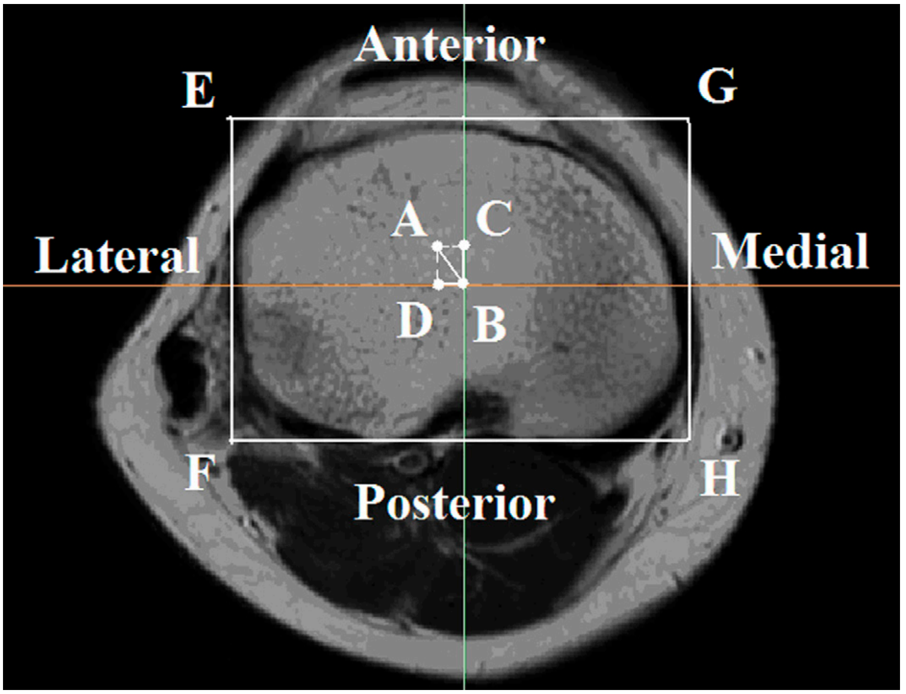

Fig. 1

The tibial shaft axis is located anterolateral to the center of the tibial plateau. A = the location of the axis of the tibial shaft, B = the center of the tibial plateau, C = the projected point of point A on the anteroposterior axis, D = the projected point of point A on the mediolateral axis, AB = the offset of the tibial shaft from the tibial plateau, BC = the anteroposterior offset, BD = the mediolateral offset, EF = the anteroposterior dimension of the tibial plateau, and EG = the mediolateral dimension of the tibial plateau.

tomic features of the proximal part of the tibia in Asian people may be different from those of Western people. For example, a study has shown that the medially offset stem may not be a good option for some Korean patients undergoing total knee arthroplasty[12]. We therefore conducted this study to identify the location of the tibial shaft axis on the tibial plateau with the use of magnetic resonance imaging scans in a Chinese population. We wanted to determine the relationship of the tibial shaft to the tibial plateau and to determine what kind of tibial stem would be most suitable for complex primary or revision total knee arthroplasty in the study population.

Materials and Methods

The study was approved by the institutional review board of our hospital, and informed consent was obtained from each study subject. The study subjects included twenty-five males (mean age [and standard deviation], 30.9 ± 12.0 years; range, seventeen to fifty-three years) and twenty-five females (mean age, 38.4 ± 11.8 years; range, sixteen to fifty-six years). None of the study subjects had had a previous knee fracture or surgical procedure, none had a deformity, and magnetic resonance imaging did not show any osseous injuries. Subjects with obvious bone deformity or limb malalignment were excluded. We acquired a magnetic resonance imaging scan of the tibial plateau and proximal 12-cm segment of the tibial shaft of each study subject with use of a Signa 1.5T Excite scanner (GE Healthcare, Milwaukee, Wisconsin). Volumetric magnetic resonance imaging data for the fifty knees were input into the image-processing computer program Mimics (version 10.01; Materialise, Leuven, Belgium) so that we could produce three-dimensional reconstructions and obtain additional measurements.

The first step of the image processing was to determine the axis of the tibial shaft. Theoretically, the stem of a tibial component should be inserted along the axis of the tibial shaft and be press-fit into the tibial canal to attain good fixation. Therefore, we put a circle representing a cross section of a tibial stem into the tibial canal in the transverse image at the resection levels of 7 and 11 cm distal to the tibial articular surface. Because the cross section of the tibial canal was triangular, we adjusted the size and position of the circle and made it come into contact with the three inner points of the cortex of the tibial shaft. The center of the circle was defined as the center of the tibial canal. An extended line connecting the two centers at the two levels represented the axis of the tibial shaft. After the axis was determined, the transverse resection images of the tibial plateau were acquired again by reslicing the tibia perpendicular to the defined axis of the tibial shaft. The point where the axis of the tibial shaft intersected with the tibial plateau at the level of the resection was marked and was

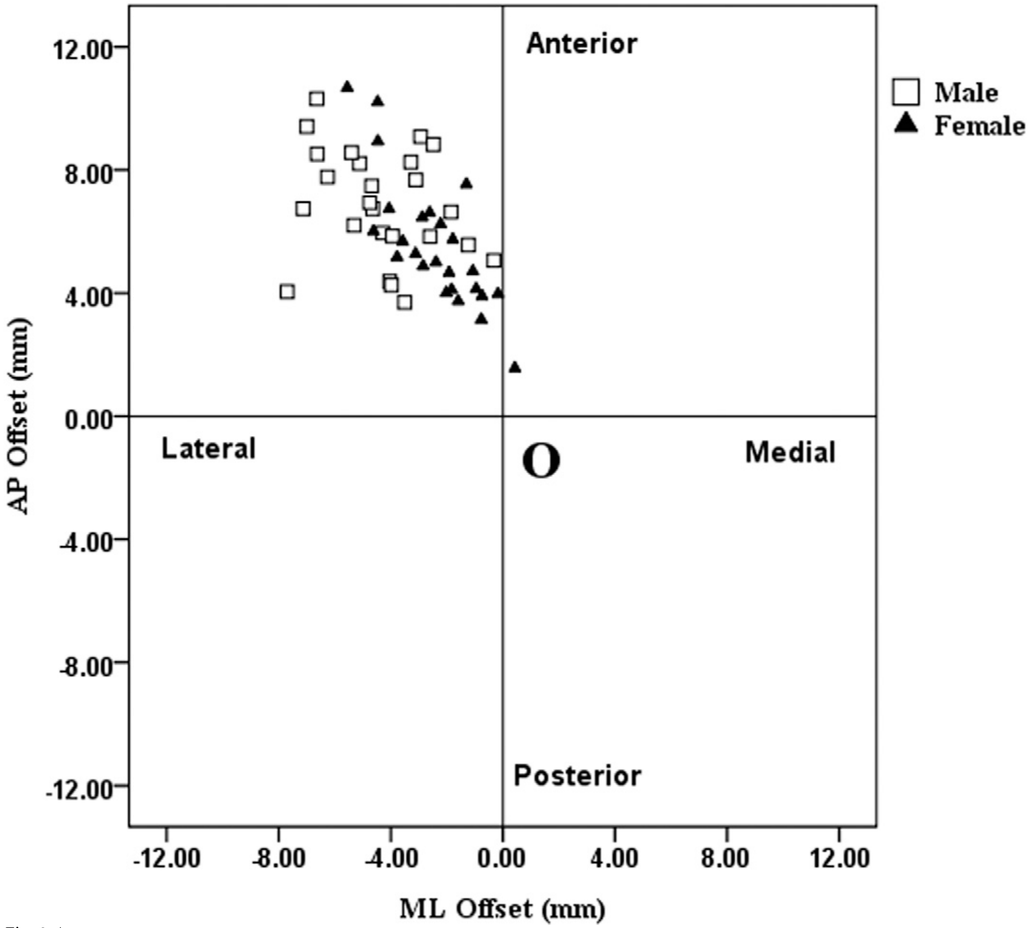

Fig. 2-A

The offset of the tibial shaft from center of the tibial plateau at the first resection level (Fig. 2-A), the second resection level (Fig. 2-B), and the third resection level (Fig. 2-C). The symbols (squares for males and triangles for females) represent the locations of the tibial shaft axis. The cross point (O) of the mediolateral axis and anteroposterior axis represents the center of the tibial plateau. AP = anteroposterior and ML = mediolateral.

defined as the location of the tibial shaft axis on the tibial plateau (Fig. 1).

The next step was to define the center of the tibial plateau at the level of the resection. Theoretically, the tibial tray should cover the maximal area of the tibial plateau remaining after the resection, with minimal overhang, and have an appropriate rotational alignment. Akagi et al.[13] noted that, in Asian people, the anteroposterior axis of the rotational alignment of the tibial tray is parallel to the line connecting the middle of the posterior cruciate ligament and the medial border of the patellar tendon attachment. Therefore, we placed a rectangle, representing a tibial tray, on the transverse resection image of the tibial plateau[9]. We adjusted the size and position of the rectangle to make its medial, lateral, and anterior borders overlap the medial, lateral, and anterior outer cortical borders, respectively, of the tibial plateau; to make its posterior border overlap the posterior outer cortical border of the lateral tibial plateau; and to make its anteroposterior axis parallel to the rotational alignment axis. The center of the rectangle was marked and was defined as the center of the tibial plateau (Fig. 1).

On the transverse resection image of the tibial plateau, the distance between the tibial shaft axis and the tibial plateau center was measured and was defined as the offset of the tibial shaft from the tibial plateau. The distance between the axis of the tibial shaft and the center of the tibial plateau was measured in the anteroposterior direction and in the mediolateral direction and was defined as the anteroposterior offset and mediolateral offset, respectively. The anteroposterior and mediolateral dimensions of the rectangle were also measured and defined as the anteroposterior and mediolateral dimensions of the tibial plateau (Fig. 1). All of the measurements were made at three resection levels. The first resection level was just distal to the subchondral bone of the medial tibial plateau, which represented the clinical situation of the level of a bone cut in a proximal tibial segment with mild bone loss. The second resection level was 5 mm distal to the subchondral bone of the medial tibial plateau, which represented the level of a

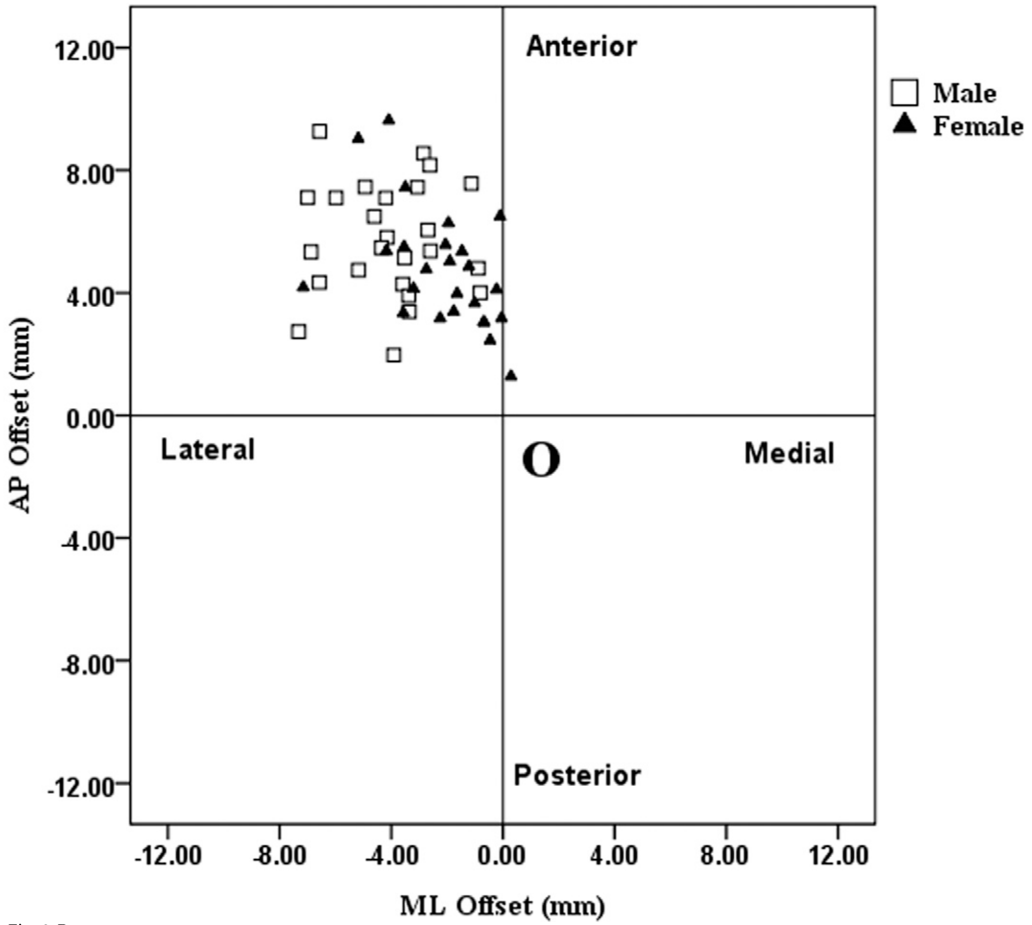

Fig. 2-B

bone cut in a proximal tibial segment with moderate bone loss. The third resection level was 10 mm distal to the subchondral bone of the medial tibial plateau, which represented the level of a bone cut in a proximal tibial segment with severe bone loss.

To identify the reproducibility of the measurements, a second researcher obtained the same measurements independently in a randomly selected group of fifteen study subjects[14].

Intraclass correlation analysis was performed to assess the extent of the reproducibility of the measurements. The Student t test was used to evaluate differences in the parameters between the sexes. Correlation analysis (the Pearson correlation coefficient) was performed to determine the associations between the dimension of the tibial plateau and the offset of the tibial shaft from the tibial plateau. A p value of <0.05 was considered to be significant.

Source of Funding

No external funding was received for this study.

Results

The intraclass correlation analysis revealed a significant (p = 0.000) correlation coefficient of 0.993, demonstrating that the measurements were reproducible.

The mean offset (and standard deviation) of the tibial shaft from the tibial plateau was 7.23 ± 2.44 mm (range, 1.62 to 12.26 mm), 6.33 ± 2.26 mm (range, 1.31 to 11.36 mm), and 4.75 ± 2.07 mm (range, 0.46 to 9.36 mm) at the first, second, and third resection levels, respectively. In forty-nine of the fifty knees that were examined, the tibial shaft axis was located anterolateral to the center of the tibial plateau at the proximal two resection levels. In only one knee was the tibial shaft axis located anteromedial to the center of the tibial plateau. At the third resection level, the axis of the tibial shaft was located anterolateral to the center of the tibial plateau in forty-seven knees, anteromedial to the center of the tibial plateau in one knee, and posterolateral to the center of the tibial plateau in two knees (Figs. 2-A, 2-B, and 2-C).

The anteroposterior and mediolateral offsets and the anteroposterior and mediolateral dimensions of the tibial plateau in the male group were significantly larger than those in the female group at each resection level (Table I).

The correlation between the anteroposterior offset and the anteroposterior dimension was estimated to be 0.435 (p = 0.002), 0.419 (p = 0.002), and 0.471 (p = 0.001) at the first, second, and third resection level, respectively. The correlation between the mediolateral offset and the mediolateral dimen-

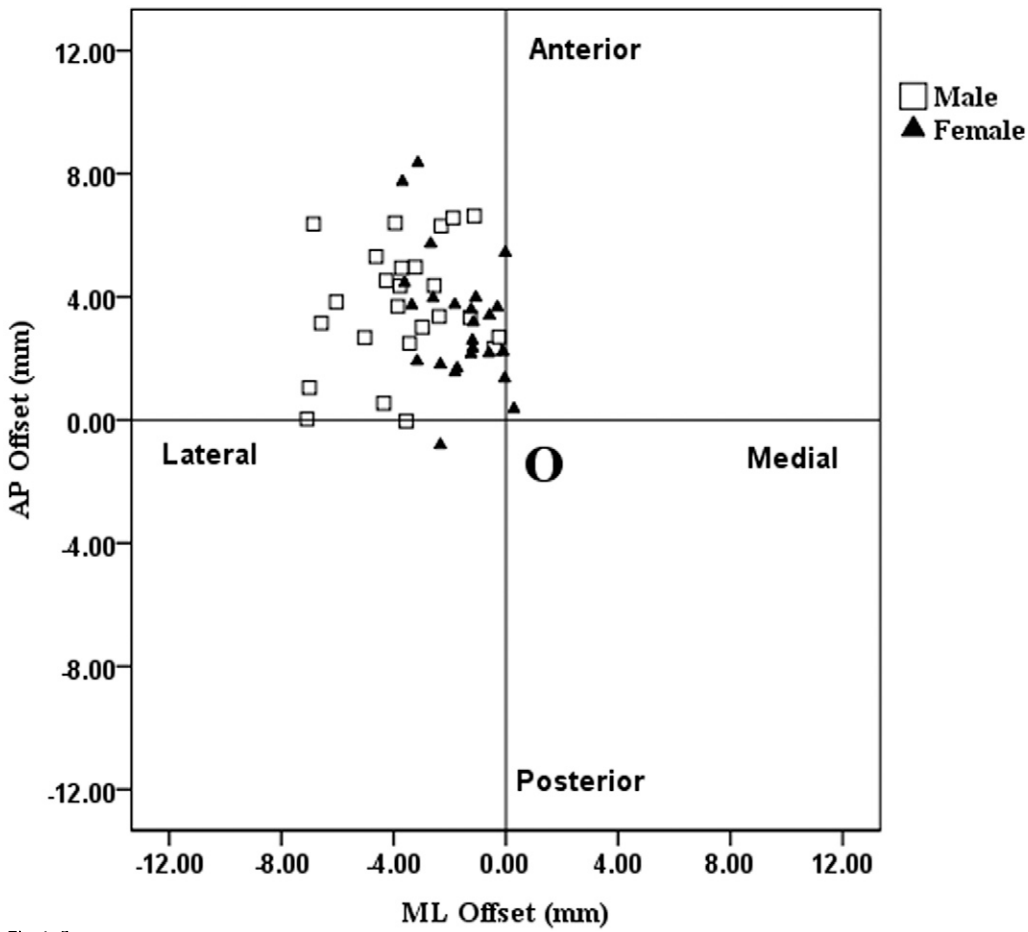

Fig. 2-C

sion was estimated to be 0.508 (p = 0.000), 0.543 (p = 0.000), and 0.426 (p = 0.002) at the first, second, and third resection level, respectively.

Discussion

In total knee arthroplasty, a long stem can provide support for a tibial component and has been shown to be advantageous in certain circumstances. Recently, offset stems have been made available to facilitate maximal tibial coverage and minimal overhang. The designs of most of these stems are based on anatomic data of Western populations[9,15,16]. However, anatomic features of Asian populations differ from those of Western populations[11,17-19]. These morphologic differences may be important to consider when designing or implanting a stemmed tibial component.

Our results confirmed that the axis of the tibial shaft does not overlap the center of the tibial plateau in Chinese study subjects. The offset of the tibial shaft from the tibial plateau averaged 7.23 mm when the resection level was just distal to the subchondral bone of the medial plateau, 6.33 mm when it was 5 mm distal to it, and 4.75 mm when it was 10 mm distal to it. Abraham et al. performed total knee arthroplasty in twenty cadaver tibiae and found that the average distance between the center of the tibial diaphysis and the center of the tibial metaphysis was 4.1 mm at the resection level of the fibular head[10]. In view of the findings of Abraham et al. as well as our observations, it would appear that an offset stem would be more suitable for Chinese patients who need a long-stemmed tibial component. We also noted that there was a large variation in the offset of the tibial shaft from the tibial plateau, ranging from 0.46 to 12.26 mm, so it would be desirable to have a wide range of offset stems available—for example, from 0 to 16 mm, in 2-mm or 4-mm increments.

Several studies have revealed that the axis of the tibial shaft is, on the average, located anteromedial to the center of the tibial plateau in the Western population, for whom a medially offset stem seems more suitable[9,15,16]. We found that the relationship of the tibial shaft axis to the center of the tibial plateau was different in the Chinese population. Our data show that, at the proximal two resection levels, the axis of the tibial shaft is typically located anterolateral to the center of the tibial plateau in Chinese study subjects; this was the case in forty-nine of fifty knees, whereas the tibial shaft axis was located anteromedial to the center of the tibial plateau in only one knee. At the third resection level, the axis of the tibial shaft was located anterolateral to the center of the tibial plateau in forty-seven knees, anteromedial to the center of the tibial plateau in one knee, and posterolateral to the center of the

TABLE I Measurements at the Three Resection Levels

Parameter*	Total† *(mm)*	Male† *(mm)*	Female† *(mm)*	P Value‡
Offset				
1st resection level	7.23 ± 2.44	8.31 ± 1.98	6.14 ± 2.41	0.001
2nd resection level	6.33 ± 2.26	7.29 ± 1.84	5.38 ± 2.28	0.002
3rd resection level	4.75 ± 2.07	5.69 ± 1.70	3.82 ± 2.01	0.001
Mediolateral offset				
1st resection level	3.40 ± 1.94	4.35 ± 1.91	2.45 ± 1.46	0.000
2nd resection level	3.14 ± 2.04	4.08 ± 1.88	2.20 ± 1.77	0.001
3rd resection level	2.68 ± 1.91	3.70 ± 1.98	1.65 ± 1.78	0.000
Anteroposterior offset				
1st resection level	6.22 ± 2.05	6.88 ± 1.80	5.56 ± 2.10	0.021
2nd resection level	5.24 ± 1.96	5.74 ± 1.86	4.73 ± 1.95	0.067
3rd resection level	3.46 ± 2.03	3.72 ± 2.00	3.21 ± 2.07	0.384
Mediolateral dimension				
1st resection level	75.21 ± 6.01	80.40 ± 3.50	70.02 ± 2.29	0.000
2nd resection level	74.67 ± 6.03	79.60 ± 3.33	69.74 ± 3.52	0.000
3rd resection level	71.40 ± 6.29	76.68 ± 3.90	66.13 ± 2.74	0.000
Anteroposterior dimension				
1st resection level	51.47 ± 4.04	54.74 ± 2.60	48.19 ± 2.05	0.000
2nd resection level	52.00 ± 4.10	55.19 ± 2.93	48.82 ± 2.01	0.000
3rd resection level	50.91 ± 4.39	53.88 ± 3.49	47.95 ± 2.97	0.000

*1st resection level = just distal to the subchondral bone of the medial plateau, 2nd resection level = 5 mm distal to it, and 3rd resection level = 10 mm distal to it. †The values are given as the mean and standard deviation. ‡For the difference between the male and female groups.

tibial plateau in two knees. Our findings were similar to those of previous studies involving Asian study subjects[11,12]. Nagamine et al. studied 133 Japanese patients and noted that the tibial shaft axis was typically located lateral to the mechanical axis[11]. In a study of 246 Korean patients, the tibial shaft axis was seen to be typically located lateral to the mechanical axis on anteroposterior radiographs[12]. After total knee arthroplasty with a medially offset tibial keel was performed in those patients, contact between the keel tip and the medial tibial cortex was seen in sixteen knees and cement was found to have leaked out of the medial cortex of the tibia in one knee[12]. Therefore, it is reasonable to presume that an anterolaterally offset tibial keel or stem would be a better option for Asian patients.

In our study, the offset of the tibial shaft from the tibial plateau in the male group was significantly larger than that in the female group, a finding that differed from that of Hicks et al.[9]. The larger offset in our male group was to be expected because the male study subjects generally had a larger tibial plateau than the female study subjects. However, the correlation was not strong between the tibial shaft offset and the tibial plateau dimension in either the sagittal or the coronal plane. Therefore, the difference in offset between the sexes is geometric instead of size-related. When stem extension is necessary in a primary or revision total knee arthroplasty, a male patient requires a larger stem offset than does a female patient.

In most other studies of this issue, the authors have examined tibial morphology by using radiography or computed tomography. We chose magnetic resonance imaging scans as the imaging method for three reasons: (1) the study subjects faced no risk of radiation exposure with magnetic resonance imaging, (2) we could obtain detailed three-dimensional measurements, and (3) the use of magnetic resonance imaging scans yielded acceptably reproducible measurements in a recent study of knee geometry[14]. Intraclass correlation analysis in our study also demonstrated good reproducibility of our measurements.

One of the limitations of our study was that the landmarks on magnetic resonance imaging scans are not as clearly defined as those on computed tomography scans, and this could have affected the measurements. However, the reproducibility of our measurements was demonstrated to be acceptable and the relationship between the tibial shaft axis and the center of the tibial plateau was not influenced. Another limitation was that our study subjects were relatively young and had no bone abnormalities. It is not clear if aging itself leads to changes in knee morphology. However, aging is a major contributor to the onset and progression of osteoarthritis. The morphology of an arthritic knee, especially one with varus or valgus deformity, may be different from that of a normal knee[20,21]. Therefore, one should be cautious about applying the results of this study to patients with severe knee deformity.

In conclusion, we have described the morphology of the proximal part of the tibia as measured on magnetic resonance imaging scans, which has not been done before, to our knowledge. We found a large variation in tibial shaft offset from the tibial plateau. The tibial shaft axis was located anterolateral to the center of the tibial plateau in our Chinese study subjects. Accordingly, an anterolaterally offset tibial keel or stem seems to be a more suitable choice for Chinese patients undergoing primary or revision total knee arthroplasty. ■

NOTE: The authors thank Katharine O'Moore-Klopf, ELS, for editorial assistance with the manuscript.

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