Digital Component Size Prediction for Total Knee Arthroplasty

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Introduction: Preoperative planning is necessary for success in orthopaedic surgery. It should be reliable and reproducible. Conventionally, preoperative planning in total knee arthroplasty (TKA) has been performed on standard radiographs with acetate overlays of the implants. Previous studies have investigated preoperative templating using acetate overlays, and reported that templating of components was accurate in 8% to 55% of the cases [1-3]. Low inter- and intra-observer reproducibility was also reported in the acetate templating [2]. With the prevalence of digital radiography, opportunities exist for improvement in preoperative planning. Recently, the digital templating was applied in preoperative planning in TKA. The accuracy of the digital templating was reportedly at least as accurate as the acetate templating [1, 3, 4], and improved reproducibility in the digital templating was reported [4].

We have sought the new method of the preoperative planning in TKA using the morphologic measurement of the femur and tibia. The purposes of this study were 1) to develop an algorithmic system utilizing morphologic measurements of the distal femur and proximal tibia in digital radiographs to predict the femoral and tibial component sizes, 2) to test the accuracy of the algorithm, and 3) to assess the inter- and intra-observer reproducibility of the algorithm.

Methods: One-hundred consecutive patients who underwent primary unilateral TKA were enrolled in this study. All patients had the EVOLUTIONTM Medial-Pivot Knee System implanted (MicroPort Orthopaedics, Arlington, TN) by the same senior surgeon using the same operative procedure. The distal femur was cut using intramedullary alignment rod, and the antero-posterior sizing device was set on the cut surface of the distal femur to decide femoral component size. Utilizing extramedullary alignment rod, the proximal tibia was resected perpendicularly to the tibial shaft in the coronal plane. The slope of the tibial cut was designed to be that of the patient’s natural slope. The tibial component size was decided using tibial component trials.

During the last preoperative visit, standing AP and lateral knee images were taken. The preoperative radiographs were measured utilizing a custom software package to measure morphologic features. On the AP radiograph, these measures included the width of the distal femur and proximal tibia. The femoral intramedullary axis was identified and the width at the level of distal femoral resection was measured. The tibial longitudinal axis was identified and the width at the level of proximal tibial resection was determined (Fig. 1). On the lateral radiograph, the posterior femoral condyle diameter, the offset of the condylar circle from the anterior femoral flange, and the tibial AP length were included in the measurement. The femoral posterior condyles and the position of the anterior femoral flange were identified, and the condyle diameter and the offset of the condylar circle from the anterior femoral flange were measured. The proximal tibial resection was designed to maintain natural slope and the
tibial AP length at the level of resection was determined (Fig. 2). All measurements were performed by the same researcher.

A multivariate regression was utilized based on acquired variables from these 100 patients, and an algorithm for both femoral and tibial component size was derived. The predictive component size using this algorithm was compared to actual implant sizes from the operative report. This algorithm was then validated by applying it to the next 54 consecutive patients who were not included in the 100 patients, and the accuracy was calculated by comparing the predicted size with that used at surgery. The predicted size was not available to the operating surgeon until after the component sizes were chosen. The inter- and intra-observer reproducibility of the algorithm was assessed using the linear weighted kappa (κ) coefficient. The inter-observer reproducibility was determined by measuring 10 randomly selected patients by the two researchers. The intra-observer reproducibility was determined by measuring 10 randomly selected patients by the same researcher twice after an interval of 3 months.

**Results:** The multiple regression analysis of the first 100 patients was carried out, and the equation for the femoral component size was derived as follows:

\[
\text{Femoral component size} = -5.436 + 0.061 \text{ (width of the distal femur)} + 0.195 \text{ (posterior condyle diameter)} + 0.044 \text{ (offset of the condylar circle from the anterior flange)}
\]

The adjusted R2 of this equation for femoral component was 75%. The equation for the tibial component size was derived as follows:

\[
\text{Tibial component size} = -5.36 + 0.086 \text{ (width of the proximal tibia)} + 0.057 \text{ (tibial AP length)}
\]

The adjusted R2 of this equation for tibial component was 73%. These algorithms were then applied to the first 100 patients and the next 54 patients for validation. The results are shown in Table 1. In the 100 patients, the size of the femoral and tibial component was predicted exactly in 60% of the cases, and the all of the predicted sizes were ±1 size of the actual components implanted. In next 54 patients, the component size was predicted within ±1 size in 100% for the femur (59% exactly) and 98% (53% exactly) for the tibia.

The inter-observer reproducibility for the femoral and tibial component were good (κ = 0.70) and excellent (κ = 0.84), respectively. The intra-observer reproducibility for the femoral and tibial component were excellent (κ = 0.85) and good (κ = 0.68), respectively.

**Discussion:** The accuracy of the acetate templating of femoral and tibial components was reportedly 8% to 55% [1-3]. Component sizing accuracy within ±1 size of the actual components implanted was 64-96% with the acetate templating [1-3]. Recently with the prevalence of calibrated digital radiography, an improvement of accuracy has been reported. The accuracy of the digital templating of femoral and tibial components was reportedly 44% to 55% [1, 3, 4]. Digital templating can reportedly predict within ±1 size in about 92-100% of cases [1, 3, 4]. Compared to the previous studies, the accuracy of our algorithm was as accurate as digital templating.

Some investigators analyzed inter- and intra-observer reproducibility of acetate and digital templating. Arora et al demonstrated that inter-and intra-observer mismatch was present in 47% and 44% of acetate templating respectively [2]. In contrast, Trickett et al reported that in digital templating, the κ coefficient for the inter- and intra-observer reproducibility were 0.65-0.66 and 0.55-0.88, respectively [4]. The inter- and intra-observer reproducibility of digital templating was higher than those of acetate templating. In this study, the intra-observer reproducibility of this algorithm was as high as that of digital
templating in the previous study, while the inter-observer reproducibility of this algorithm was higher
than that of digital templating.
With this degree of accuracy and reproducibility of our algorithmic system, it is possible to minimize the
number of surgical trays needed in the operating room and reduce the cost.
**Significance:** With this degree of reliability of our algorithmic system, opportunities exist for cost
reduction with minimization of instrumentation prepared for each case.

Fig. 1
The width of the distal femur and proximal tibia were measured on the anteroposterior radiograph.
The posterior femoral condyle diameter, offset of the condylar circle from the anterior femoral flange and tibial AP length were measured on the lateral radiograph.

Table 1. Error from the actual implant size

<table>
<thead>
<tr>
<th>Error (size)</th>
<th>First 100 cases Femur</th>
<th>First 100 cases Tibia</th>
<th>Next 54 cases Femur</th>
<th>Next 54 cases Tibia</th>
</tr>
</thead>
<tbody>
<tr>
<td>-2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1 (2%)</td>
</tr>
<tr>
<td>-1</td>
<td>23 (23%)</td>
<td>22 (22%)</td>
<td>8 (15%)</td>
<td>8 (15%)</td>
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<tr>
<td>0</td>
<td>60 (60%)</td>
<td>60 (60%)</td>
<td>32 (59%)</td>
<td>29 (53%)</td>
</tr>
<tr>
<td>+1</td>
<td>17 (17%)</td>
<td>18 (18%)</td>
<td>14 (26%)</td>
<td>16 (30%)</td>
</tr>
<tr>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Number±1</td>
<td>60 (100%)</td>
<td>60 (100%)</td>
<td>54 (100%)</td>
<td>53 (98%)</td>
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</tr>
<tr>
<td>Out±1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1 (2%)</td>
</tr>
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</table>

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