Errors in the identification of the transepicondylar and anteroposterior axes of the distal femur in total knee replacement using minimally-invasive and conventional approaches

A CADAVER STUDY

We have investigated the errors in the identification of the transepicondylar axis and the anteroposterior axis between a minimally-invasive and a conventional approach in four fresh-frozen cadaver knees. The errors in aligning the femoral prosthesis were compared with the reference transepicondylar axis as established by CT.

The error in the identification of the transepicondylar axis was significantly higher in the minimal approach (4.5˚ of internal rotation, SD 4) than in the conventional approach (3˚ of internal rotation, SD 4; p < 0.001). The errors in identifying the anteroposterior axis in the two approaches were 0˚ (SD 5) and 1.8˚ (SD 5) of internal rotation, respectively (p < 0.001).

Correct rotational alignment of the femoral prosthesis in total knee replacement (TKR) is important, in order to avoid patellar maltracking1-6 and condylar lift-off.7 Four different methods are commonly used to determine the rotation of the femoral component during the operation. These include using the transepicondylar axis,8-12 the anteroposterior (AP) axis,1,13,14 the posterior condylar line3 and balancing the flexion-gap.8,15,16 All have been studied in detail in the context of TKR through a conventional incision.

The use of minimal incision surgery in TKR has gained popularity in the past few years. This is said to give an improved cosmetic result and potentially easier rehabilitation in the early post-operative period.17-20 However, because the exposure is limited, there are concerns about precision in the identification of anatomical landmarks, including those used for rotational alignment of the femoral component.21

The transepicondylar axis is identified by palpating the two femoral epicondyles. Many surgeons align the femoral component in parallel to this axis,8-12 but some prefer to refer to the AP axis of the distal femur,1,13,14 which is a line joining the deepest point of the trochlea and the highest point of the intercondylar notch. The rotation of the femoral component is set perpendicular to this line. The limited exposure in the minimal approach may render location of these anatomical landmarks difficult. The question is whether the accuracy in the identification of these two axes, and hence that in the determination of the correct rotation of the femoral prosthesis, is then jeopardised. To our knowledge, there has been no previous study which has addressed this.

Our aim therefore was to compare the potential errors in the identification of both these axes of the distal femur in the minimal and conventional approaches. We used cadaver knees. The errors in the rotational alignment of the femoral prosthesis were compared with a reference transepicondylar axis established by CT.

Patients and Methods
We studied four sections of fresh-frozen cadaver legs with intact knees and ankles. There was no evidence of patellofemoral dysplasia or advanced osteoarthritis of the knee in any of the specimens. Each limb was mounted with the knee in 90˚ of flexion. The knee was approached anteriorly as in a standard TKR.

The joint was first approached using a skin incision of approximately 10 cm (Fig. 1). A mini quadriceps-tendon splitting technique was used.21 A comparison of the features of the minimally-invasive and conventional approaches is shown in Table I. The transepicondylar axis was defined as a line joining the two femoral epicondyles, which were identified by palpation. The AP axis was identified by visual inspection of the deepest part of the
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Trochlea and the highest point of the intercondylar notch. Repeat identification of the two axes was performed sequentially 25 times by two orthopaedic surgeons in the same setting. One of the observers (CHY) was a trainee. The other (WPY) was experienced in performing TKR using both conventional and computer-navigation techniques. The method of choice of the two observers in aligning the rotation of the femoral component in \textit{in vivo} TKR was the balanced flexion gap method. The transepicondylar and AP axes of the distal femur were identified intra-operatively as ancillary references in aligning the rotation of the femoral prosthesis. The spatial orientations of these axes were recorded using an optical computer-navigation system (VectorVision CT-free Knee 1.1; BrainLAB AG, Munich, Germany).

The incision was then extended to approximately 20 cm and a conventional medial parapatellar approach performed (Table I). The two axes were again identified 25 times sequentially by the two surgeons in the same setting.

The spatial orientations of these axes were stored using the optical computer-navigation system.

CT of the entire leg was performed using a 16-detector CT scanner (LightSpeed 16, GE Healthcare, Milwaukee, Wisconsin). Each cadaver leg was placed with its long axis along the length of the scanning couch. The scanning parameters used were 120 kV, 9 mA, 0.6 mm slice collimation, 512 $\times$ 512 matrix and a bone algorithm with no gantry tilting. The images were loaded into a computer workstation (Advantage Workstation 3.1; GE Healthcare). The medial and lateral femoral epicondyles were identified in the axial CT images by six independent observers (four orthopaedic surgeons and two radiologists) on two separate occasions which were at least one week apart. The means of these data were used to calculate the reference transepicondylar axis. The errors in the identification of this and the AP axis of the distal femur in both approaches were calculated by comparing the data recorded by the navigation system with the references established by CT.

<table>
<thead>
<tr>
<th>Table I. Technical criteria for the minimally-invasive and conventional approaches</th>
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<tr>
<td>Minimally-invasive</td>
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<tr>
<td>Length of incision (cm)</td>
</tr>
<tr>
<td>Position of patella</td>
</tr>
<tr>
<td>Splitting of quadriceps tendon</td>
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<tr>
<td>Position of knee during registration</td>
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</tbody>
</table>

Fig. 1a

Photographs showing the different amount of exposure using a) a minimally-invasive and b) a conventional approach.
Statistical analysis. The null hypothesis stated that there was no difference in the identification of both the axes of the distal femur using the computer-navigation technique between the two approaches in a cadaver knee. This was tested by use of the independent t-test. The variations of the errors in both approaches were compared with those of the CT data using the analysis of variance (ANOVA). Statistical significance was assumed if \( p \leq 0.05 \). The interobserver differences in the identification of these two lines were recorded. Potential outliers were defined as a difference of more than 5˚ in the identification of these two axes.

Results

Three cadaver specimens were of the right knee with one of the left.

Transepicondylar axis. The mean errors in the identification of the transepicondylar axis in the minimal and conventional approaches were 4.5˚ (SD 4) and 3˚ (SD 4) of internal rotation, respectively. The error in identifying the axis in the minimal approach was significantly higher than that in the conventional approach (independent t-test, \( p < 0.001 \); Fig. 2). The details of the errors in the identification of the axis in the four specimens are shown in Figure 3. Using the minimal approach, the range of the values of the error was between a minimum of 7˚ in specimen 1 and a maximum of 15˚ in specimen 4. By contrast, the error ranged between 6˚ in specimen 2 and 9˚ in specimen 4 when the axis was identified by the conventional approach.

There was no significant difference between the two observers when the axis was identified using both the minimal (independent t-test, \( p = 0.394 \)) and conventional approaches (independent t-test, \( p = 0.468 \), Table II and Figure 4). The mean differences between the two observers were only 0.5˚ (SD 0.6) in both approaches.

Anteroposterior axis. The mean error in the identification of the AP axis across all specimens was 0˚ of internal rotation (SD 5) using the minimal and 1.8˚ (SD 5) using the conventional approach (Fig. 5). The details of the error in the identification of this axis in the four specimens are shown in Figure 3. With the minimal approach, the error ranged between a minimum of 6˚ in specimen 4 and a maximum of 21˚ in specimen 2. The range of the error was between 8˚ in specimen 4 and 17˚ in specimen 1 when the axis was identified using the conventional approach.

There was a significant difference between the two observers when the axis was identified using both the minimal (independent t-test, \( p < 0.001 \)) and conventional approaches (independent t-test, \( p = 0.009 \), Table II and Fig. 4).

Discussion

Many surgeons refer to the transepicondylar axis in determining the rotational alignment of the femoral component. However, because of the thick soft tissue covering the two epicondyles and the inconspicuous morphology of the medial epicondyle, there is a potentially high margin for error which will affect the rotational alignment.\(^{22-27}\)

Whiteside and Arima\(^1\) and Arima et al\(^{14}\) first described the use of an AP axis of the distal femur as an alternative method of defining the rotation of the femoral prosthesis. The prosthesis should be aligned perpendicular to this axis (the Whiteside line). The benefit from alignment with reference to this axis is optimal patellar tracking.\(^1\)
In order to carry out a minimal approach successfully, there was a need to modify the operative technique and the surgical instruments used for the conventional procedure.\textsuperscript{17,18,20} Many surgeons have found identification of the two femoral epicondyles difficult in a small wound and some have elected to use the AP axis as a reference.\textsuperscript{17,18}

However, the question remained as to whether identification of the Whiteside line is also affected by the limited exposure in the minimal approach.

In identifying the transepicondylar axis we found that the use of the minimal approach led to a significant increase in both the mean error and the number of outliers (SD > 5°).

With the AP axis precision was not jeopardised by a limited approach. This was probably because the two landmarks used were visually identified and could be seen clearly in both approaches (Fig. 1). Our results even suggested that the precision of the identification was higher in the minimal approach (independent \(t\)-test, \(p < 0.001\)), but because of the small number of cadavers studied and observers involved, they should be interpreted with extreme caution.

There was a tendency for both the axes to be identified in an internally rotated direction (Figs 2 and 5). The correct rotational alignment of the femoral prosthesis in TKR is important for patellar tracking\textsuperscript{1-5} and in balancing the flexion gap. If the axial alignment is not accurate patellofemoral complications may be associated with incorrect rotation of the femoral and tibial components.\textsuperscript{5,28}

### Table II. Amount of errors in the identification by the surgeons of the transepicondylar axis and anteroposterior axis of the distal femur as compared with the data acquired by CT

<table>
<thead>
<tr>
<th></th>
<th>Minimal*</th>
<th>Conventional</th>
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<tbody>
<tr>
<td>Transepicondylar axis</td>
<td></td>
<td></td>
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<tr>
<td>Surgeon 1</td>
<td>4.7˚ IR (SD 4)</td>
<td>3.2˚ IR (SD 5)</td>
</tr>
<tr>
<td>Surgeon 2</td>
<td>4.2˚ IR (SD 4)</td>
<td>2.7˚ IR (SD 4)</td>
</tr>
<tr>
<td>p-value\textsuperscript{†}</td>
<td>0.394</td>
<td>0.468</td>
</tr>
<tr>
<td>Anteroposterior axis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surgeon 1</td>
<td>1.6˚ IR (SD -5)</td>
<td>2.7˚ IR (SD 5)</td>
</tr>
<tr>
<td>Surgeon 2</td>
<td>1.5˚ ER (SD -4)</td>
<td>1˚ IR (SD 5)</td>
</tr>
<tr>
<td>p-value\textsuperscript{†}</td>
<td>&lt; 0.001</td>
<td>0.009</td>
</tr>
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</table>

* IR, internal rotation; ER, external rotation
† independent \(t\)-test
proper tracking of the patella, it is important to avoid internal rotation of the femoral component. Slight external rotation of the femoral component is considered to optimise patellar tracking. Patellar maltracking is more likely to occur when the femoral and tibial prostheses are implanted in a combined internal rotation of more than 7°. If an error of more than 5° of internal rotation is defined as unacceptable in rotational alignment of the femoral component, 43% of the transepicondylar axes (49% in the minimal and 38% in the conventional approach) and 23% of the AP axes (16% in the minimal and 30% in the conventional approach) fall in this outlier zone. This malrotation could lead to problems in patellar tracking, especially if combined with a malrotation of the tibial component.

The range of the error and the SD in all specimens were extremely large. The experience of the observers may have been one of the potential reasons for this finding. However, this observation is in keeping with the results of recent studies performed using conventional incisions, both in vitro and in vivo. Siston et al reported a range of error of up to 27° in a cadaver experiment involving 11 observers. Jenny and Boeri found that the maximum range of intra- and interobserver errors was 15° for both when the transepicondylar axis was identified by two observers three times in a series of 20 TKRs. Yau et al observed a maximum range of error of up to 28° in the transepicondylar and 32° in the AP axes in a series of TKRs performed by a single surgeon with image-free computer navigation.

There were significant differences between the two observers in identifying the AP axis of the distal femur. One consistently identified it in a more externally rotated orientation (Table II and Figure 4). A similar observation was reported by Siston et al. It is reasonable to suggest that the use of the AP axis as a reference for aligning the femoral prosthesis should preferably be performed by surgeons familiar with this technique. However, the small sample size of only two observers made it difficult to conclude if there would be significant interobserver errors overall.

There were several limitations in our study. Most of the specimens did not have end-stage osteoarthritis. The extent of osteophytosis in the trochlear region was minimal. In advanced OA of the knee, it is not uncommon to observe large osteophytes in the trochlea and the intercondylar notch distorting the normal anatomy and causing difficulty in defining the AP axis. Thus, our study probably underestimated the potential error in defining this axis in patients suffering from advanced end-stage osteoarthritis.

Also, the collection of the data of the rotational axes of both the minimal and conventional approaches was carried out at the same time point. There was concern about the
Errors in the identification of the anteroposterior axis of the distal femur using a) the minimally-invasive and b) the conventional approaches. The vertical lines indicate the outliers outside 5˚ internal rotation and 5˚ external rotation.

repeatability of the data if the experiment was performed on two different occasions. The purpose of collecting all the data at one time was to minimise the potential error which could be introduced during repeated registrations in computer-navigation-assisted TKR. For image-free navigation systems, a co-ordinate system specific to the anatomy of the studied specimen needs to be built before acquiring additional data for the rotational axes by a process called ‘registration’. The landmarks registered include, but are not limited to, the centre of the femoral head, the centre of the proximal tibia, and the medial and lateral malleoli. This co-ordinate system can be shared if the collection of the data is done in the same time point. A repeated registration of the co-ordinate system will be required if data are collected on two separate occasions. This may potentially introduce further error in the experiment.

We found that the precision in the identification of the AP axis of the distal femur was not jeopardised by the use of a minimal approach, although the range of the errors was extremely wide. However, the use of this approach led to an increase in error in the identification of the transepicondylar axis and there was a higher percentage of surgical outliers of more than 5˚ of internal rotation when the transepicondylar axis was identified.

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


