Morphologic features of the distal femur and tibia plateau in Southeastern Chinese population
A cross-sectional study

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Abstract
Morphologic measurements of the femoral and tibial features of western population have been done in several studies, which provides the fundamental data for the design of total knee arthroplasty prosthesis used globally, including China. However, researches on anatomic and morphologic features of the knee in Chinese populations of both sexes have never been conducted. Our study was aimed at investigating the anatomic and morphologic features of the knees of the Southeastern Chinese population by magnetic resonance imaging (MRI) scans, so as to provide parameters for sex- and ethnic-specific implant designs in the future.

A total of 245 knees from 244 Chinese adults (130 females and 114 males, aging from 18 to 89 years) who received knee MRI scan from November 2014 to October 2015 were recruited and analyzed. A set of linear and angular parameters, and 6 normalized ratios were measured and calculated on the distal femur and proximal tibia.

The knee size was significantly different between sexes. Compared with women, men have larger ($P < .01$) medial–lateral (ML) and anterior–posterior (AP) dimensions in both distal femur and proximal tibia. Differences in femoral shape, represented by the femur surface ratio, between both sexes were also identified (1.23 ± 0.07 vs 1.27 ± 0.07, $P < .01$), whereas the ML/AP ratios of the tibia are similar between both sexes (1.44 ± 0.07 vs 1.44 ± 0.09, $P = .97$). We also found substantial difference in the morphology of femur and tibia plateau in Southeastern Chinese population compared with data obtained from western populations.

Our study measured the anatomic and morphologic features of the knees in Southeastern Chinese population, and identified knee morphologic differences between both sexes, as well as western and Chinese population. Further clinical studies are needed to determine other essential parameters for the design of prosthesis to the Chinese populations.

Abbreviations: AML = anterior mediolateral length, AP = anterior–posterior, FOV = field of view, FSE = fast echo-spin sequence, FSR = femur surface ratio, ICC = intraclass correlation coefficient, LAP = lateral anteroposterior height, LPH = height of lateral tibia plateau, MAP = medial anteroposterior height, ML = medial–lateral, MPH = height of medial tibia plateau, MPW = width of the medial tibia plateau, MRI = magnetic resonance imaging, PCA = posterior condyle angle, PDWI = proton density weighted imaging, PML = posterior mediolateral length, TEA = Transepicondylar axis, TKA = total knee arthroplasty.

Keywords: femur, morphology measurements, MRI, Southeastern Chinese, tibia, TKA

1. Introduction
Total knee arthroplasty (TKA) is an effective surgical intervention that can relieve the pain of patients who suffered from end-stage arthritis and restore their joint functions.[1–3] A critical part of the TKA procedure is to assure the mechanical axis of the lower limb and the rotational alignment of prosthesis, which highly depends on an accurate osteotomy. Besides, using proper prosthesis of femoral and tibial components is also crucial for the function rehabilitation of patients and the service lives of prostheses.

At present, the artificial knee joint prosthetic systems widely used in China are designed in accordance with anatomical features of the European and American populations. Due to ethnic differences, prosthesis mismatch often occurs when these joint replacement systems designed for westerners are used in Asian patients.[4–7] Some studies[8,9] found that the Chinese population had lower and more flat anterior condyles and larger posterior condyles than westerners. Femoral prosthesis mismatch often occurs at the anterior–posterior (AP) bone cut, resulting in overstuffing between prosthesis and the femur, thus influencing the postoperative pressure of patellofemoral joint and knee extension. Downsizing the distal femur during the surgery would also result in undesirable outcomes: overresection of the posterior femoral condyles would increase the flexion gap; increased femoral component flexion may lead to cam-post impingement and polyethylene wear in a PS (posterior cruciate-stabilizing) knee; and femoral notching has been found to be associated with increased risk of supercondylar fracture. Besides, the size of the tibia prosthesis model is often larger if use the same size of femoral prosthesis in Chinese patients.
To design the artificial knee joint system in line with Chinese anatomical characteristics, to reduce the incidence of postoperative complications, and to improve surgical results, we used a set of the femoral and tibial parameters obtained from morphologic measurements of the distal femur and tibia plateau based on magnetic resonance imaging (MRI) scan images of patients with soft tissue injury for implant design and surgical procedure.

2. Subjects and methods

2.1. Patients and MRI scan

We analyzed 257 patients suffering from soft tissue injury of knees who underwent MRI examination at our hospital from November 2014 to October 2015. The study was approved by the regional Human Research Ethics Committee. All patients were completely informed and signed consent according to the protocol. Patients were limited to those who lived in Southeastern China for 3 generations. Patients were excluded from the study if they are < 18 years old; substantial bone loss and/or degradation requiring augmentation was involved; the knee had a varus or valgus deformity (varus >0° or valgus >7°); patient did not have a fully developed skeletal system. All the patients were limited to Chinese Han ethnics. In total, 8 patients were excluded for being < 18 years old, 3 for varus knee, and 2 for bone loss. Finally, morphologic data from the distal part of the femur and the proximal aspect of the tibia in 245 knees of 244 patients were measured and analyzed. In these patients, 131 knees (53.5%) were from female patients and 114 (46.5%) from males. The mean age of the 130 women was 48.3 ± 13.7 years (range, 19–85 years) and that of the 114 men was 43.9 ± 17.1 years (range, 18–89 years). During the data collection process, all authors can access to the information that could identify individual participants.

2.2. Image and parameter measurement

A set of linear and angular measurements were calculated on the distal femur and the proximal tibia. The 10, 15, and 20 mm slices above the surface of the distal femur were selected, and the image at the level of the epicondyles was used for parameter measurement. The osteotomy plane in the proximal tibia (usually about 8 mm below the lateral tibial plateau) was selected for measurements. Transepicondylar axis (TEA) was determined first according to previous descriptions.[10] A set of linear and angular measurements were then calculated on the distal femur (Fig. 1) and proximal tibia (Fig. 2). In total, 9 femoral parameters (Table 1) and 6 tibial parameters (Table 2) were recorded. Three ratios of distal femur were then calculated according to the above-described parameters, including femoral surface ratio (FSR), anterior mediolateral length/posterior mediolateral length (AML/PML), and medial anteroposterior height/lateral anteroposterior height (MAP/LAP). Ratios of the proximal tibia were also calculated, including mediolateral width/tibia plateau length (ML/AP), width of the lateral tibia plateau/height of lateral tibia plateau (LPW/LPH), and width of the medial tibia plateau/height of medial tibia plateau (MPW/MPH). RadiAnt DICOM Viewer (version 1.9) was used for measuring the parameters.

2.3. Statistical analysis

The original MRI data of 245 knees were collected by one author (XL). Two authors (LF and PZ) independently measured the 245 femoral and tibial parameters, and discrepancies (>3 mm of difference in linear or 3° in angular) were resolved by discussion with another author (GL). The average value of 2 authors’ measurements was recorded as the final data. Statistical analysis was conducted using the software SPSS 20.0. Level of concordance of reviewers was measured by intraclass correlation coefficient (ICC) 2-way mixed model. Dichotomous factors of the...
sex that affect the means of femoral measurements and tibia measurements were tested by \( t \) test. The patients were divided into 6 subgroups according to their age (\( \leq 20, 30–40, 40–50, 50–60, 70–80, >80 \)) and were then compared using one-way analysis of variance (ANOVA). Hypothesis of equal variance was tested using \( f \) test. A \( P \) value < .05 was considered as statistically significant, except where otherwise specified.

3. Results

The coefficient of internal consistency of the measurements in this study was > 0.70 (Supplement Table 2, http://links.lww.com/MD/B937), indicating high consistency between the extracted data from the 2 reviewers.

Significant morphologic differences existed between both sexes. All femoral linear measures in men were larger than those in women (Table 3), although angular parameter, such as \( \angle \) ACA and \( \angle \) PCA, had no significant difference between women and men (\(-4.1 \pm 3.5 \) vs \(-3.3 \pm 3.7, P = .08; 5.1 \pm 2.5 \) vs \(4.5 \pm 2.5, P = .06; \) Table 3). Using the above linear and angular measurements, 6 normalized ratios of femur and tibia were used to classify and describe the femoral and tibial shapes. The femoral ratio parameters, FSR, PML/AML, and LPW/LPH, showed a statistically significant difference between both sexes (Table 3). The FSR of 2 sexes was \(1.23 \pm 0.07\) vs \(1.27 \pm 0.07, P < .01\), indicating that man has a more fat and wider femur compared with woman. As the tibial parameters (Table 4) demonstrated, women have a similar tibial ML/AP ratio as men (\(1.44 \pm 0.07\) vs \(1.44 \pm 0.09, P = .97\)), which may be attributed to the fact that both sexes had rectangle-shaped proximal tibias. In addition, there are significant differences between women and men in LPW/LPH (\(0.95 \pm 0.08\) vs \(0.93 \pm 0.07, P = .01\)) and MPW/MPH (\(0.70 \pm 0.07\) vs \(0.68 \pm 0.04, P = .42\)).

Aside from sex differences, we also compared these ratios among different age subgroups and found no significant difference among patients with different ages (Supplement Table 1, http://links.lww.com/MD/B937).

4. Discussion

The influence of sexual and ethnic differences on bony anatomy has been intensely studied in recent years, and several studies\(^{10,11}\) have compared the anatomic differences in the femoral and proximal tibia among Caucasian, Asian, and African populations. However, the morphologic features of Chinese knees remain to be investigated, mostly due to the fact that the TKA prosthesis systems used in China nowadays cannot fit well with the Chinese patients. After analyzing 245 knees from Southeastern Chinese population, the present study has identified the sexual and ethnic differences in femoral and tibial anatomic features, thus providing primary data and parameters for future sex- and ethnic-specific implant designs.

4.1. The posterior condyle angle of femur

Inaccurate track of the patellofemoral joint induced by the wrong femoral rotational alignment is one of the main reasons causing unsatisfied outcomes and limited range of knee motion after TKA surgery.\(^{12,13}\) Although the surgical epicondylar axis is considered the axis of rotation in the knee with osteoarthritis,\(^{14}\) the bone cut of femoral posterior condyle and the positioning of femoral rotational alignment are mainly according to the posterior condyle line due to easy access. The surgical instruments and prosthesis are also designed by the same approach. According to Griffin et al,\(^{11}\) the measurement of the posterior condylar angle according to the surgical epicondylar axis yielded

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### Table 1

**Measurement definitions for the distal femur.**

| Measurement | Definition |
|-------------|------------|
| Transepicondylar axis (TEA) | Distance between medial and lateral epicondyles |
| Anterior condyle line (ACL) | The tangent line of anterior condyle (ACL) |
| Posterior condyle line (PCL) | The tangent line of posterior condyle (PCL) |
| Mediolateral length (ML) | The TEA projection on the PCL |
| Anteroposterior height (AP) | Maximum distance between anterior cortex and the posterior plane |
| Medial anteroposterior height (MAP) | Distance between most anterior and posterior aspects of the medial condyle |
| Lateral anteroposterior height (LAP) | Distance between most anterior and posterior aspects of the lateral condyle |
| Anterior condylar angle (ACA) | The angle between TEA and ACL |
| Posterior condylar angle (PCA) | The angle between TEA and PCL |
| Posterior mediolateral length (PML) | Maximum distance between the 2 most posterior aspects of the medial and lateral condyles |
| Anterior mediolateral length (AML) | The angle between TEA and ACL |
| Medial anteroposterior height (MAP) | Distance between most anterior and posterior aspects of the medial condyle |
| Lateral anteroposterior height (LAP) | Distance between most anterior and posterior aspects of the lateral condyle |

### Table 2

**Measurement definitions for the proximal tibia.**

| Measurement | Definition |
|-------------|------------|
| Mediolateral width (ML) | Maximum width of the tibia plateau in the TEA direction |
| Anteroposterior height (AP) | Length of the tibia plateau in the anteroposterior direction, passing through the midpoint of the tibia intercondylar eminence |
| Lateral plateau mediolateral length (LPW) | Length of the lateral tibia plateau in the mediolateral direction |
| Lateral plateau anteroposterior height (LPH) | Length of the lateral tibia plateau in the anteroposterior direction, passing through the LPW midpoint |
| Medial plateau mediolateral width (MPW) | Length of the medial tibia plateau in the mediolateral direction |
| Medial plateau anteroposterior height (MPH) | Length of the medial tibia plateau in the anteroposterior direction, passing through the MPW midpoint |
There are several reasons that could explain the minor difference in patients. The distal femoral cutting guides are often placed with an additional 3° of external rotation or the femoral components should include a valgus angle of 3°. Some studies have demonstrated that the Chinese population, especially women, have larger medial condyles than westerners, though the published data are still limited and the results are controversial.[8–10,15–20] According to the study involving 41 cadaver measurements by Yip et al.[8] the average posterior condylar angle (PCA) of Chinese men is (5.1 ± 1.9)°, which is smaller (P < .05) than that of Chinese women (5.8 ± 1.8)°. In consistence with this study, we calculated the mean PCA of (4.5 ± 2.5)° in men and (5.1 ± 2.5)° in women, which is different from the data of the Caucasian population[8,10,11,18,21,22] (Table 5). There are several reasons that could explain the minor difference of these angles in the same ethnic group.[16] First, different diagnostic modalities, such as CT and MRI scans, would obviously provide different parameters of PCA, and the axial plane can be different depending on whether the cartilage is counted in. Second, the determinations of TEA may also contribute to the difference: some obtained the TEA data through 3-dimensional reconstructions, whereas others may measure TEA with axial images of the knee. Finally, the distinct average age and the subethnics of the included participants may explain part of the difference. Even in the same races, different extent of cartilage erosion and different life style would also contribute to the difference in patients’ PCA.

### Table 3

| Femoral linear and angular measurements. | Female | Male | P     |
|-------------------------------|--------|------|-------|
| **Parameter**                 | Mean   | SD   | Mean  | SD   |<.01 |
| TEA (mm)                      | 71.1   | 3.6  | 79.8  | 3.2  |     |
| ML (mm)                       | 71.2   | 3.4  | 80.6  | 3.5  |     |
| AP (mm)                       | 57.8   | 3.9  | 63.6  | 3.7  |     |
| AML (mm)                      | 33.8   | 2.3  | 38.6  | 2.6  |     |
| MAP (mm)                      | 59.6   | 3.6  | 64.9  | 3.5  |     |
| LAP (mm)                      | 58.3   | 3.9  | 64.0  | 3.8  |     |
| PML (mm)                      | 46.3   | 3.0  | 51.8  | 3.5  |     |
| PCA (°)                     | –4.1   | 3.5  | –3.3  | 3.7  |<.01 |
| SR (ML/AP)                  | 5.1    | 2.5  | 4.5   | 2.5  |<.01 |
| FSR (ML/AP)                   | 1.23   | 0.07 | 1.27  | 0.07 |<.01 |
| PML/AML                      | 1.37   | 0.09 | 1.35  | 0.09 |<.02 |
| MAP/LAP                      | 1.03   | 0.04 | 1.02  | 0.03 |<.05 |

### Table 4

| Tibial linear measurements. | Female | Male | P     |
|----------------------------|--------|------|-------|
| **Parameter**               | Mean   | SD   | Mean  | SD  |<.01 |
| ML (mm)                     | 67.1   | 3.4  | 75.4  | 3.2  |     |
| AP (mm)                     | 46.6   | 2.9  | 52.5  | 3.5  |     |
| MPW (mm)                    | 28.0   | 2.9  | 32.5  | 2.6  |     |
| LPW (mm)                    | 39.0   | 3.2  | 42.6  | 2.9  |     |
| MPH (mm)                    | 45.9   | 3.1  | 52.1  | 3.3  |     |
| LPW (mm)                    | 41.3   | 3.1  | 47.0  | 3.2  |     |
| MLAP                        | 1.44   | 0.07 | 1.44  | 0.00 |<.97 |
| LPW/LPH                     | 0.95   | 0.06 | 0.93  | 0.07 |<.01 |
| MPW/MPH                     | 0.7    | 0.07 | 0.68  | 0.04 |<.42 |

### Table 5

| Measurement of posterior condylar angle compared with published data. | Number of knees | Ethnicity | Posterior condylar angle (PCA) |
|--------------------------------------------------------------------|-----------------|----------|--------------------------------|
| **Parameter**                                                    | Mean            | SD       | Mean              | SD       |<.01 |
| Griffin et al[10]                                                | 104             | White    | 3.6 ± 1.8         | 3.7 ± 2.6 |     |
| Berger et al[2]                                                  | 75              | White    | 3.5 ± 1.2         | 0.3 ± 1.2 |     |
| Yau et al[26]                                                    | 99              | Chinese  | 6.2 ± 2.4         | 5 ± 2    |     |
| Yip et al[31]*                                                   | 82              | Chinese  | 5.1 ± 1.9         | 5.8 ± 1.8 |     |
| Our study                                                        | 253             | Chinese  | 4.5 ± 2.5         | 5.1 ± 2.5 |     |
| Li et al[15]                                                    | 142             | Chinese  | 6.2 ± 2.03        | 7.19 ± 1.78 |    |
| Xie et al[28]*                                                   | 83              | Chinese  | 5.29 ± 1.04       | 5.6 ± 1.18 |     |

* Articles in Chinese.

### 4.2. The femur surface ratio

In the present study, femur surface ratio (FSR) was used for the rough estimate of the femoral shape. The width–height ratio of the prosthesis is a key factor for how well it will match the femoral surface. Some studies have reported adverse effects resulting from the mismatch between the prosthesis and the femoral surface.[23,24] Hitt et al.[5] demonstrated that the medial or lateral overhanging on the femur or tibia could result in soft tissue irritation and thus affecting knee balance. In addition, the exposed cancellous bone resulting from undersized components could be a source of bleeding into the knee joint space in the immediate postoperative period.

There is also significant difference in FSR between sexes and races. Several authors have described the morphometric features of the distal femur and the anthropometric sex differences in their studies.[25–27] Chin et al.[26] reported average FSRs of 1.27 in men and 1.22 in women. A Chinese study by Li et al.[28] reported the ratios of 1.26 and 1.24, respectively. The 2 studies both demonstrated that the femurs of women are “narrower” comparing to men. Therefore, the use of a “narrow” component in women can be useful to avoid painful overhang, which may cause extrusion and collision between prosthesis and the adjacent soft tissues.[29] Our study showed that among the Southeastern Chinese population, the FSRs were 1.23 ± 0.07 in women and 1.27 ± 0.07 in men (P < .01), which is comparable to the results of studies by Chin et al.[26] and Li et al.[28]. Although no direct records about FSRs in western population have been reported currently, we assume that this ratio would be smaller in western population because the ratio of femur prosthesis designed for westerns ranges between 1.08 to 1.16. Therefore, the femur components used in China should be “wider” to match the distal femur morphometric feature of the Chinese population.

### 4.3. Morphologic measurements of the tibia plateau

An appropriate tibia component will provide not only sufficient coverage of the cut surface, but also a longer roll-back translation length during flexion–extension motion of the knee, which will enhance the stability of the prostheses and reduce the stress concentration effect.[30,31] It has been reported that the tibial plateau morphology are different between sexes and races, which may lead to a mismatch between prosthesis and tibia. In this study, we found that the lateral tibia condyle was smaller than the medial tibia condyle by an average size of 4.6 ± 2.5 mm in women and 5.1 ± 2.3 mm in men (P = .11), which is consistent to the results by Hitt et al.[5] demonstrating that the lateral tibia condyle is smaller than
the medial tibia condyle by an average of 4.3 mm in women and 5.2 mm in men. In addition, with increased AP dimension of the plateau, the aspect ratio would decrease. Dai et al. reported that Caucasians had larger ML tibia condyle difference than Indians. After comparing our results with other studies, we find that the Southeastern Chinese population have smaller tibia size than Caucasians ($P < .01$), whereas there is no significant difference in ML tibia condyle difference comparing with Caucasians ($P = .09$) and Japanese ($P = .86$), as well as both sexes in each ethnic group (Supplement Table 3, [http://links.lww.com/MD/B937](http://links.lww.com/MD/B937)).

### 4.4. Limitations

Our study has some limitations. First, all participants enrolled in the present study were limited to the single orthopedic center in Shanghai, which may not sufficiently represented the whole Southeastern Chinese population. Second, due to the limitation in medical source, we did not get enough MRI imaging slices in each participant, and the localization of several parameters such as TEA and ML of femur are not accurate enough, which may introduce systematic errors. Third, 3-dimensional reconstruction of lateral femur and proximal tibia was not done in this study. As a result, parameters like femoral curvature and caster angle of the tibia were not available. Further studies are needed to address these issues.

### 5. Conclusions

The present study identified the anatomic and morphologic features of the femur and the tibia in the Southeastern Chinese population, which may help refine the design of TKA implants used in China. Further investigations are needed to evaluate the clinical impact brought by the future design changes.

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