Variation in Optimal Sagittal Alignment of the Femoral Component in Total Knee Arthroplasty

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Abstract

Accurate sagittal alignment of the femoral component in total knee arthroplasty is crucial for prosthesis longevity, improved function, and patient satisfaction. However, there is variation in the techniques used to attain optimal sagittal femoral component placement in total knee arthroplasty. Femoral component flexion in imageless navigation is based on the mechanical axis rather than the distal femoral anatomy, and there is significant variability in the anatomy of the distal femur. The purpose of this study was to accurately determine the mean distal femoral flexion angle of a representative population and whether variability of the distal femoral flexion angle correlates with race, femur length, or radius of curvature. The mean degree of distal femoral flexion was determined by assessing distal femoral anatomy on computed tomography scans of paired femurs of 1235 patients without evidence of previous fracture, deformity, or surgical implants. The mean±SD distal femoral flexion angle was 2.90°±1.52°, with 80.2% of knees within 3°±2°. Therefore, placing the component in 3° of flexion from the mechanical axis would attain a satisfactory position in most cases. However, further analysis of the patient data revealed 11.4% of Asians, 7.3% of African Americans, and 8.3% of whites had a distal femoral flexion angle greater than 5°. Additionally, the data revealed a moderately strong negative correlation between the distal femoral flexion and the overall radius of curvature of the femur. This preliminary study highlights the need for improved methods for selecting femoral component position in the sagittal plane when using navigation for total knee arthroplasty. [Orthopedics. 2017; 40(2):102-106.]

To maximize the success and longevity of a total knee arthroplasty (TKA), the surgeon must place the femoral and tibial components in the optimal position to re-create the operative limb’s proper anatomic alignment.1,3 Traditionally, the alignment of each component in the coronal and sagittal planes has been measured relative to the mechanical axis of the femur and tibia. Although some conflicting evidence exists in the literature, neutral coronal alignment has shown improved survivorship and remains the gold standard.2,4

Historically, femoral component sagittal alignment was not thought to contribute significantly to the longevity of a TKA or to postoperative range of motion.5,6 However, further study has shown negative consequences of sagittally malaligned femoral components. Increased flexion of a posterior-stabilized femoral component can lead to impingement of the femoral cam on the tibial post, resulting in increased wear and potential loosening.7,8 Conversely, placement of the femoral component in extension may lead
to notching of the anterior femoral cortex, which has been shown to increase the risk of periprosthetic fracture.9 Additionally, an extended distal femoral resection may lead to selection of a larger femoral component, which may result in complications including anterior knee pain and instability.10–12

Although there is a lack of consensus on the optimal femoral component positioning in the sagittal plane, one can surmise the general goal of knee arthroplasty is to re-create the anatomy of the native femur.4,13 There is, however, significant variability in the anatomy of the femur. Previous studies have shown significant variation by race in the radius of curvature of the femur.13–19 Additionally, numerous studies have investigated the implications of femoral bowing for component positioning.4,13,20,21

The variance of the femoral radius of curvature could significantly impact the flexion angle of the distal femur and the optimal flexion of the femoral component. Although the use of a flexible rod has been proposed as one method to more closely match the distal femoral anatomy while selecting the angle of distal femoral resection, care must also be taken to ensure appropriate coronal alignment when using a flexible rod.11

The purpose of this study was to accurately determine the mean distal femoral flexion (DFF) angle of a representative population and whether variability of the DFF angle correlates with race, femur length, or radius of curvature.

**Materials and Methods**

The authors retrospectively reviewed the morphologic features of paired femurs from a consecutive series of pulmonary embolism protocol computed tomography (CT) scans obtained between December 1999 and March 2010 for 1235 patients without evidence of prior surgery involving the femur. This study received exemption from the University of Michigan institutional review board. These images were from a series of consecutive patients with and without arthritic changes who were undergoing imaging primarily to evaluate for the presence of pulmonary embolism. Pulmonary embolism CT scans at the authors’ hospital previously included combined CT pulmonary angiography and lower extremity venography. Axial images of the chest with 1.25-mm slice thickness and axial images of the iliac wing to tibial plateaus with standard 5-mm slice thickness were generated. Computed tomography scans of patients with radiographic evidence of fracture or dislocation or with femoral or pelvic implants (eg, hip prosthesis, intramedullary nail) were excluded from the study. Scans of patients with residual deformity secondary to trauma or surgical interventions were also excluded.

The CT scans were imported from the clinical picture archiving and communication system archive into a research image archive and analysis system developed in MATLAB (The MathWorks, Natick, Massachusetts) as described previously, and the use of a CT venogram for lower extremity morphologic measurement has been previously validated.18 The volumes were processed and body position was normalized.18

A semi-automated process with manual verification of critical points was used to determine the center of the femoral head, epicondylar axis, posterior condyle points, and centroid points along the femoral shaft. The length of the femur, radius of curvature, and mechanical axis were then calculated (Figure). The authors defined DFF as the angle formed between the centroid line of the distal third of the femur and the mechanical axis in the plane perpendicular to the epicondylar axis. Although no study, to the authors’ knowledge, has been published validating this measurement technique, this method is intuitively correct and easily reproducible. All measurements were done 3-dimensionally. Patient records were reviewed for demographic information. Demographic and measurement data were imported into SPSS Statistics software (IBM Corporation, Armonk, New York).

**Results**

Data were collected from 1235 patients with a mean±SD age of 52.2±16.1 years. Sixty-seven percent of these patients were female. The mean±SD height and weight of the population were 1.67±0.10 m and 82.4±23.9 kg, respectively. The mean±SD femoral length was 432.1±28.8 mm. Seventy-nine percent of the sample identified as white, 12% as African American, 5% as Asian, and 6% as other or unknown race.

The DFF angles of the femurs assessed in this study ranged from 1.72° of extension to 8.01° of flexion, with a mean±SD of 2.90°±1.52° of flexion relative to the mechanical axis. Further analysis revealed that 46.5% of the population had a DFF angle within 3°±1°, and 80.2% had this angle within 3°±2°. A significant portion of the population (8.1%) was...
found to have a DFF angle greater than 5° (Table 1). A higher proportion of Asians (11.4%) had a DFF angle greater than 5° compared with African Americans (7.3%) and whites (8.3%) (Table 2). Pearson’s correlation coefficient showed a moderately strong negative correlation (-0.56) between the degree of DFF and the radius of curvature ($P<0.01$).

### Discussion

Extensive study has been performed on ideal coronal alignment of the femoral component in total knee prostheses. In contrast, there is little information on ideal sagittal alignment. On the basis of the literature that does exist, it is generally accepted that the femoral component should be placed in 0° to 3° of flexion relative to the mechanical axis. However, there is significant variation in the techniques used to determine femoral component flexion, and a clear consensus on the ideal alignment of the femoral component in the sagittal plane is lacking.

Ideally, flexion of the femoral component of a total knee prosthesis should recreate the native anatomy, barring pathology, of the distal femur in the sagittal plane. The current study of nearly 2500 femurs found a mean DFF angle of 2.90°, with 80.2% of the femurs showing a distal flexion angle of 3°±2° relative to the mechanical axis. The use of intramedullary guides often re-creates this anatomy adequately because the guides adapt to the variation in the distal femoral anatomy. In contrast, imageless navigation systems, such as handheld gyroscope-based systems, calculate sagittal alignment of the femoral component based on the mechanical axis. These systems do not adapt to account for distal femoral anatomy. The surgeon selects the desired flexion of the femoral resection, and 3° of flexion closely replicates the native anatomy in most cases.

However, the current data indicate extensive variability of the DFF angle, and a significant proportion (8.1%) of the population was found to have a DFF angle greater than 5°. Placed at a targeted 3° of flexion, the femoral components of these patients would be in relative hyperextension.

Although gyroscope-based navigation systems may have an increased risk of sagittal malalignment, it is important to recognize that even CT-based navigation systems may result in malposition of the femoral component if the distal femoral anatomy is not respected. Hananouchi et al compared CT-based TKA planning with conventional methods, finding that 94% of the CT-planned prostheses were templated in relative extension. As previously discussed, placement of a femoral component in extension may lead to notching and increase the risk of periarticular fracture. Additionally, ma-

### Table 1

<table>
<thead>
<tr>
<th>Distal Femoral Flexion Angle</th>
<th>No.</th>
<th>Percent of Population</th>
</tr>
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<tbody>
<tr>
<td>&lt;0.99°</td>
<td>145</td>
<td>11.8</td>
</tr>
<tr>
<td>1°-1.99°</td>
<td>224</td>
<td>18.1</td>
</tr>
<tr>
<td>2°-2.99°</td>
<td>285</td>
<td>23.1</td>
</tr>
<tr>
<td>3°-3.99°</td>
<td>289</td>
<td>23.4</td>
</tr>
<tr>
<td>4°-4.99°</td>
<td>193</td>
<td>15.6</td>
</tr>
<tr>
<td>&gt;5°</td>
<td>99</td>
<td>8.1</td>
</tr>
</tbody>
</table>

### Table 2

<table>
<thead>
<tr>
<th>Race</th>
<th>&lt;0.99°</th>
<th>1°-1.99°</th>
<th>2°-2.99°</th>
<th>3°-3.99°</th>
<th>4°-4.99°</th>
<th>&gt;5°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asian</td>
<td>11.4%</td>
<td>17.1%</td>
<td>28.6%</td>
<td>17.1%</td>
<td>14.3%</td>
<td>11.4%</td>
</tr>
<tr>
<td>African American</td>
<td>16.6%</td>
<td>19.9%</td>
<td>17.9%</td>
<td>27.2%</td>
<td>11.3%</td>
<td>7.3%</td>
</tr>
<tr>
<td>White</td>
<td>10.4%</td>
<td>17.0%</td>
<td>23.8%</td>
<td>23.7%</td>
<td>16.7%</td>
<td>8.3%</td>
</tr>
<tr>
<td>Unknown/other</td>
<td>18.3%</td>
<td>31.0%</td>
<td>21.1%</td>
<td>14.1%</td>
<td>11.3%</td>
<td>4.2%</td>
</tr>
</tbody>
</table>

Navigation during TKA is becoming increasingly popular because the literature has shown its use assists in accurate component placement and reduces the incidence of outliers compared with the use of standard instrumentation in TKA. Data from the Australian registry showed increased survivorship in a subset of patients who underwent navigated TKA. However, accurate component positioning in the sagittal plane remains elusive, even with the use of navigation. Numerous studies have detailed that the use of navigation during TKA can increase the risk of anterior femoral notching because of an increased risk of placing the component in extension. The risk of sagittal malalignment during navigated TKA increases in patients with shorter femurs and those with increased anterior bowing, which is commonly seen in women and patients who are Asian.

The current study showed a significant correlation between the degree of DFF and the radius of curvature of the femur. The authors have shown that with decreasing radius of curvature, the DFF angle increases. They have also shown a trend that patients of Asian descent are more likely to have a DFF angle greater than 5°. In shorter femurs with increased anterior bowing, there is an increased risk of placing the femoral component in extension with navigation unless the relatively increased DFF relative to the me-
Mechanical axis is accounted for in planning the distal resection. Although the majority of the population is not at risk of sagittal malalignment while using navigation, the current authors’ data do identify a select subset of the population for whom further preoperative planning and intraoperative adjustments may be necessary. The findings of this study may also influence and support the placement of the femoral component in greater than 3° of flexion in the preoperative planning phase of custom cutting block fabrication if that position were to better reproduce the distal anatomy on the 3-dimensional model.

A limitation of this study was that nearly 80% of the study population identified as white. However, the percentage contribution of each minority to this study’s population was representative of the patient population served by the academic medical center where this research was performed and the overall population of the region. Additionally, although not statistically significant, there was a trend that individuals who identified as Asian were more likely to have a greater DFF angle than the general population. The authors believe the lack of significance was due to the small sample; however, this trend should not go unnoticed. An additional limitation of this study was the reliance on CT scans of the lower limb with 5-mm–thick slices. Ideally, thinner slices would be used for this anatomic study; however, the CT scans collected were repurposed from their initial use in assessing for the presence of deep venous thromboses or pulmonary embolisms.

**CONCLUSION**

To the authors’ knowledge, no previous work has shown that the DFF angle is highly variable within a given sample population. This study, in association with the current literature, indicates that failure to account for this important contributor to distal femoral anatomy may result in TKA femoral component placement in relative hyperextension in select populations. These data support further investigation of the use of preoperative advanced imaging and 3-dimensional planning with the goal of improving sagittal and overall femoral component alignment when using navigation in knee replacement.

**REFERENCES**

24(4):570-578.


