Is radiographic measurement of distal femoral torsion reliable?

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Summary
Background: Distal femur torsion (DFT) is a crucial parameter in knee replacement surgery. The reference standard for measuring DFT is posterior condylar angle (PCA) measurement using computed tomography (CT). The objective of this study was to assess the feasibility and reliability of a radiographic PCA measurement method.

Materials and methods: We studied 125 osteoarthritic knees in 79 patients (42 women and 37 men) with a mean age of 71.6 ± 8.8 years (range 47 to 86 years); 32 knees were aligned, 85 in varus, and eight in valgus. DFT was measured on an antero-posterior (AP) radiograph of the knee in 90° of flexion (known as the seated AP view). The PCA was defined as the angle subtended by the tangent to the posterior condyles and the transepicondylar axis (anatomic PCA [aPCA]) or the line connecting the lateral epicondyle to the medial sulcus (surgical PCA [sPCA]). The PCA was conventionally recorded as positive in the event of external torsion and negative in the event of internal torsion. PCA measurements were performed three times by each of five observers to allow assessments of inter-observer and test-retest reliabilities.

Results: aPCA was consistently negative (mean, −6.1 ± 1.6°) (range, 0 to −10°); inter-observer and test-retest reliability were satisfactory (0.54 < rw 0.80). sPCA was positive in 41 knees and negative in 84 knees (mean, −0.3 ± 1.4°) (range, −5° to +2°); inter-observer and test-retest reliabilities were poor (0.28 < r < 0.69). A weak but significant correlation was found between aPCA and coronal alignment, with a trend towards greater internal torsion in the group of valgus knees.

Conclusion: Radiographic measurement of DFT is simple and non-invasive. Measurement reproducibility was satisfactory for aPCA but not for sPCA. aPCA showed marked inter-individual variability and tended to increase when the knee was in valgus. Mean aPCA values were comparable to those reported using CT. In contrast to CT, radiographic DFT measurement can easily be...
Distal femoral torsion (DFT) is a crucial parameter for knee replacement surgery as it governs knee kinematics, most notably patellar tracking, as well as ligament balance in flexion [1–10]. Therefore, rotational malposition of the femoral component might result in failure of total knee arthroplasty (TKA) [11,12]. DFT was first evaluated in the 1990s, using computed tomography (CT) [13,14]. In 1987, Yoshioka et al. [15] defined DFT as the condylar twist angle or posterior condylar angle (PCA) formed by the tangent line to the posterior condyles and the transepicondylar axis. In 1993, Berger et al. [16] distinguished the anatomic PCA (aPCA) described above and the surgical PCA (sPCA) for which the medial landmark was the medial sulcus of the medial epicondyle, which they felt was easier to identify. Although CT is now the reference standard for DFT [11,13–16], routine CT may not be feasible given radiation exposure considerations, the limited availability of CT machines, and difficulties with bony landmark identification in some patients [11,14,17]. These limitations have prompted studies of radiographic methods for DFT measurement [18,19]. Using original methods based on antero-posterior (AP) radiographs of the knee in flexion, Takai et al. [18] in 2003 and Kanekasu et al. [19] in 2005 found DFT values similar to those obtained using CT. These simple and reproducible methods have not gained widespread acceptance and, to our knowledge, have not been evaluated in independent studies.

The objective of this study was to assess the inter- and test-retest reliability of a standardised radiographic method for measuring DFT. We evaluated this method in a consecutive series of osteoarthritic knees.

**Material and method**

We prospectively evaluated 125 osteoarthritic knees for which TKA was performed between January and November 2010, in 79 patients (42 women and 37 men) with a mean age of 71.6 ± 8.8 years (range, 47 to 86 years). The osteoarthritis was primary in 108 knees, post-traumatic in seven (sequelae of epiphyseal fractures were excluded), and secondary to inflammatory joint disease in 10. In the coronal plane, 32 knees were aligned, 85 were in varus, and eight were in valgus. Mean preoperative mechanical tibio-femoral axis (hip-knee-ankle [HKA] angle) was 175 ± 5° (range, 164 to 192°).

DFT was measured on an AP radiograph of the knee in the seated position (known as the AP seated view), i.e., with the knee flexed to 90°, according to a method derived from those described by Takai et al. [18] and Kanekasu et al. [19] (Fig. 1). The patient was seated on a radiotransparent table with the legs hanging over the edge. The axis of the femur was strictly perpendicular to the film, which was in direct contact with the anterior aspect of the knee. Neutral rotation was ensured by the weight of the leg. The X-ray source was behind the patient, 1 m from the film, and centred on the popliteal fossa. The X-ray beam was angled upwards 15° from the horizontal. X-ray-beam constants were adapted to patient build and soft-tissue thickness. The AP seated radiograph was considered properly performed if it showed the Roman arch-shaped intercondylar notch, medial and lateral epicondyles, medial sulcus, and posterior edges of both condyles (Fig. 2). These bony landmarks were used to define two angles (in°) determining DFT:

- the aPCA between the tangent line to the posterior condyles and the transepicondylar axis;
- and the sPCA between the tangent line to the posterior condyles and the line connecting the lateral epicondyle to the medial sulcus of the medial epicondyle.

When the tip of the angle pointed laterally, the distal femur was twisted internally and the PCA was arbitrarily reported as negative (anti-clockwise direction for the left knee). When the tip of the angle pointed medially, the distal femur was twisted externally and the angle was positive (clockwise direction for the left knee) (Fig. 2).

To allow an assessment of inter-observer and test-retest reliabilities, each of five observers (three junior and two senior orthopaedic surgeons) each measured the angles three times at intervals of 1 month.

Figure 1 Antero-posterior (AP) seated radiograph of the knee: the patient is seated with the legs hanging down and the knee in contact with the film. The source is behind the patient and the X-ray beam has 15° of upwards obliquity.

Inter-observer and test-retest reliabilities were assessed based on the intraclass coefficient (ICC), with $r$ values greater than 0.5 being considered satisfactory. Pearson’s correlation coefficient was computed to assess relationships between DFT and the mechanical axis of the limb. Finally, we used Student’s $t$ test to evaluate DFT differences between men and women.

Results

PCA measurements proved feasible in all patients with no modifications to the equipment for individual patients and no need for additional analgesic therapy, even in patients with severe baseline pain, advanced age, or obesity. The only requirement was an ability to flex the knee to $90^\circ$. We obtained 1875 measurements on 125 radiographs.

\subsection*{aPCA}
- $aPCA$ was consistently negative, with a range of $0^\circ$ to $-10^\circ$ ($n=6$), almost normal distribution (mean, $-6.1 \pm 1.6^\circ$) with a median of $-6.0^\circ$ (Fig. 3), and 95% of values between $-9.3^\circ$ and $-2.9^\circ$. No statistically significant difference was found between men and women ($P=0.64$). The correlation between $aPCA$ and the HKA angle was weak ($r=-0.26$, $P=0.003$) but internal torsion tended to increase with the HKA angle (Fig. 4).
- For each observer, a similar normal distribution of the values was noted. The mean value for each observer showed little variation ($-5.9^\circ$ to $-6.5 \pm 1.8^\circ$ to $2.3^\circ$, Table 1).
- The ICC values indicated good inter-observer and test-retest reliabilities for both the junior and the senior observers ($0.54 < r < 0.80$) (Table 2).

\subsection*{sPCA}
- Overall, $sPCA$ was negative in 84 cases and positive in 41 cases. The value ranged from $-5^\circ$ to $+2^\circ$. Value distribution was skewed (Fig. 4). The mean value was close to $0^\circ$ ($-0.3 \pm 1.4^\circ$). The median value was $-1^\circ$, and 95% of values were between $-3.1^\circ$ and $+2.5^\circ$. Values in men and

\begin{table}[h]
\centering
\caption{Mean $\pm$ SD ($^\circ$) values for the anatomic posterior condyular angle ($aPCA$) and surgical PCA (sPCA) for each of the five observers. Note the substantial scatter of the sPCA values.}
\begin{tabular}{|c|c|c|c|c|c|}
\hline
 & Junior 1 & Junior 2 & Junior 3 & Senior 1 & Senior 2 \\
\hline
$aPCA$ ($^\circ$) & $-6.0 \pm 1.8$ & $-5.9 \pm 1.8$ & $-6.3 \pm 2.1$ & $-5.9 \pm 2.3$ & $-6.5 \pm 1.8$ \\
$sPCA$ ($^\circ$) & $0.75 \pm 1.7$ & $-0.1 \pm 1.9$ & $1.7 \pm 1.4$ & $-0.6 \pm 1.8$ & $-1.0 \pm 1.8$ \\
\hline
\end{tabular}
\end{table}
women were not significantly different (P = 0.56). A weak correlation was found between sPCA and the mechanical axis (r = −0.18; P = 0.04).
- The mean value varied across observers from −1.0° to +1.7°, with wide standard deviations (1.4° to 1.9°) (Table 1).
- The ICC values showed considerable variability in inter-observer and test-retest reliabilities for both junior and senior observers (0.28 < r < 0.69) (Table 3).

Discussion

Rotational malposition of the femoral component during TKA can create a trapezoidal flexion gap that alters knee ligament balance and patellar tracking. Despite general agreement that internal rotation of the femoral component is deleterious [5,7,9,11], the optimal value of femoral component rotation remains unclear and the best method for assessing this parameter is controversial. Reliance on ligament tension and achievement of a similar quadrilateral gap in flexion and extension has been advocated by some authors [10], whereas others have recommended the identification of bony landmarks defining DFT [20–23], which is an anatomic and functional measure that reflects femoral condyle asymmetry in the horizontal plane.

PCA measurement has been evaluated in several studies that used a variety of methods. The results are somewhat conflicting depending on whether the measurements were obtained in cadavers or patient cohorts, on osteoarthritic or normal knees, using instruments or CT, and with a focus on aPCA or on sPCA. Overall, mean aPCA is about 6° of internal torsion and mean sPCA about 3° [13–16,17–22,24–26] with no significant differences according to gender (except for sPCA in a study by Berger et al. [16]), side, osteoarthritis severity, or axial malalignment [14,27]. Although CT remains the reference standard for PCA measurement, several factors limit its use: CT machines are not always widely available, wait times are longer than for standard radiographs and cost about five times greater, the technique is not standardised (knee position, section plane, section thickness), and the radiation dose (which depends on the type of machine and selected settings) is considerably higher (5 to 20 mSv). For a reliable assessment of bony landmarks, the horizontal sections must go through all the landmarks simultaneously. Obstacles to meeting this criterion include knee positioning difficulties (e.g., fixed flexion), presence of metallic artefacts, and severe osteoarthritis with osteophytes. Yoshino et al. [17] reported that the medial sulcus was identifiable in only 30% of patients. Similarly, in a study of 111 knees, Akagi et al. [14] identified three types of medial sulcus: easily recognisable, n = 27; barely recognisable, n = 55; and not recognisable, n = 29 (26%). Difficulties in identifying bony landmarks were reported in most studies, regardless of the method used [11,14,17]. These difficulties may affect the reliability of sPCA measurement. Three-dimensional CT requires additional time to perform the reconstruction and seems to improve neither definition nor measurement reliability [25].

Radiographic measurement holds promise as an alternative to CT. In 2003, Takai et al. [18] reported the use of a kneeling view, with the knee in 80° of flexion. The patient kneels on the radiographic film, with the hip in neutral rotation. The X-ray beam is vertical, centred on the popliteal fossa and perpendicular to the tibial shaft. Takai et al. studied 39 osteoarthritic and 19 normal knees. The epicondyles were clearly visible on all radiographs. Mean aPCA was −6.5 ± 1.7°. No differences were found between men and women or between the left and right sides. Intra-observer and test-retest reliabilities were good. In 2005, Kanesaku et al. [19] reported another method in which the patient is seated with the legs hanging down. The X-ray beam is behind the patient, centred on the popliteal fossa, with a variable degree of obliquity depending on

### Table 2 Intra-class coefficients for anatomic posterior condylar angle (aPCA) measurements: r was consistently greater than 0.5, indicating good inter-observer and test-retest reliabilities.

<table>
<thead>
<tr>
<th>Observers</th>
<th>Junior 1 (r)</th>
<th>Junior 2 (r)</th>
<th>Junior 3 (r)</th>
<th>Senior 1 (r)</th>
<th>Senior 2 (r)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Junior 1</td>
<td>0.77</td>
<td>0.60</td>
<td>0.59</td>
<td>0.80</td>
<td>0.79</td>
</tr>
<tr>
<td>Junior 2</td>
<td>0.68</td>
<td>0.59</td>
<td>0.64</td>
<td>0.61</td>
<td>0.57</td>
</tr>
<tr>
<td>Junior 3</td>
<td>0.65</td>
<td>0.54</td>
<td>0.57</td>
<td>0.57</td>
<td>0.57</td>
</tr>
<tr>
<td>Senior 1</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
</tr>
<tr>
<td>Senior 2</td>
<td></td>
<td>0.62</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 3 Intra-class coefficients for surgical posterior condylar angle (sPCA) measurements: r was close to or less than 0.5 (except in two cases), indicating poor inter-observer and test-retest reliabilities.

<table>
<thead>
<tr>
<th>Observers</th>
<th>Junior 1 (r)</th>
<th>Junior 2 (r)</th>
<th>Junior 3 (r)</th>
<th>Senior 1 (r)</th>
<th>Senior 2 (r)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Junior 1</td>
<td>0.56</td>
<td>0.53</td>
<td>0.7</td>
<td>0.53</td>
<td>0.65</td>
</tr>
<tr>
<td>Junior 2</td>
<td>0.52</td>
<td>0.52</td>
<td>0.37</td>
<td>0.51</td>
<td>0.51</td>
</tr>
<tr>
<td>Junior 3</td>
<td>0.42</td>
<td>0.47</td>
<td>0.56</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Senior 1</td>
<td>0.74</td>
<td></td>
<td>0.28</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Senior 2</td>
<td></td>
<td></td>
<td>0.36</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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patient build. In osteoarthritic knees, mean aPCA was $-6.9 \pm 1.4^\circ$. Inter-observer differences were smaller than or equal to $1^\circ$. This method showed good reproducibility and proved feasible even in patients with knee pain or instability. Both studies [18,19] compared the standard radiography method to CT. In the study by Takai et al. [18], mean aPCA was $-6.5 \pm 1.7^\circ$ by standard radiography and $-6.3 \pm 1.7^\circ$ by CT, with no significant difference between these two values in the osteoarthritic or normal knees. Kanekasu et al. [19] found a correlation coefficient greater than 0.9 with a mean discrepancy of 0.5° and a maximal discrepancy of 1.9°. Both authors concluded that performances of the radiographic and CT methods were comparable.

We used a method derived from those described by Takai et al. [18] and, above all, Kanekasu et al. [19]. However, we clarified or modified some of the parameters in order to improve accessibility, as well as inter-observer and test-retest reliabilities. Instead of kneeling as in the method described by Takai et al. [18], the patient is seated, as advocated by Kanekasu et al. [19], with the knees flexed to about 90°. This position is easier to obtain in patients with severe pain, advanced age, or obesity. The film is strictly perpendicular to the femoral axis to ensure visibility of the epicondyles and in direct contact with the patella to minimise femoral axis errors. X-ray beam obliquity in the sagittal plane is not variable as in the study by Kanekasu et al. [19] but instead is equal to 15° in all patients. This 15° angle minimises soft-tissue superimposition without compromising bony-landmark visibility. The obliquity of the beam relative to the film induces some measure of image distortion, but this distortion is constant and does not substantially alter bony-landmark position. Takai et al. [18] showed that variations in CT section obliquity relative to the longitudinal axis of 70° to 90° had no significant impact on PCA measurement.

The AP seated radiograph described here can be performed in all patients who are able to flex their knee to 90°. Our mean aPCA of about $-6^\circ$ is consistent with earlier reports [13–16,17–22]. The good reliability of aPCA measurement can be ascribed to the ease of recognition of the epicondyles, particularly the medial epicondyle, regardless of the pattern of osteoarthritis. On the other hand, difficulties with identification of the medial sulcus limited the inter-observer and test-retest reliabilities of sPCA measurement. The osteoarthritic lesions, most notably the osteophytes, probably partly mask the medial sulcus. In our cohort characterised by a predominance of medial-compartment osteoarthritis with knee malalignment, standard radiography did not perform better than CT for identifying the medial sulcus.

Our results confirm the considerable inter-individual variability in aPCA values, with no significant differences according to gender or limb mechanical axis. The trend towards greater internal torsion in valgus knees may be ascribable to posterior and distal hypoplasia of the lateral condyle. This considerable inter-individual variability with a range of 0 to 10° may call into question the recommendation by some authors that the same degree of femoral component rotation be used during all TKA procedures. Instead, our data support TKA customisation to individual patient anatomy.

Conclusion

Radiographic DFT measurement is feasible in all patients who can flex their knee to 90°. Reliability is good for aPCA but not for sPCA. The aPCA values are comparable to those reported using CT. Our AP seated radiograph is associated with lower costs, greater accessibility, and lower radiation exposure compared to CT and may therefore deserve consideration as a routine evaluation during pre- and postoperative TKA work-ups.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

References


