An Additional Reference Axis for Determining Rotational Alignment of the Femoral Component in Total Knee Arthroplasty

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Abstract: No studies have examined the trochlear line connecting the most anterior projections of the lateral and medial femoral condyles in relation to the surgical epicondylar axis. To determine if the trochlear line is more consistent relative to the transepicondylar axis than the posterior condylar axis and the Whiteside’s line, the angles between the surgical epicondylar axis and each of the 3 axes in 50 knees of cadavers were measured using computed tomography scans. The results showed that the variability in the trochlear line for referencing the transepicondylar axis was comparable to those of the Whiteside line and the posterior condylar axis. The trochlear line may be considered as an additional reference axis for determining the rotational alignment of the femoral component in total knee arthroplasty. Key words: trochlear line, rotational alignment, transepicondylar axis, total knee arthroplasty.

Of the many variables that contribute to the success of total knee arthroplasty (TKA), the proper rotational alignment of the femoral component has attracted considerable attention because of its influence on the balance of the flexion gap and the patellar tracking [1-3]. Several reference axes have been proposed to establish the proper rotational alignment of the femoral component, including the posterior condylar axis (PCA) [4], the Whiteside’s line (anteroposterior [AP] axis) [5], and the transepicondylar axis (TEA) [6]. Anatomical and biomechanical studies have suggested that the TEA approximates the flexion-extension axis of the knee [6-8]. Berger et al [6] have proposed 2 transepicondylar axes: the surgical epicondylar axis, which is a line connecting the lateral epicondylar prominence and medial sulcus of the medial epicondyle, and the clinical epicondylar axis, which is a line connecting the lateral epicondylar prominence and the most prominent point of the medial epicondyle. They concluded that the surgical epicondylar axis is a more reliable and reproducible reference than the clinical epicondylar axis. An in vivo study using a biplanar image-matching technique further demonstrated that the functional flexion-extension axis of the knee corresponds to the surgical epicondylar axis during a 0° to 90° flexion [9]. However, the practical use of this axis is limited because it is difficult to localize the sulcus of the medial epicondyle precisely during surgery. Therefore, the AP axis and the PCA in relation to the TEA have been investigated in normal [10] and osteoarthritic knees [11] by using computed tomography (CT) or magnetic resonance imaging (MRI) for referencing the TEA. This is because the
2 axes can be more easily identified intraoperatively than the TEA. However, in osteoartritic knees, the destruction of the posterior condylar surface, osteophytes formation, and trochlear wear or intercondylar osteophytes make it difficult for surgeons to accurately define these axes in an operative field. In particular, in cases with a conversion of failed unicompartmental arthroplasty (UKA) to TKA, the posterior condyle of the affected side and the trochlear were resected so that determining the level of rotational alignment would be a challenge. Therefore, there is a need for an additional reference axis that can be easily identified and is not affected by the conditions cited earlier. In clinical practice, we found that most prominences of the lateral and medial condyles are relative intact despite the severe destruction of the posterior condylar surface and trochlear groove wear in some osteoarthritic cases. There are no reports on the trochlear line connecting most anterior projections of the lateral and medial femoral condyles in relation to the surgical epicondylar axis. We hypothesized that the trochlear line can be a reliable landmark for determining the proper rotational alignment of the femoral component. The aim of this study was to determine if the trochlear line was more consistent relative to the TEA compared to the PCA and the Whiteside’s line in normal knees.

**Materials and Methods**

Computed tomography images of the distal femur used in this study were obtained from the Digital Korean Human Information Database, containing CT images of 50 male and 50 female cadavers. The CT data of the 50 right distal femurs, from 25 male and 25 female cadavers without any evidence of degenerative arthritis and bone pathology (ie, tumors) were included in this study. The mean age was 44.7 ± 11.5 years (age range, 23-60 years) at the time of death (men, 43.8 ± 11.7 years; women, 46.2 ± 11.3 years). A CT (Pronto, Hitachi, Japan) scan of the low extremity was performed for each knee in full extension at 1-mm intervals using a 512 × 512 pixel matrix, and the scan direction was aligned perpendicular to the longitudinal axis of the femur. Only the CT scan of the right distal femur, approximately 200 consecutive slices for each case, was imported into special medical imaging software (Lucion, Mevisys Co, Ltd, Seoul, South Korea). The computer software was used to draw the lines or points on the CT scans, for projecting a line or a point on one scan to another scan, and for measuring the angles between the 2 lines.

Transverse sections through the most prominent part of the 2 femoral condyles were used for the measurements. The trochlear line, the surgical epicondylar axis, the AP axis, and the PCA were determined on a series of CT scans by using the following method. Initially, the most anterior projective point of the lateral condyle (Fig. 1A) and the most anterior projective point of the medial condyle (Fig. 1B) were identified with several continual CT scans and marked individually on 2 different slices. The lateral point marked was then projected onto the slice in which the most anterior projective point of the medial condyle was recog-
nized (Fig. 1B). A line connecting the 2 most anterior projective points on a slice was defined as the proposed trochlear line (Fig. 1B). Likewise, the surgical epicondylar axis, the PCA, and the AP axis were determined in the same manner as previously described. Briefly, the surgical epicondylar axis was defined as a line connecting the most prominent point of the lateral epicondyle and the deepest point of the sulcus on the medial epicondyle. The case difficult to identify the sulcus due to flattening of the medial epicondyle was excluded. Another case in which the sulcus can be clearly identified was chosen from the image database for measurement. The AP axis was a line connecting the deepest part of the patellar groove anteriorly and the center of the intercondylar notch posteriorly. The PCA was a line connecting the most posterior points of the medial and lateral femoral condyles. Finally, the trochlear line, the AP axis, and the PCA were projected onto the slice in which the surgical epicondylar axis was determined (Fig. 1C), and the angles of these axes relative to the surgical epicondylar axis were measured on that scanning slice, and are expressed as the “trochleoeipcondylar angle,” “Whiteside-epicondylar angle (superolateral aspect),” and “posterior condylar angle,” respectively. The intraobserver reproducibility assessed by a single observer (Cui) for repeat angular measures from single acquisitions, as measured by the coefficient of variation, was 5.6% for the trochleoeipcondylar angle, 6.2% for the Whiteside-epicondylar angle, and 5.2% for the posterior condylar angle. F tests were used to identify any significant differences in the variability of the 3 reference axes. The level of significance was set at $\alpha = 0.05$.

### Results

Table 1 gives a summary of the results of the angular measurements.

The mean value of the trochleoeipcondylar angle was $8.0^{\circ} \pm 1.76^{\circ}$ (range, $4.3^{\circ}$-11$^{\circ}$) of internal rotation in all subjects, $8.8^{\circ} \pm 1.36^{\circ}$ (range, $6.0^{\circ}$-$11^{\circ}$) in men and $7.3^{\circ} \pm 1.82^{\circ}$ (range, $4.3^{\circ}$-10.6$^{\circ}$) in women. The distribution was monomodal with a peak between 7.1$^{\circ}$ and 9.8$^{\circ}$ (54%, n = 27).

The average Whiteside-epicondylar angle was $86.7^{\circ} \pm 2.36^{\circ}$ (range, $83.0^{\circ}$-$93.0^{\circ}$) for all subjects, $87.3^{\circ} \pm 2.6^{\circ}$ (range, $83.1^{\circ}$-$93.0^{\circ}$) for men and $86.0^{\circ} \pm 1.9^{\circ}$ (range, $83.0^{\circ}$-$89.0^{\circ}$) for women. The distribution was monomodal with a peak between 86.0$^{\circ}$ and 88.80$^{\circ}$ (46%, n = 23).

The posterior condylar angle had a mean value of $3.3^{\circ} \pm 1.12^{\circ}$ (range, $1.2^{\circ}$-$5.4^{\circ}$), $3.9^{\circ} \pm 1.0^{\circ}$ (range, $1.7^{\circ}$-$5.2^{\circ}$) for men and $2.8^{\circ} \pm 1.0^{\circ}$ (range, $1.2^{\circ}$-$5.4^{\circ}$) for women. The distribution was monomodal with the peak between 2.5$^{\circ}$ and 4.5$^{\circ}$ (56%, n = 28). There were significant sex differences in these 3 angles ($P = .001$, $P = .047$, $P < .001$, respectively).

The F tests showed no significant difference in variability between the trochlear line and the AP axis ($\alpha = 0.30$) or the PCA ($\alpha = 0.48$) for referencing the surgical epicondylar axis.

### Discussion

The aim of this study was to identify a clearly discernible, reliable secondary anatomic axis that could be used to determine the rotational orientation of the femoral component when those axes commonly used in TKA cannot be used. To our knowledge, this is the first study to investigate the relationship between the trochlear line and the surgical epicondylar axis in normal knees by using CT. The results showed that the variability of the trochlear line for referencing the surgical epicondylar axis was comparable to that of the PCA or the AP axis. This indicates that our proposed axis may be an additional reference axis for establishing rotational alignment.

Although the importance of proper rotational alignment in TKA surgery is recognized, the determination of rotational alignment is controversial when compared to the determination of the axial alignment. It is believed that the surgical epicondylar line is the most reliable axis for precisely rotating the femoral component when the medial and lateral epicondyles are clearly discernible, reliable secondary anatomic axis that could be used to determine the rotational orientation of the femoral component when those axes commonly used in TKA cannot be used. To our knowledge, this is the first study to investigate the relationship between the trochlear line and the surgical epicondylar axis in normal knees by using CT. The results showed that the variability of the trochlear line for referencing the surgical epicondylar axis was comparable to that of the PCA or the AP axis. This indicates that our proposed axis may be an additional reference axis for establishing rotational alignment.

### Table 1. Angular Measurements Relative to the Surgical Epicondylar Axis

<table>
<thead>
<tr>
<th>Angles measured</th>
<th>Subjects (n = 50)</th>
<th>Men (n = 25)</th>
<th>Women (n = 25)</th>
<th>Difference ($P$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trochleoeipcondylar angle</td>
<td>8.1 ± 1.76</td>
<td>8.8 ± 1.36</td>
<td>7.3 ± 1.82</td>
<td>.001</td>
</tr>
<tr>
<td>Whiteside-epicondylar angle</td>
<td>86.7 ± 2.36</td>
<td>87.3 ± 2.6</td>
<td>86.0 ± 1.9</td>
<td>.047</td>
</tr>
<tr>
<td>Posterior condylar angle</td>
<td>3.3 ± 1.12</td>
<td>3.9 ± 1.0</td>
<td>2.8 ± 1.0</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

Average values ± standard deviations are expressed in degrees. $P < .05$ is considered significant.
visible. However, the sulcus of the medial epicondyle and the peak point of the lateral epicondyle, covered by soft tissue, are difficult to identify precisely in a surgical setting [1,6], which limits the usefulness of this axis. The posterior condylar and AP axes are directly visible and hence easier to use under such conditions. Arima et al [1] recommended the AP axis as a reliable landmark for use in a valgus knee. Constructing the AP axis relies on a normal anatomy of the trochlear groove and intercondylar notch of the distal femur. In arthritic knees, the AP axis is sometimes difficult to define due because of trochlear wear or intercondylar osteophytes. These significant arthritic distortions may decrease the reliability of the AP axis. Poilvache et al [12] reported the disadvantages of the AP axis in their study of 100 arthritic knees. Severe trochlear dysplasia causes excessive external rotation of the femoral component, which was shown by the greater range of angles compared to the epicondylar axis.

Most of current cutting guide systems are designed to apply a few degrees (3°-5°) of external rotation relative to the PCA. However, in varus knees, an excessive rotational angle may be applied because of cartilage surface destruction, resulting in the creation of a greater flexion gap and medial instability, patellar dislocations, and subluxation. In contrast, in the valgus knees, 3° of external rotation from the posterior condyles causes internal rotation of the femoral component relative to the TEA due to lateral condyle erosion [13]. Moreover, when PCA is used as the reference axis, it is difficult to insert the rotational guide needed to make complete contact with the posterior condyles, and the most posterior point of the medial and lateral femoral condyles is often not seen as a result of osteophytes, joint narrowing, and meniscus.

This study introduces an additional reference axis, the trochlear line, to determine the rotational alignment of the femoral component. Detailed anatomic descriptions of this axis are scarce. In only 1 clinical study, Poilvache et al [12] measured the angle between this line and the clinical epicondylar axis intraoperatively in arthritic knees using a metallic plate, and reported a mean value of 4.95° ± 2.15°, 5.40° ± 2.32° in valgus knees, and 4.89° ± 2.13° in varus or neutral knees. The accuracy of the measurements performed at surgery using a goniometer and metallic templates is questioned and was not measured in relation to the surgical epicondylar axis. The results of this study should therefore be interpreted cautiously. Our results showed that the trochlear line had a mean value of 8.0° of internal rotation relative to the surgical epicondylar axis, with a smaller deviation (1.76°) than that (2.36°) of the AP axis. Importantly, the variability of the trochlear line for referencing the surgical epicondylar axis is comparable to that of the PCA or the AP axis commonly used in TKA. It should be noted that the study population was limited to Korean subjects with normal knees. The data may be typical for knees in Asian subjects, but not for those in white or other populations.

The clinical relevance of this axis is that it can provide a better visualization and exposure after patellar erosion, and it is easy to place a guide plate and measure. In particular, it can be used in cases with conversion of failed UKA to TKA and minimally invasive TKA. Therefore, the trochlear line is recommended as an additional reference axis for determining the rotational alignment of the femoral component in TKA when the Whiteside line and the PCA cannot be used because of the destruction of the posterior condylar surface and trochlear wear or intercondylar osteophytes.

References