Accuracy of Preoperative Planning with Three-dimensional Bone Model in Total Knee Arthroplasty: Two-dimensional Computed Tomography Slices can Induce Internal-rotated Position of The Femoral Component.

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Disclosures:

Introduction:
Total knee arthroplasty (TKA) has become one of the most successful orthopedic procedures with reported survival rates of greater than 90% after 15 years [1]. Accurate preoperative planning and proper surgical techniques are important for the success of TKA. Surgeons usually use radiographs for the preoperative planning and computed tomography (CT) are sometimes available for more accurate evaluation. However, these measurements are two-dimensional (2D) analyses which are affected by limb position and scanning direction easily. In contrast, recently, three-dimensional (3D) analyses achieve detailed preoperative planning with 3D bone models reconstructed from CT. The first purpose of this study is to compare the reproducibility of 2D and 3D measurements for preoperative planning of the femoral side. The second purpose is to evaluate the factors affecting the difference between the 2D and the 3D measurements.

Methods:
A total of 50 osteoarthritis knees before primary TKA were assessed (Table 1). We measured FVA (femoral valgus angle), PCA (the angle between the posterior condylar line and the clinical epicondylar axis <CEA>), and PSA (the angle between the posterior condylar line and the surgical epicondylar axis <SEA>). Three-dimensional measurements used 3D bone model reconstructed from the CT data and the coordinate system as the previous reports [2] (Figure 1). FVA was measured on the plane perpendicular to Y axis (XZ plane), PCA and PSA were measured on the plane perpendicular to Z axis (XY plane) (Figure 1 and 2). The full-length weight-bearing anteroposterior radiograph and a selected appropriate CT slice were used for the 2D measurements. The intra- and inter-observer reliabilities (ICC) were checked from measurements performed by two orthopedic surgeons. We compared the mean values of the 3D and the 2D measurements, and evaluated whether preoperative factors (preoperative flexion contracture, femorotibial angle, body mass index, and actual limb position) affected the differences between the 3D and the 2D measurements. Actual limb position was defined as the position of femoral mechanical axis relative to the actual CT scanning direction.

In addition, 3D simulation was performed to check the relationship between the PCA and the femoral mechanical axis relative to the CT scanning direction (Figure 3). In the coordinate of the 3D simulation, neutral position was defined as the position when femoral mechanical axis aligned with the CT scanning direction. The femoral bone (the femoral mechanical axis) was rotated by 10° on the basis of the X (flexion-extension), and Y axis (varus-valgus) from the neutral position. The PCA was measured on the neutral, 10° of varus-valgus, and 10° of flexion-extension.

Results: The mean values with 3D and 2D measurements and the ICC were shown in Table 2. All the FVA, PCA and PSA were more reliable with
the 3D measurements. The mean differences were 0.5 ± 1.1° (-1.4 - 3.6) in the FVA, 0.8 ± 2.2° (-5.5 - 10.9) in the PCA and 0.9 ± 1.8° (-3.7 - 5.3) in the PSA. The average values of 3D measurements were larger than that of 2D measurements at all factors. There was a significant difference in measurements of PCA (p=0.04) and PSA (p=0.02). Ten percentage in the PCA and 16% in the PSA had over 3 degrees of the difference between the 3D and the 2D measurements. The actual limb position was 1.1 ± 3.1° in flexion, 4.4 ± 3.5° in varus, and 0.4 ± 8.2° in external rotation on average. No preoperative factors (preoperative flexion contracture, femorotibial angle, body mass index, and actual limb position for the femur) affected the difference between the 3D and the 2D measurements significantly. In the 3D simulation, PCAs were 7.2 ± 1.7° in neutral, 7.2 ± 2.6° in flex, 7.4 ± 2.2° in extension, 4.9 ± 2.8° in varus, 9.1 ± 2.6° in valgus respectively. The 3D simulation showed varus and valgus positioning relative to CT scanning direction influenced the PCA significantly. The differences between the 3D and the 2D measurements were smaller significantly when the position of the femoral bone (the femoral mechanical axis) were in more varus to the CT scanning direction (Figure 4).

Discussion:
From our study, the 3D measurements were highly reliable. In the 2D measurements, the measurements on axial plane showed less interobserver reliability because of the difficulty of picking the same CT plane and the same points of femoral bony landmarks. In the 3D measurements, observers can pick up the anatomical reference points of the bone surface more easily and accurately. The mean difference between the 3D and 2D measurements was small, however, the range was large and more than 10% of our cases were over 3 degrees which can induce the malalignment of the femoral component even if surgeons perform the precise bone cutting. Particularly, smaller values of the PCA and PSA with the 2D measurement have a risk of internal-rotated position of the femoral component.

From the 3D simulation, varus and valgus positioning relative to CT scanning direction influenced the PCA significantly. The 3D simulation showed the medial posterior condyle of femur was smaller in the varus position. In contrast, the lateral posterior condyle was smaller in the valgus position. Most of knees in this study had varus deformity and physiological valgus anatomical feature. When the scanning direction of the CT was along with the anatomical axis of the femur, mechanical axis of the femur was in the varus position which must be one of reasons that the PCA and PSA with the 2D measurement were smaller than with the 3D. In clinical situation, it is difficult to fit the CT scanning direction to the femoral mechanical axis and to measure PCA accurately in the 2D measurements. Therefore, surgeon should pay attention that the 2D planning can cause the unexpected malrotation of femoral component. The 3D measurement is very useful to evaluate the femoral anatomical feature and to avoid malpositioning occurred from the 2D measurements.

Significance: Preoperative planning with three-dimensional bone model in total knee arthroplasty is very useful and accurate. Two-dimensional CT slices can induce internal-rotated position of the femoral component.

Acknowledgments:

References:
Table 1. Preoperative demographic data

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<tr>
<td>Number of knees</td>
<td>50</td>
</tr>
<tr>
<td>Age (years)</td>
<td>75.9 ± 6.8 (57 - 89)</td>
</tr>
<tr>
<td>Sex (male / female)</td>
<td>8 / 42</td>
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<tr>
<td>Height (cm)</td>
<td>150.1 ± 6.7 (141.7 - 167.0)</td>
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<tr>
<td>Weight (kg)</td>
<td>56.8 ± 8.0 (39.1 - 77.0)</td>
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<tr>
<td>Body mass index (kg/m²)</td>
<td>25.2 ± 3.3 (19.1 - 37.9)</td>
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<tr>
<td>Hip-knee-ankle angle (*)</td>
<td>191.9 ± 5.1 (177.7 - 201.1)</td>
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<tr>
<td>Knee flexion angle (*)</td>
<td>123 ± 15 (75 - 145)</td>
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<tr>
<td>Knee extension angle (*)</td>
<td>-9 ± 9 (-40 - 0)</td>
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Table 2. The mean values with 3D and 2D measurements and the ICC

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<thead>
<tr>
<th></th>
<th>3D</th>
<th></th>
<th>2D</th>
<th></th>
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<tr>
<td></td>
<td>Mean</td>
<td>ICC(1,1)</td>
<td>ICC(2,1)</td>
<td>Mean</td>
</tr>
<tr>
<td>FVA(*)</td>
<td>7.3 ± 2.4 (2.9 - 12.2)</td>
<td>0.99</td>
<td>0.99</td>
<td>7.0 ± 2.3 (2.2 - 11.9)</td>
</tr>
<tr>
<td>PCA(*)</td>
<td>7.2 ± 1.7 * (3.3 - 10.7)</td>
<td>0.93</td>
<td>0.97</td>
<td>6.4 ± 2.4 * (-1.7 - 11.8)</td>
</tr>
<tr>
<td>PSA(*)</td>
<td>3.0 ± 1.7 † (-0.32 - 6.81)</td>
<td>0.91</td>
<td>0.91</td>
<td>2.1 ± 2.0 † (-2.5 - 6.7)</td>
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Figure 1

Hip center

Z axis
(Mechanical axis of femur)

Knee center
(Center of CEA)

Y axis

X axis
(Projected CEA to the plane perpendicular to Z axis)
Figure 3: Relationship between the femoral mechanical axis relative to the CT scanning direction.

- **Neutral**
- **Varus 10°**
- **Valgus 10°**

- **CEA**
- **PC-L (neutral)**
- **PC-L: Posterior condylar line**
- **Red arrowed line: CT scanning direction**
- **Blue line: Femoral mechanical axis**
Figure 4: Simulated Cutting Plane of Femur

Neutral

Valgus 10°

Varus 10°

PC-L (neutral)

PC-L (valgus 10°)

PC-L (varus 10°)

Lateral

Medial

PC-L: Posterior condylar line

CEA

1.8°