Anthropometric measurements of knee joints in Thai population: Correlation to the sizing of current knee prostheses

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ABSTRACT

Anthropometric data on the distal femoral condyle and the proximal tibia of 200 knees in 200 Thai subjects were measured using magnetic resonance imaging (MRI). The data including the resected femoral anterior–posterior (AP) length, the resected femoral medial–lateral (ML) width, the resected tibial AP length and the resected tibial ML width were measured. A characterization of the aspect ratio (the ML to AP dimensions) was made for the distal part of the femur and the aspect ratio (the AP to ML dimensions) was made for the proximal part of the tibia. All parameters were compared to the size of the total knee prosthesis with four prosthetic systems which currently used in Thailand: NexGen (Zimmer), P.F.C. Sigma (Depuy-Johnson & Johnson), Genesis II (Smith & nephew), and Scorpio (Stryker). The results of this study could provide fundamental data for the design of knee prostheses suitable for the Thai population.

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1. Introduction

In total knee arthroplasty (TKA), maximal implant coverage on the bone surface minimizes the stress applied to the bone-implant interface [1,2]. A good shape of the knee prosthesis which matches the resected surface of knee has been reported as a factor for long-term survivorship in TKA [3]. Clinical study has been reported that the anatomical profiles of Asian knees were smaller than those of the Caucasian, and has been suggested that the Asian population require smaller range of component size for knee replacement [4]. Several studies [2–6,8,10] demonstrated sizing the prosthesis components and the patient's knee morphology. However, the number of patients in previous studies was limited and may not represent the Asian population. The Thai people are an ethnic group among the Asian population who have similar stature and anatomical profile to the Chinese or the Japanese. Thus, the anthropometry of the Thai is the same as those of the Chinese and the Japanese. The objective of this study was to evaluate whether current total knee prostheses were proportionally matching to anatomical profiles of the Thai knees.

2. Materials and methods

Between January 2007 and December 2007, a descriptive study of 200 consecutive knee magnetic resonance imaging (MRI) studies done in 200 selected Thai volunteer subjects at King Chulalongkorn Memorial hospital were evaluated. Informed consents were obtained from all subjects who participated in the study and the study proposal was approved by the institutional review board. The selection criteria of each subject included 40 to 70 years of age, normal lower limb alignment, no clinical symptoms or signs of knee arthritis, and normal anatomical profile of the femoral and tibial bones.

2.1. MRI measurements

MRI was performed using a 1.5 Tesla whole body MRI system (Siemens 1.5 Tesla, Avanto, Germany) with an extremity coil. Pulse sequences were T1-weighted images. The direction of axial slice imaging placed the slice perpendicular to the femoral mechanical axis in the coronal plane and perpendicular to the long axis of the femur in the sagittal plane. Before performing the study, the MRI was pre-calibrated to provide a 0% of magnification with the use of a cadaveric specimen. All 200 MRI files were reconstructed at 3-mm intervals. The study of knee joint structures was divided into two parts including the distal femoral condyle and the proximal tibia.

2.2. Part I: distal femoral condyle

In frontal plane, a line which was perpendicular to the mechanical axis of the femur at the level of 9 mm from the joint line was drawn to simulate the distal femoral bone cut in TKA. In axial plane, the anterior–posterior (AP) length and the medial–lateral (ML) width of the distal femoral condyle were measured after the simulation of distal femoral bone cut. Simulated femoral sizing and rotation were made...
according to the anterior referencing system and transepicondylar (TE) axis, respectively. Then, simulated resected distal and AP femoral condyle were made with respect to the measured size of the femoral component. The anterior simulated femoral AP cut was made with a line drawn along the anterior cortex of the distal femoral condyle. The posterior simulated femoral AP cut was followed the method described by Ho WP. et al. and Urabe et al. Following the simulation of bone cuts, the resected AP length and the ML width are described in Fig. 1A and B, respectively. In addition, a characterization of the aspect ratio (the ML width divided by the AP length x 100) was made for the femur.

The AP length and ML width of simulated resected distal femur were evaluated for proportionally matching to the femoral component of four systems available in Thailand, including the NexGen (Zimmer): P.F.C. Sigma (Depuy-Johnson & Johnson), Genesis II (Smith & nephew) and Scorpio (Stryker).

2.3. Part II: proximal tibia

Simulated proximal tibial bone cut was made following the standard TKA surgical technique with 7 degrees of posterior slope and 10-mm thickness of the high side of the tibial plateau. Referred to the TE axis of the distal femur, the ML width of the resected proximal tibia is measured as described in Fig. 1C. The AP length of the resected proximal tibia was measured as described by Uehara et al. A characterization of the aspect ratio (the AP length divided by the ML width x 100) was made for the tibia.

Similarly, the AP length and ML width of simulated resected proximal tibia were evaluated for proportionally matching to the tibia component of those four total knee systems.

All measurements were recorded in millimeters using the DICOM imaging software.

3. Statistical analysis

The GraphPad Prism 5.01.336 software (La Jolla, CA, USA) was used for statistical analysis. Descriptive statistic was used for subjects’ demographics and bone dimension measurements. Linear regression analysis was performed to determine correlations of simulated resected bones and size-matched components among 4 total knee prosthetic systems. Comparative statistical analyses between genders were made using the t-test for parametric continuous data and the Mann–Whitney U test for nonparametric continuous data. A p value of <0.05 indicated a significant difference.

4. Results

Eighty-one patients were males and 119 were females. The demographic data are shown in Table 1. There were no statistical differences between genders in terms of age and side of bone in this study.

4.1. Part I: distal femoral condyle

Following the simulated resection of the distal and AP femoral condyle to match the selected femoral sizing, the mean resected AP length, the mean resected ML width and the mean femoral aspect ratio of all subjects were 45.43 (SD 4.5) mm, 64.06 (SD 6.31) mm and 141% (SD 12) respectively. In male group, the mean resected AP length, the mean resected ML width and the mean femoral aspect ratio were 48.55 (SD 3.73) mm, 70.15 (SD 3.87) mm and 145% (SD 11%) respectively. In female group, the mean resected AP length, the mean resected ML width and the mean femoral aspect ratio were 43.32 (SD 3.69) mm, 59.91 (SD 3.75) mm and 139% (SD 12%) respectively. There were significant differences between genders in terms of the resected AP length (p<0.0001), resected ML width (p<0.0001) and femoral aspect ratio (p<0.0001) (Table 2).

4.2. Correlations of four current femoral components and the resected femoral condyle

There were correlations of simulated resected distal femur and size-matched femoral components between two total knee prosthetic systems, including the NexGen and the Sigma. However the Genesis II and the Scorpio had a larger ML width than the ML width of the resected femur for a given femoral implant AP length (Fig. 2). These implants tend to overhang the ML width of the resected femurs of Thai subjects. While the ML and AP measurements closely approximated the simulated data for all knees (Fig. 2), the femoral components for females tended to be too large for a given AP measurement, with the most overhang in the larger sizes (Fig. 3). The femoral aspect ratio for the simulated data showed a higher ratio for smaller knees and a lower ratio for larger knees (Fig. 4).

4.3. Part II: proximal tibia

Following the simulated resection of proximal tibia, the mean resected AP length, the mean resected ML width and the mean tibial aspect ratio of all subjects were 50.15 (SD 3.09) mm, 74.44 (SD 3.44) mm and 67% (SD 3%) respectively. In male group, the mean resected AP length, the mean resected ML width and the mean tibial aspect ratio were 51.0 (SD 3.09) mm, 73.59 (SD 4.1) mm and 68% (SD 3.1%) respectively. In female group, the mean resected AP length, the mean resected ML width and the mean femoral aspect ratio were 43.23 (SD 3.69) mm, 59.91 (SD 3.75) mm and 139% (SD 12%) respectively. There were significant differences between genders in terms of the resected AP length (p<0.0001), resected ML width (p<0.0001) and femoral aspect ratio (p<0.0001) (Table 2).

Table 1

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Total Mean ± SD (range)</th>
<th>Total</th>
<th>Male Mean ± SD (range)</th>
<th>Female Mean ± SD (range)</th>
</tr>
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<tbody>
<tr>
<td>Number</td>
<td>200</td>
<td></td>
<td>81</td>
<td>119</td>
</tr>
<tr>
<td>Age (year)</td>
<td>52 ± 7.5 (40–70)</td>
<td></td>
<td>51 ± 7.6 (40–70)</td>
<td>52 ± 7.4 (40–68)</td>
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<tr>
<td>Weight (kg)</td>
<td>64.38 ± 13.13 (41–100)</td>
<td></td>
<td>73.69 ± 13.13 (54–100)</td>
<td>59.58 ± 12.10 (41–97)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>158.75 ± 7.57 (150–176)</td>
<td></td>
<td>166.83 ± 8.11 (152–176)</td>
<td>156.55 ± 5.85 (150–170)</td>
</tr>
</tbody>
</table>

SD: standard deviation.

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respectively. The differences in the resected AP length, resected ML width and resected AP length/resected ML width ratio between males and females were significant \((p<0.0001)\) (Table 3).

4.4. Correlations of 4 current tibial components and the resected proximal tibia

There were correlations of simulated resected proximal tibia and size-matched tibial components among three total knee prosthetic systems, including the NexGen, the Sigma and the Scorpio. However the Genesis II had a larger AP length than the AP length of the resected tibia for a given tibia implant ML width (Fig. 5).

Like as the femoral components, for females tended to be too large for a given ML measurement, with overhang in the larger sizes. It was found that the Genesis II systems tended to overhang the AP length of the resected tibia in the range of large resected ML width but they tended to be equal to the AP length of the resected tibia followed the smaller simulated data of the tibias those are shown in Fig. 6.

The tibial aspect ratio from the simulated data showed differing slopes for male and female. The tibial aspect ratio from the simulated data showed a higher ratio for smaller knees and a proportionally lower ratio for larger knees especially in female group (Fig. 7).

5. Discussion

According to the present study, the resected femoral AP length, the resected femoral ML width, the femoral aspect ratio, the resected tibial AP length, the resected tibial ML width and the tibial aspect ratio were significantly different between males and females. On the femoral side, simulated resected distal femurs and size-matched femoral components correlated with the NexGen and the Sigma systems; however, the ML width of the resected femur seemed too small for femoral implant of the Genesis II and the Scorpio systems. On the tibial side, simulated resected proximal tibias correlated with size-matched tibial components of the NexGen, the Sigma and the Scorpio, while there was a tendency to overhang with the Genesis II system. Female gender tended to have both overhanging size-matched femoral and tibial components with all four total knee systems.

Besides the surgical principle in TKA, proper sizing of the prosthesis is one of factors for a successful TKA [9]. TKA requires an accurate soft-tissue balancing and maximal coverage of components on the bone surface to minimize the stress applied to the bone-implant interface [10]. Figgie et al. [11] reported that overhanging or undersizing femoral components could lead to altered soft-tissue tensioning and altered patellofemoral stresses. In addition, Noble et al. [12] emphasized that, besides surgical procedure, improve of the prosthetic design still needed to restore normal function in patients after TKA.

Regarding femoral rotation, several studies recommended that the femoral component should be inserted parallel to the TE axis [13,14]

### Table 2

The distal femoral condyle dimensions.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Total</th>
<th>Male</th>
<th>Female</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean±SD (range)</td>
<td>Mean±SD (range)</td>
<td>Mean±SD (range)</td>
<td></td>
</tr>
<tr>
<td>Resected AP length (mm)</td>
<td>45.43±4.5 (35–56.9)</td>
<td>48.55±3.73 (40–56.9)</td>
<td>43.32±3.69 (35–55)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Resected ML width (mm)</td>
<td>64.06±6.31 (52–78.9)</td>
<td>70.15±3.87 (61.4–78.9)</td>
<td>59.91±3.75 (52–76.3)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Aspect ratio (ML width/AP length)×100</td>
<td>141±12 (111–177)</td>
<td>148±11 (124–177)</td>
<td>139±12 (111–177)</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

Fig. 2. Graphs demonstrating correlations of resected femoral AP length and ML width of knees in the studied group among four prosthetic systems.
or parallel to the AP axis [15]. However, there are two different TE axes including the anatomical TE axis (ATE) and the surgical TE axis (STE) [16]. As one study reported that the ATE axis is more perpendicular to the AP axis than that of STE axis [16] and another study [17] found that it was difficult to locate the medial sulcus of the medial epicondyle to define the STE axis so we used the ATE axis in our study as the reference line for various measurements which we believed that it was more consistent and reliable axis.

Most prosthetic total systems have only one AP length for one ML width. Similar to several studies, the present study found that women have generally narrower femur than those of men when they have the same AP dimension [17–20]. According to this study, the future femoral components may be designed with several ML widths for an AP length to avoid overhanging or undersizing problems at the medial or lateral condyle.

In general, the geometry of the tibial component should match the resected surface as much as possible which will provide the best stability and load transfer for both cemented and cementless fixations. Although some authors have reported substantially better fit for asymmetric tibial components [21,22], Incavo et al. [2] reported that the tibial coverage was improved with symmetric designs. However, no studies have compared tibial component survival rates between asymmetric and symmetric baseplate designs. On the other hand, Cheng et al. [3] suggested that the design of the prosthetic tibial base plate should be based on the data from resected diseased knee, rather than the normal knee. Although the maximum coverage of tibial component on bone is mandatory, some investigators believed that proper rotational positioning is more important [1,4]. In order to accomplish the most appropriate tibial rotation, the present study placed the tibial component following the femoral component rotation, which was

Table 3
The proximal tibial dimensions.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Total</th>
<th>Male</th>
<th>Female</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resected AP length (mm)</td>
<td>46.04±4.4 (37.6–56.6)</td>
<td>50.15±3.09 (44–56.6)</td>
<td>43.23±2.57 (37.6–52)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Resected ML width (mm)</td>
<td>68.8±5.8 (57.8–86)</td>
<td>74.44±3.44 (65.6–86)</td>
<td>64.95±3.45 (57.8–78.6)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Aspect ratio (AP length/ML width)</td>
<td>67±3 (59–77)</td>
<td>67±3 (61–75)</td>
<td>67±3 (59–77)</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

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based on the ATE axis. The simulated data in the present study demonstrated that when the tibial AP dimension increased, there was a decreasing tibial AP/ML aspect ratio, while most implants had a relatively constant aspect ratio. The limitation of this study was a simulated resected MRI study in the normal knee. The ideal femoral and tibial rotations following the TE axis were presented in every single knee, while variation of femoral and tibial rotation in actual patients may affect the size and the coverage of femoral and tibial components.

6. Conclusion

Anatomical profiles of the Thai population, which can represent the Asian population, were proportionally matching current total knee prostheses, including the NexGen, the Sigma, the Genesis II and the Scorpio. However, the female subgroup have significantly smaller femoral ML dimension than that of male subgroup. Thus, female subgroup may need modified femoral prostheses from those of current prostheses.
7. Conflict of interest

The authors have no benefits or funds received in support of the study and no personal relationships with organizations that could inappropriately influence (bias) this work.

References


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