The Use of Computed Tomography to Determine Femoral Component Size
A Study of Cadaver Femora

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Abstract
Computed tomography is used to assess whether ideal femoral component size in knee arthroplasty can be made more accurately. Ideal femoral component size was measured on radiography, computed tomography, and by direct measurement of 20 cadaver femora and analyzed statistically. There was no significance between the tomographically anticipated ideal femoral component size and ideal femoral size values (Wilcoxon W 388.5; p 0.565). There was difference between radiographically anticipated ideal femoral size and ideal femoral size values (Wilcoxon W 324.5; p 0.020). Anticipating the ideal femoral size can be made more precisely with computed tomography than radiographs in cadaver femora. Anticipating the ideal femoral component size by computed tomography may solve the problems in “in-between sizes.” Future total knee designs may be manufactured in more anatomic sizes.

Component sizing is one of the factors affecting the outcome in knee arthroplasty. In the tibia and patella it is relatively simple. However, femoral sizing has a specific function, which is its effect on flexion and extension gaps. During preoperative planning, templates are used for anticipating the femoral component size from radiographs. However magnification of bony structures in radiographs may mislead the surgeon. Definite femoral sizing is made by instruments during the operation. It is made by referencing either the posterior femoral condyle (posterior referencing) or anterior femoral condyle (anterior referencing). The posterior reference system is the recommended method for preventing complications.

Scans obtained in computed tomography (CT) are described as scout-views and used for measurement of distances and angles with software programs. Precise measurements in bony structures and implant size measurements can be done reliably in dental surgery using the quantitative properties of CT. Therefore, in search of a more sensitive and reliable tool for preoperative femoral sizing, an analysis of the efficacy of using CT may be useful.

Materials and Methods
Twenty cadaver femurs (10 right and 10 left) were included in the study.

Step 1
Direct true lateral radiographs of the femur were taken paying special attention to the conjunction of the contours of the posterior femoral condyles (PFC) on one another. The radiographic settings were as follows: 40 kW, 2.5 mAs, 44 ms. The distance between the beam and the femur was 1 meter. The same operator (MU) identified the landmarks and made the measurements. The most posterior point of the PFC and the anterior femoral cortex superior to anterior femoral condyle (AFC) were determined. A tangent line to anterior femoral cortex was drawn passing through the AFC. A perpendicular line from the PFC to the tangent line was drawn and its length was determined in millimeters by a ruler designed for
accurate measurement with regard to the magnification property of radiography (Template for Osteonics® Series 7000 Total Knee, Printed in U.S.A, Osteonics Corp., 1994). The measurements for each femur were recorded as the “radiographically anticipated ideal femoral size” (RAIFS) (Fig. 1).

**Step 2**
Femurs were placed in the center of the gantry of the CT machine and lateral scans of the femur were taken paying special attention to conjunction of the contours of the PFC on one another and placing the femoral condyles in the center of the CT gantry. The scans were taken with the following settings: 120 kvp, 50 mA, matrix 512 and length 500 mm. The same operator (TK) identified the landmarks and made the measurements. The most posterior point of the PFC and the anterior femoral cortex superior to anterior femoral condyle (AFC) were determined. A tangent line to anterior femoral cortex was drawn passing through the AFC. A perpendicular line from the PFC to tangent line was drawn and its length was determined in millimeters by CT processing. The measurements for each femur were recorded as the “tomographically anticipated ideal femoral size” (TAIFS) (Fig. 2).

**Step 3**
The femoral sizing and anterior femoral resection was made by using the total knee instrumentation system.
(Genesis 2 Total Knee System, Smith and Nephew Inc.) by the authors (MU and BO). The femoral canal was opened with a 9.5 mm drill and an intramedullary rod was placed with a valgus alignment guide and the bushing positioned to either left or right side. Posterior paddles of the valgus alignment guide were in contact with the posterior condyles. The femoral sizing guide for posterior referencing was attached to the valgus alignment assembly. The stylus was lowered to the lateral anterior cortex and anterior femoral resection was made. At this point the indicated size was not taken into consideration and the resection was made from wherever the stylus pointed (Fig. 3). The distance between the anterior cut surface and the PFC was measured by digital calipers and recorded as the “ideal femoral size” (IFS) (Fig. 4).

Statistical Analysis
Step 1: Pearson bivariate correlation analysis was performed between IFS, RAIFS and TAIFS to search for correlation.
Step 2: IFS, RAIFS, and TAIFS values were analyzed with non-parametric tests (Kruskal-Wallis Test, Mann-Whitney Test) to search for differences.
Step 3: For each femur the difference between the anticipated values (TAIFS and RAIFS) and IFS was calculated and shown in Figure 5.

Results
Minimum, maximum, mean, and standard deviation values for IFS, RAIFS, and TAIFS are shown in Table 1. TAIFS values were correlated with IFS values ($r$: 0.940) and RAIFS values were correlated with IFS values ($r$: 0.874). The difference between three groups (RAIFS, TAIFS and IFS) was analyzed with the non-parametric

Kruskal-Wallis Test. There was a significant difference between the three groups (chi-square: 9.299; $p$ 0.01). In order to demonstrate the difference, the Mann Whitney Test was used. There was no significant difference between the TAIFS and IFS values (Wilcoxon W 388.5; $p$ 0.565). There was a difference between RAIFS and IFS values (Wilcoxon W 324.5; $p$ 0.020).

Discussion
Preoperative planning is one of the most important steps of arthroplasty. Although, contemporary arthroplasty designs provide preoperative templates for anticipating component size from radiographs, in hip arthroplasty, anticipated magnification may differ from actual magnification and in 17% of cases it was found to affect the choice of implant size. In knee arthroplasty, anticipating the femoral component size is more challenging. Using posterior condyles as a reference the surgeon has to make a decision regarding the anterior femoral resection level in order to achieve the “downsize without notching” goal. The detailed method for femoral sizing with current femoral component sizes results in contradictions, especially for components that are “in-between” sizes. As opposed to the patella and tibia, femoral components

Table 1
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<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std dev</th>
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<tbody>
<tr>
<td>IFS</td>
<td>20</td>
<td>48.73</td>
<td>62.00</td>
</tr>
<tr>
<td>RAIFS</td>
<td>20</td>
<td>47.00</td>
<td>59.00</td>
</tr>
<tr>
<td>TAIFS</td>
<td>20</td>
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<td>62.90</td>
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have been found to differ in size in 6.7% of patients between right and left knees of the same patient undergoing bilateral knee replacement. For those reasons several investigators have looked for a better method to estimate magnification and bone morphology of the distal femur. Macher and colleagues demonstrated that bone models created by analysis of three-dimensional ultrasound images are useful for the simulation of knee replacements. Mensch and associates developed nomograms for precise preoperative morphologic evaluation. However, the clinical validity of these methods is controversial. In the current study, both TAIFS and RAIFS values were correlated with IFS. However the correlation of IFS was higher with TAIFS than RAIFS. In addition, there was no statistical difference between the TAIFS and IFS values (p 0.565). The current study demonstrates that anticipating the ideal femoral size can be made more precisely with CT scans than radiographs in cadaver bones and CT scans can be used as an alternative method for preoperative size anticipation.

Current knee arthroplasty designs use anteroposterior (AP) height in the production of knee prosthesis and mediolateral (ML) width is calculated with an AP/ML ratio of 0.8:1.0. Anteroposterior height has a key role in femoral sizing. The femoral components come in a spectrum of sizes and anteroposterior sizes usually vary between 3 mm and 5 mm. However contemporary designs do not provide surgeons with the ideal femoral size in all cases. The surgeon is usually expected to tailor the femur according to the size of the pre-manufactured prosthesis. This process may reveal complications such as anterior femoral notching or patella femoral disorders at “in-between sizes.” Size increments in contemporary femoral designs do not seem to provide an ideal fit of prosthesis to femur in all cases. Intraoperative measurement of distal femurs reveals that there is a need to generate femoral component sizes that are more likely to fit across the wide variation of cases. Precise preoperative determination of AP height may contribute to the efficacy of preoperative planning and serve this purpose.

Radiographs have a serious magnification problem that cannot be easily standardized. This situation arises from the fact that the radiographic image is not an exact picture of the bone, but rather a projection of the bone. And this projection is magnified by several variables in the process, like object film distance, focal film distance, and object size. The magnification ratio in standard lateral knee radiographs was found to be 3.8% in one study. However, the standard measurement templates are manufactured with a magnification ratio of 10%. This may be one of the factors causing the relatively poor correlation between RAIFS and IFS values. Additionally, since X-rays have a diverging projection geometry, magnification ratios of medial and lateral condyles in lateral radiographs differ and make the radiographic assessment of implant size more difficult.

A CT scan is a scout view and a two-dimensional projection of a three-dimensional structure like a radiograph. However, in CT the radiation source moves at a fixed distance to the center of the object, which is at the intersection of the sagittal and frontal planes. Magnification in the central tomographic plane has been reported as 1:1. The highly correlated TAIFS values with ideal femoral component sizes found in the current study support that the magnification in CT scans is minimal under controlled conditions. Clinical studies must be carried out in order to further research the relevance and utility of CT in femoral sizing.

Anterior referencing or cutting the femur in 3 degrees flexion are alternatives to femoral sizing using posterior referencing systems in “in-between sizes.” However these solutions bring their own complications with them. Anterior referencing may result in flexion instability. Cutting the femur in 3 degrees flexion may result in post-impingement in the posterior cruciate substituting systems. Manufacturing the “between size” femoral components may provide more congruous femoral component implantation. In such a situation, precise preoperative anticipation of femoral sizes may provide advantage to the surgeon and the patient.

Conclusion
Preoperative analysis of CT scans and anticipating the ideal femoral component size more precisely may help to solve the problems inherent in patients that require in-between sized implants. If precise preoperative methods for anticipating component size and their clinical use improve, future implant designs may be manufactured in a wider range of anatomic sizes.

Acknowledgment
We thank Cumhur Boratav, M.D., for his kind assistance in the statistical study of this article.

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