KNEE

The position and orientation of total knee replacement components

A COMPARISON OF CONVENTIONAL RADIOGRAPHS, TRANSVERSE 2D-CT SLICES AND 3D-CT RECONSTRUCTION

We studied the intra- and interobserver reliability of measurements of the position of the components after total knee replacement (TKR) using a combination of radiographs and axial two-dimensional (2D) and three-dimensional (3D) reconstructed CT images to identify which method is best for this purpose.

A total of 30 knees after primary TKR were assessed by two independent observers (an orthopaedic surgeon and a radiologist) using radiographs and CT scans. Plain radiographs were highly reliable at measuring the tibial slope, but showed wide variability for all other measurements; 2D-CT also showed wide variability. 3D-CT was highly reliable, even when measuring rotation of the femoral components, and significantly better than 2D-CT. Interobserver variability in the measurements on radiographs were good (intraclass correlation coefficient (ICC) 0.65 to 0.82), but rotational measurements on 2D-CT were poor (ICC 0.29). On 3D-CT they were near perfect (ICC 0.89 to 0.99), and significantly more reliable than 2D-CT (p < 0.001).

3D-reconstructed images are sufficiently reliable to enable reporting of the position and orientation of the components. Rotational measurements in particular should be performed on 3D-reconstructed CT images. When faced with a poorly functioning TKR with concerns over component positioning, we recommend 3D-CT as the investigation of choice.

Malpositioning and malorientation are two major causes of pain following total knee replacement (TKR).1-3 The assessment of the position of the components after TKR is generally performed on radiographs.4-12 Gross malposition, particularly in varus-valgus and flexion-extension, might be identified on radiographs, but accurate measurement is prone to error owing to variation in rotation of the leg and magnification.5,13 Measurement of rotation of the components is difficult.14-16 Routine assessment of component position can also be performed on CT scans.4,6 Depending on the CT imaging protocol, the post-operative sagittal, coronal and rotational alignment of the components can be determined.17,18 Several different methods of measurement have been described.4,19 For rotational measurement of the femoral component, most authors use transverse 2D-CT slices measuring the angle between the surgical epicondylar axis and the posterior prosthesis axis.4,6 Less frequently, CT images are reconstructed in 3D, with the images aligned to standardised frames of reference, and rotational alignment is assessed on these images.20 For this purpose, specific protocols have been described that include not only the knee but also the head of the femur and the mid-ankle.21,22 This assessment of rotation may be more accurate and reproducible than measurements on 2D-CT slices. Only in 3D-CT can the measurements be adjusted for the variability of the position of the patient's leg in the scanner, which may lead to a more reliable identification of the anatomical landmarks such as the medial and lateral femoral epicondyles.

The primary purpose of this study was to evaluate which of these imaging modalities best documented the position and orientation of the components of a TKR. We therefore set out to establish the intra- and interobserver reliability of tibial and femoral component measurements in patients after TKR using radiographs, axial 2D-CT images and 3D-CT.

Patients and Methods

A total of 30 knees were investigated in 29 patients with a mean age of 71 years (39 to 89) who had undergone primary TKR. The study was approved by our institutional review board.
The sagittal (γ and δ) and coronal (α and β) positions of the components were assessed according to Ewald\textsuperscript{23} on weight-bearing anteroposterior (AP), lateral and skyline radiographs of the knee (Fig. 1). For femoral sagittal alignment (flexion-extension, γ angle) an angle between the line of the midshaft of the femur and the neutral line of the femoral component was assessed. For tibial sagittal alignment (slope, δ angle) an angle between the line of the midshaft of the tibia and an AP tangent of the tibial component was determined. For femoral coronal alignment (varus-valgus, α angle) an angle between the line of the midshaft of the femur and a tangent of the distal condyles of the component was measured. For the tibial coronal alignment (varus-valgus, β angle) an angle between the line of the midshaft of the tibia and a tangent of the plateau of the component was measured.

The rotational alignment of the femoral component was assessed on axial 2D-CT images (Fig. 2) using the method described by Berger et al.\textsuperscript{4} In addition, the sagittal, coronal and rotational alignment of both components was assessed on 3D reconstructed CT images (Fig. 3) and using customised software as previously described.\textsuperscript{20,21} The rotation of the femoral component (femoral posterior component axis) was measured in relation to the epicondylar axis. The rotation of the tibial component (tibial posterior component axis) was measured in relation to the posterior tibial plateau axis.

Measurements were performed three times by an orthopaedic surgeon (MTH) at an interval of two weeks, each in random order, for assessment of intra-observer reliability. For assessment of interobserver reliability, the measurements were repeated by an orthopaedic surgeon (MTH) and a radiologist (PK). The observers were not aware of any previous measurements at the time.

**Statistical analysis.** Data were analysed using SPSS version 13.0 (SPSS Inc., Chicago, Illinois). Sample size was calculated according to the reported estimates for reliability studies using intraclass correlation coefficients (ICCs), a measure that takes into account not only the aspect of correlation but also systematic differences between the observations.\textsuperscript{24} An ICC value of 1 indicates perfect reliability, 0.81 to 1 very good, 0.61 to 0.80 good, 0.41 to 0.60 moderate and < 0.40 poor reliability.\textsuperscript{24} The sample size was calculated on the basis of three repetitions of the measurements. The α-error and β-error was 0.05 and 0.20, respectively. In order to describe interobserver reliability, the ICC and mean Pearson correlation r of the three observations was calculated. Intra-observer reliability was calculated comparing the mean of the three observations of the first observer with those of the second. The reliability between 2D and 3D imaging methods was compared by applying the same calculations using the mean values of
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The mean, minimum and maximum differences of the observed values were calculated for all comparisons. In order to compare the strength of reliability between the ICCs of 2D versus 3D imaging methods, Fisher’s z- and t-values of the difference of the ICCs were calculated. A p-value < 0.05 was considered to be statistically significant.

Results

The ICCs representing intra- and interobserver reliability for measurement of the position of the components on radiographs, 2D-CT and 3D-CT images are presented in Tables I and II.

Intra-observer reliability of the measurements on radiographs were moderate or poor, with the exception of the posterior tibial slope (ICC 0.81). 2D-CT was only moderately reliable in measuring the rotation of the femoral component, but 3D-CT was significantly better (ICC 0.60 vs 0.73; p < 0.001). The ICC values for all other measurements on 3D-CT were highly reliable (ICC 0.96 to 0.99).

Measurements on radiographs showed moderate to good interobserver reliability (0.65 to 0.82), but rotational measurements of the femoral component on 2D-CT were less reliable (ICC 0.29). The interobserver reliability for the measurements of all variables on 3D-CT slices were near perfect (ICC 0.89 to 0.97). Measurements of the rotation of the femoral components on 3D-CT showed a significantly higher interobserver agreement than measurements on 2D-CT images (ICC 0.91 vs 0.29, p < 0.001; Table III).

The ICCs and Pearson’s correlations comparing the different measurements and imaging modalities show that the only plain radiological variable that approaches reliable correlation with the 3D method is the posterior slope of the tibia (Table IV), but even this has a maximum difference of 8.1°; 2D measurements of femoral rotation correlate well with 3D-CT, yet the maximum difference here is 6.2° (Table IV).

Discussion

This study investigates the intra- and interobserver reliability of different methods (radiographs, 2D-CT, 3D-CT) of assessing the position of the components after TKR. Three important findings emerged. First, the measurements of
rotation of the components using 3D-CT were highly reliable with regard to inter- and intra-observer variability. In contrast, the rotational measurements on 2D-CT slices showed variable results and less intra- and interobserver reliability. Secondly, all ICC values for intra- and interobserver measurements of femoral varus-valgus, femoral flexion-extension, tibial rotation, tibia varus-valgus and tibial slope on 3D-CT were highly reliable. Thirdly, the measurements on radiographs showed good intra- and interobserver variability and low or only moderate ICC values for all positions and indicators of orientation. The sole exception was measurements of the sagittal tibial slope, which were highly reliable.

This study has two weaknesses. It was a small study, containing information from only 30 knees. However, the strength of the ICC values in the 3D group and the size of the difference in values gives some confidence that the findings are more widely applicable. We have not validated the 3D method using a standard such as digitised phantoms, which would have further supported the methods and conclusions. However, the focus of this paper is clinical practice, from which the images were obtained, so the data obtained have clinical relevance. The high reliability of the 3D-CT data suggests that there is no major problem with this dataset, nor with this method.

The outcome of TKR depends on a number of details, such as patient-related factors, restoration of the mechanical axis, adequate soft-tissue balancing and appropriate alignment of the components.\cite{1,2,4,6,7,11}

Abnormal varus or valgus alignment has been reported to be a cause of loosening. Abnormal femoral extension or flexion may lead to notching or early loosening owing to gapping of the anterior femoral cortex-prosthesis interface. Rotational malalignment leads to patellar maltracking, anterior knee pain, femorotibial flexion instability, decreased movement and increased polyethylene wear.\cite{25-31}

Higher revision rates have been found in patients with malaligned femoral or tibial components,\cite{1,2,4,6,32,33} and so identifying malalignment is crucial for optimal management of patients with a painful TKR.

A variety of different methods using conventional radiographs or axial 2D-CT images have been used to assess the position of the components after TKR.\cite{2,4,10,20,23,34,35} Most commonly the American Knee Society’s radiological assessment system, which is based on the anatomical axis is used.\cite{23}

However, based on our findings, the inter- and intraobserver variability of plain radiographs is high, indicating low clinical utility and reproducibility. Another major limitation is that although the coronal and sagittal orientation can easily be assessed using plain radiographs, the assessment of rotation of the components is difficult.\cite{4,34} To our knowledge, only Eckhoff et al\cite{10,11} have described a technique for measuring rotation from plain radiographs. However, its use was limited by problems with standardisation of radiographs, and it could only be used with a specific type of TKR.

More recently Berger et al\cite{36} described a technique using axial 2D-CT images and the transepicondylar and posterior prosthetic component axes to assess rotation. They showed that excessive internal rotation of the femoral and tibial components was associated with an increased incidence of patellofemoral symptoms. As in their study, we used the commonly applied epicondylar axis for assessment of the femoral component. This is generally accepted as representing the functional flexion-extension axis of the knee joint.\cite{20,34} The posterior tibial axis, combined with a tangential line to the posterior aspect of the tibial component, was used for assessment of the tibial component.\cite{20,34}

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**Table III.** Comparison of interobserver intraclass correlation coefficient (ICC) values of the different imaging methods (2D, two-dimensional; 3D three-dimensional)

<table>
<thead>
<tr>
<th></th>
<th>ICC</th>
<th>Difference ICC (Fisher’s test)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2D</td>
<td>3D</td>
</tr>
<tr>
<td>2D-femoral rotation - 3D-femoral rotation</td>
<td>0.29</td>
<td>0.91</td>
</tr>
<tr>
<td>Femoral varus-valgus - α</td>
<td>0.65</td>
<td>0.97</td>
</tr>
<tr>
<td>Femoral flexion-extension - γ</td>
<td>0.82</td>
<td>0.97</td>
</tr>
<tr>
<td>Tibial varus-valgus - β</td>
<td>0.70</td>
<td>0.89</td>
</tr>
<tr>
<td>Tibial slope - δ</td>
<td>0.79</td>
<td>0.96</td>
</tr>
</tbody>
</table>

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**Table IV.** Intraclass correlation coefficient (ICC) and Pearson’s correlation for femoral and tibial measurements on different imaging and/or measurement methods (2D, two-dimensional; 3D three-dimensional)

<table>
<thead>
<tr>
<th></th>
<th>Pearson r</th>
<th>ICC</th>
<th>p-value</th>
<th>Mean difference</th>
<th>Minimum difference</th>
<th>Maximum difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>2D-femoral rotation - 3D-femoral rotation</td>
<td>0.52</td>
<td>0.44</td>
<td>0.007</td>
<td>2.5</td>
<td>0.0</td>
<td>6.2</td>
</tr>
<tr>
<td>3D-femoral varus-valgus - α</td>
<td>0.15</td>
<td>0.04</td>
<td>0.405</td>
<td>5.5</td>
<td>0.0</td>
<td>13.7</td>
</tr>
<tr>
<td>3D-femoral flexion-extension - γ</td>
<td>-0.21</td>
<td>negative</td>
<td>-</td>
<td>4.0</td>
<td>0.3</td>
<td>21.6</td>
</tr>
<tr>
<td>3D-tibial varus-valgus - β</td>
<td>0.31</td>
<td>negative</td>
<td>-</td>
<td>2.8</td>
<td>0.0</td>
<td>6.8</td>
</tr>
<tr>
<td>3D-tibial slope - δ</td>
<td>0.59</td>
<td>0.58</td>
<td>&lt; 0.001</td>
<td>2.8</td>
<td>0.2</td>
<td>8.1</td>
</tr>
</tbody>
</table>
2D-CT is an accurate method for determining rotation, but reliable identification of the anatomical landmarks remains the biggest problem.\(^{10,11,20,34}\) Clearly, the visualisation of both the lateral and medial epicondylar landmarks on the same CT slice is dependent on the orientation of the patient’s legs at the time of the CT scan and the width of the CT slices. This major limitation could be partly overcome by using 3D reconstructed CT images for assessment of the component. This does not solve the problem of having reliable anatomical landmarks for orientation, but minimises the inconsistencies.

Based on our findings, we recommend the use of a low-dose 3D reconstructed CT for determining the rotational, sagittal and coronal orientation of the components after TKR to reduce measurement errors. This method is fit for the purpose of describing the position and orientation of the components, whereas neither plain radiographs nor 2D-CT is sufficiently reliable to be effective. For the poorly functioning TKR, this technique will enable the surgeon to describe the accuracy of placement of the components with confidence.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

References