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A three-dimensional computed tomography study of distal femoral morphology in Japanese patients: Gender differences and component fit

Masami Ishimaru, Kazunori Hino, Yoshio Onishi, Yasutake Iseki, Naohiko Mashima, Hiromasa Miura *

Department of Bone and Joint Surgery, Graduate School of Medicine, Ehime University, Japan

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ABSTRACT

Background: Previous anthropometric studies have reported gender differences in distal femoral morphology. However, to date, very few studies have investigated the knee morphology of Japanese adults and possible gender differences. The purpose of this study was to examine the distal femoral morphology of Japanese patients, to characterize anatomical differences between male and female, and to evaluate the need to create gender-specific knee prostheses.

Material and methods: We evaluated 80 knees in 40 male and 40 female Japanese patients scheduled for total knee arthroplasty (TKA). The mediolateral (ML) and anteroposterior (AP) dimensions of the knees at different levels were measured preoperatively using three-dimensional computed tomography, and ML/AP aspect ratios were calculated.

Results: On the distal femoral cut surface, the mean ML widths were 74.9 mm for male and 65.1 mm for female, and the mean AP lengths were 63.4 mm for male and 58.9 mm for female. Such values were generally smaller compared to data from European and North American studies. In this study, the mean ML/AP aspect ratios were 1.31 for male and 1.25 for female, higher than those from non-Asian regions. The ML/AP ratios of Japanese patients were negatively correlated with distal femoral AP length.

Conclusions: Japanese female had a relatively narrower femoral width for a given AP length than male. Our study suggests the utility of Japanese-specific implants and provides useful insights for manufacturers to design components of appropriate sizes and aspect ratios for Japanese TKA patients.

1. Introduction

With the recent rise in the number of total knee arthroplasty (TKA) procedures performed annually, this procedure has gained more attention as an effective means to relieve persistent knee pain, restore knee function, and improve patient quality of life [1]. In order to maintain long-term postoperative performance of TKA prostheses, adequately sized components and appropriate surgical procedures are both important. The femoral component size affects the contact stress and contact area of the patellofemoral and tibiofemoral joints, and anteroposterior (AP) length is associated with soft tissue balance in extension and flexion [2]. Several studies have indicated gender differences in the morphological dimensions of the distal femur: in female, mediolateral (ML)/AP ratios were smaller for a given AP length and the anterior aspect of the medial and lateral condyles was less prominent than in male [3,4]. After TKA, females have a higher prevalence of medial or lateral femoral component overhang, which could be responsible for postoperative knee pain and decreased range of motion [3]. Consequently, gender-specific knee prostheses were designed to accommodate female morphology.

International manufacturers have created a variety of TKA implants with unique shapes and designs. However, a large percentage of commercial TKA implants available in Japan are imports based on morphometric data from European and North American populations. There may be a need to specifically design TKA prostheses to match the distal femur dimensions and variation patterns of the Japanese population. Although some authors have reported on the morphological characteristics of Japanese knees, such as Miyake using plain radiographs [5], Nishiwaki et al. using magnetic resonance (MR) imaging [6], and Urabe et al. [7] and Akagawa et al. [8] using computed tomography (CT), gender differences in anatomic features and variation patterns remain to be explored.

The objective of this study was to characterize the distal femoral dimensions and variation patterns of Japanese knees with those of individuals of other ethnic or racial groups.

2. Material and methods

This retrospective study included patients with end-stage primary osteoarthritis of the medial knee refractory to conservative treatment

* Corresponding author at: Department of Bone and Joint Surgery, Graduate School of Medicine, Ehime University, Shitsukawa, Toon, Ehime, 791-0295, Japan. Tel.: +81 89 960 5343; fax: +81 89 960 5346.
E-mail address: miura@m.ehime-u.ac.jp (H. Miura).

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who were candidates for TKA between May 2010 and April 2012. Patients with secondary knee osteoarthritis as a result of connective tissue disease (e.g., rheumatoid arthritis) and trauma were excluded. The characteristics of the study participants are summarized in Table 1. There were statistically significant differences between males and females in mean height and weight, but not mean age or body mass index (BMI). On average, males and females had a similar femorotibial angle (FTA) and degrees of knee extension and knee flexion (Table 1).

Full-length lower limb computed tomography, CT scans were taken preoperatively using a 64-slice CT scanner (Brilliance 64, Philips Electronics Japan Ltd., Tokyo, Japan). A slice thickness of 5 mm was used for the hip and foot joints, whereas a slice thickness of 1 mm was used to scan the region spanning from 20 cm above to 20 cm below the knee joint line. CT images were reconstructed into 0.67 mm-thick sections and then converted into three-dimensional and multi-planar reconstruction (MPR) images in the axial, sagittal, and coronal directions. These images were employed to virtually simulate the bone cuts during TKA. The mechanical axis of the femur was defined as the line from the center of the femoral head to the midpoint of the surgical epicondylar axis (SEA) in the coronal plane. The femoral distal end was defined as a point 9 mm from the most distal articular surface of the femur in the coronal plane (including the cartilage, considered to have a thickness of 2 mm). The distal femoral cut line was drawn perpendicular to the mechanical axis in the coronal plane and perpendicular to the anatomical axis on the sagittal image (Supplemental Fig. 1a, b). The anterior femoral cortical cut was drawn parallel to the SEA in the axial plane and parallel to the femoral anatomical axis in the sagittal plane (Supplemental Fig. 2a). The posterior condylar cut surface was defined to be perpendicular to the distal femoral cut line. The cut surface was defined to be 10 mm anterior and parallel to the post-condylar axis at the SEA level. The rotational alignment axis of the distal femur was drawn parallel to the SEA (Supplemental Fig. 2b).

After the simulated bone cut lines were drawn, the following parameters were measured to characterize femoral morphology (Supplemental Fig. 3): (i) ML width of the anterior chamfer edge (ant-ML) (Supplemental Fig. 3a), (ii) ML width of the femur at the SEA level (SEA-ML) (Supplemental Fig. 3b), (iii) ML width of the distal cut surface determined by projection of the SEA (cut-ML) (Supplemental Fig. 3c), (iv) medial and lateral AP lengths at the SEA level (SEA-med-AP and SEA-lat-AP) (Supplemental Fig. 3b), (v) AP length of the femoral box defined by the anterior chamfer and posterior condyle cuts (AP-box) (Supplemental Fig. 3d), (vi) medial and lateral AP lengths of the distal femoral cut surface (cut-med-AP and cut-lat-AP) (Supplemental Fig. 3c), and (vii) medial and lateral AP lengths of the anterior femoral condyle surface created by anterior chamfer cut (med-anterior and lat-anterior) (Supplemental Fig. 3d). Patients in whom femoral morphology was clearly altered by significant osteophyte formation were excluded. In the remaining patients, we measured the parameters in a manner that excluded osteophytes as previously reported [7]. In brief, we determined the area of osteophytes on CT images based on differences in bone density compared to healthy bone, and such areas were not included in our measurements.

In this study, a single examiner (the first author) measured the parameters of interest. Intraclass correlation coefficients (ICC) were used to determine the inter-observer and intra-observer reproducibility. In the present study, three orthopedic surgeons with significant experience with TKA (including the first author) independently measured the distal femur of 10 (12.5%) randomly selected study patients to assess the inter-observer reproducibility. For the inter-observer reproducibility, the mean ICC value was 0.94 (min: 0.92, max: 0.97). To assess the intra-observer reproducibility, the first author measured the distal femurs of the same setting of 10 patients twice with a three-month interval; the mean ICC value for intra-observer reproducibility was 0.98 (min: 0.96, max: 0.99).

The AP length and ML width of simulated resected distal femur were evaluated for proportionally matching to the femoral component of seven prosthetic systems commonly used in Japan: NexGen LPS-Flex, GSF (Zimmer, Warsaw, Indiana); Scorpio, Triathlon (Stryker Howmedica Osteonic, Allendale, New Jersey); VANGURD (Biomet, Warsaw, Indiana); Sigma (Johnson & Johnson, Raynham, Massachusetts); Genesis II (Smith & Nephew, Memphis, Tennessee).

2.1. Statistical analysis

Statistical differences between sexes were determined using the two tailed Student's t-test and Mann–Whitney *U* test. A p-value of <0.05 was considered to indicate statistical significance.

3. Results

There were 80 knees in 40 male and 40 female Japanese patients with medial knee osteoarthritis scheduled for unilateral TKA analyzed in this study. The measurements are summarized in Table 2. Statistically significant gender differences were observed in the ML/AP ratios on the SEA and resection levels, with female having smaller ratios. In both male and female, ML width and AP length were positively correlated. However, the rates of ML increase were smaller for larger AP lengths in both groups (Fig. 1).

The femoral components for female tended to be too large for a given AP measurement, with the most overhang in the large sizes. In male, the prosthetic designs tended to be smaller than the morphologic data in the ML width for a given AP measurement. The patterns of femoral size variation were analyzed to evaluate the degree of component fit with commercially available unisex and gender-specific products from one manufacturer (NexGen LPS-Flex [LPS-Flex] and NexGen Gender Solutions Femoral [GSF]). ML/AP ratios were negatively correlated with the distal femoral AP length. Female, particularly those with large AP dimensions, had a higher likelihood of ML overhanging with LPS-Flex implants than with GSF implants. Male had a significant risk of ML undersizing with LPS-Flex components, particularly male with short AP lengths (Fig. 2).

4. Discussion

The dimensions and sizes of the human femur have been reported in the literature, as measured by dissection of cadaver knees, plain radiographs or CT scans of living subjects, or other means. For example, Seedhom et al. [9] reported data collected in England, and Bellemans et al. [10] reported data on European whites. Erkman and Walker [11], Mensch and Amstutz [12], and Hitt et al. [3] reported data collected in the USA, whereas Gillespie et al. [13] compared the anatomy of the distal

Table 1
Patient characteristics.

	Male (n = 40)	Female (n = 40)	p-Value
Age (years)	74.7 ± 7.3	75.7 ± 5.7	0.51
Height (cm)	161.2 ± 6.1	149.4 ± 5.0	<0.0001
Weight (kg)	67.9 ± 8.7	59.3 ± 9.6	<0.001
BMI (Body Mass Index) (kg/m^2)	26.1 ± 2.9	26.5 ± 3.4	0.65
FTA (femorotibial angle) (deg)	185.7 ± 5.9	187.7 ± 4.9	0.11
Knee extension (deg)	−8.8 ± 7.7	−9.5 ± 9.8	0.72
Knee flexion (deg)	120.6 ± 17.0	117.8 ± 22.4	0.55

'±' is a standard deviation.

Table 2
Measurements of the resected femur in males and females.

	Male (mm)	Female (mm)	Combined (mm)
Ant-ML	54.0 ± 3.74	47.0 ± 3.99	50.5 ± 5.22
SEA-ML	82.6 ± 3.38	73.4 ± 3.66	78.0 ± 5.81
Cut-ML	74.9 ± 4.20	65.1 ± 2.88	70.0 ± 6.10
SEA-med-AP	60.7 ± 2.89	56.0 ± 2.82	58.3 ± 3.69
SEA-lat-AP	63.4 ± 2.91	58.9 ± 3.63	61.1 ± 3.98
AP-box	44.3 ± 3.13	41.2 ± 2.92	42.8 ± 3.38
Cut med-AP	46.7 ± 3.98	45.3 ± 3.90	46.0 ± 3.98
Cut-lat-AP	48.7 ± 4.14	45.7 ± 4.06	47.2 ± 4.36
Med-anterior	6.4 ± 1.31	5.1 ± 1.70	5.7 ± 1.64
Lat-anterior	9.1 ± 2.28	7.7 ± 2.92	8.4 ± 2.70
SEA-ML/med-AP	1.36 ± 0.08	1.31 ± 0.06	1.34 ± 0.08
SEA-ML/lat-AP	1.31 ± 0.06	1.25 ± 0.09	1.28 ± 0.08
Cut-ML/cut-med-AP	1.55 ± 0.16	1.45 ± 0.13	1.53 ± 0.16
Cut-ML/cut-lat-AP	1.62 ± 0.15	1.43 ± 0.12	1.49 ± 0.16