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The rotation of the PE component in a mobile bearing total knee arthroplasty compensates the malrotation of the fixed tibial base plate

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Abstract

Purpose:
The purpose of this Multi Detector Computed Tomography (MDCT) study is to evaluate if a mobile TKA can correct the malrotation of the fixed tibial base plate in a mobile (PSM) Total Knee Arthroplasty (TKA). The premise is that the mobile PE has the ability to correct the malrotation of the fixed tibial base plate. Various authors reported that 0.4% to 49% of all patients have Anterior Knee Pain (AKP) after TKA. Internal malrotation of the TKA components have been described to be a major reason for AKP. The null hypothesis of this study is that the rotation of the mobile PE is not correlated with the malrotation of the fixed tibial base plate.

Methods:
Patients with a PSM TKA without AKP were retrospectively enrolled. Questionnaires, radiography (standard long leg and patella skyline radiographs) and MDCT scans measuring the femoral-, tibial- and polyethylene component rotation were obtained.

Results:
In 10 patients the average combined femoral and tibial base plate rotation was 2.1° external rotation. We found a significant correlation coefficient of 0.85 (p<0.001) between the rotation of the mobile PE and the fixed tibial base plate.

Conclusion:
This pilot study demonstrated in a group of patients without AKP the ability of the mobile PE to correct the malrotation of the fixed tibial base plate. This ‘forgiving’ compensating feature may help prevent AKP, but this remains to be proven. Greater attention to and understanding of AKP will lead to pain relief and overall patient satisfaction after TKA.

Keywords: Anterior Knee Pain; Malrotation; Total Knee Arthroplasty; Internal rotation
Introduction

Total Knee Arthroplasty (TKA) has become the standard treatment for patients with various disabling disorders of the knee\(^1\,\,3\,\,21\,\,30\,\,33\). Improvements in prosthetic design, instrumentation and surgical techniques have resulted in good to excellent patient satisfaction and long-term survival rates of greater than 90% to 95%\(^3\,\,12\,\,27\,\,31\,\,24\,\,32\). Despite the success various authors have reported that a large proportion of all TKA patients, from 0.4%-49%, experience Anterior Knee Pain (AKP)\(^1\,\,4\,\,6\,\,10\,\,12\,\,13\,\,18\,\,19\,\,24\,\,27\,\,28\,\,31\,\,33\). This pain reduces patient’s quality of life and is reported as one of the main reason for early revision\(^4\,\,6\,\,18\,\,19\). Over the years different reasons for Anterior Knee Pain (AKP) have been postulated: malpositioning or malrotation of the components\(^4\,\,6\,\,18\,\,19\,\,34\), prosthesis design\(^12\,\,24\,\,27\,\,29\,\,32\), resurfacing the patella\(^3\,\,10\,\,17\,\,24\), wear\(^30\), referred pain\(^33\), patella instability after TKA\(^25\), soft tissues\(^14\,\,33\) and patient characteristics\(^11\).

Proper axial alignment has been recognized as an important factor influencing the success of TKA and preventing AKP\(^4\,\,6\,\,7\,\,18\,\,19\). Various authors have indicated that patellofemoral complications, in the absence of axial malalignment, are associated with improper rotation of the femoral and/or tibial components\(^4\,\,6\,\,7\,\,18\,\,19\). Berger et al linked combined component internal rotation (the sum of internal rotation of the femoral component and internal rotation of the tibial component) of a fixed bearing TKA to patellar tilt, subluxation, dislocation and patellar component failure\(^6\). Barrack et al reported a correlation between AKP and component rotation following a fixed bearing TKA, and concluded that patients with combined component internal rotation were more than five times as likely to experience AKP compared to those with combined component external rotation\(^4\). In their study, Nicoll and Rowley indicated a threshold value of 9\(^\circ\) internal malrotation of the tibial component before patients are expected to experience pain\(^26\). All three studies were performed with a fixed bearing TKA\(^4\,\,6\,\,26\). Mobile bearing TKA are thought to correct the malrotation of the tibial component base plate by compensating rotation of the PE component. Since this is debated, the purpose of our study is to test the null hypothesis stating that rotation of the mobile PE bearing is not correlated with the malrotation of the fixed tibial base plate.
Patients and Methods

A study of 10 patients with a well functioning mobile bearing TKA and no complaints of AKP was conducted. Patients were randomly selected from the NexGen patient population. As no data was available for a power analysis, the study was originally designed and approved as a pilot with 10 patients. The Institutional Review Board approved the study protocol and patients gave informed consent. The patients in the study group received their TKA from one of three experienced knee surgeons (more than 10 years experience as a knee surgeon). All patients were treated according to the same intra and post-operative protocol. The prosthesis used was the NexGen Posterior Stabilized Mobile TKA (Zimmer, Warsaw, IN, USA). Exclusion criteria were AKP or any unexplained pain that a patient experienced prior to or at the time of follow-up. At the outpatient clinic standard physical examination of the knee was performed, and standard long leg, patella skyline radiographs and Multidetector CT (MDCT) scans were obtained. To include the subjective aspect of pain, patients were specifically asked if knee pain was present and how severe the pain was the last 30 days. This was measured by use of a Visual Analog Scale (VAS) ranging from 0 (no pain) to 100 (severe pain) \[9\]. Additionally, the patients filled in the Oxford 12 item knee questionnaire with a score of 12 (no complaints) to 60 (severe complaints) \[16\], the American Knee Society Score (AKSS) both knee and function score ranging from 0 (worse) to 100 (best) \[20\], and the SF 36 health related questionnaire, thirty-six questions reflect eight dimensions of functioning. The data was entered in a database and the statistical analysis was performed using SPSS 20.0 (SPSS Inc, Chicago, IL). The results were checked for inconsistencies and errors. Continuous data were checked for normality visually and by use of the Shapiro-Wilk test and were described as means and Standard Deviations (SD) or medians with accompanying ranges in case of skewed distributions. The reliability of the measurements performed by the two observers, SB and MH, was determined with the use of the Intraclass Correlation Coefficient (ICC). A p-value <0.05 was considered statistically significant.

**MDCT acquisition**

With the use of a multi-slice spiral CT scanner ‘Brilliance’ (Philips, Eindhoven,
the Netherlands), with scanning parameters 120Kv, 120mA, 0.75sec rotation time and 3 mm image thickness with the “BoneKernel” setting, data acquisition was performed is 3D scanner can obtain higher and better measurement accuracy than the previously used CT-scanners in similar studies. The method described by Berger et al and Barrack et al was adapted [6]. The radiographic measurements of the CT-images were analysed with OsiriX® measurement program and were evaluated by two observers, SB and MH. The results were subsequently checked for inconsistencies and errors by MM.

Measurements:

Femoral component rotation

The femoral component rotation was determined by measuring the prosthetic posterior condylar angle. The Posterior Condylar Line (P.C.L) in the axial CT image (figure 1, line 1) is tangential to the medial and lateral posterior condylar surfaces. The Surgical Epicondylar Axis (S.E.A) (figure 1, line 2) connects the lateral epicondylar prominence and the medial sulcus of the medial epicondyle. The posterior condylar angle is the angle between these two lines [6]. The normal value for the posterior condylar angle is 0.3°(±1.2°) internal rotation for females and 3.5°(±1.2°) internal rotation for males relative to the SEA [6]. This rotation was deducted from the measured condylar angle to obtain the (mal) rotation value.

Figure 1. Femoral component rotation as measured on a coronal CT section.

The Posterior Condylar Line (P.C.L.) is tangential to the medial and lateral condylar surface (line 1). The Surgical Epicondylar Axis (S.E.A.) connects the lateral epicondylar prominence and the medial sulcus of the medial epicondyle (line 2). The angle between these two lines is the posterior condylar angle(P.C.L.).
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Tibial base plate rotation

Tibial component rotation was determined from four axial slices, one just below the tibial base plate, one at the level of the base plate, one at the level of the PE and one at the level of the most prominent part of the tibial tuberosity. The geometric centre is found by connecting the lines of the ellipse of the best fit just below the tibial base plate (figure 2a, red circle). A line was drawn parallel to the posterior tibial base plate. From this line a perpendicular line was drawn through the geometric centre (figure 2b). The tibial tubercle axis was determined by transposing the geometric centre to the image with the most prominent point of the tibial tubercle (figure 2c, red line). The angle between the tibial tubercle axis and the line perpendicular to the posterior borderline of the tibial base plate was determining the tibial component rotation (figure 2d). The normal rotation value of 18° (±2.6°) internal rotation for the tibial component was deducted from the line connecting the middle of the tibial tubercle en the geometric centre (figure 2e). The angle that remained determined the amount of internal or external rotation (figure 2f).

Case example; tibial rotation:

Figure 2 illustrates a case example of tibial component rotation of a right knee after the geometric centre of the tibial base plate was obtained (red circle, figure 2 a). A line was drawn parallel to the posterior tibial base plate. From this line a perpendicular line was drawn through the geometric centre (figure 2 b). A line is drawn from the geometric centre to the most prominent point of the tibial tubercle (figure 2 c). The angle between the tibial tubercle axis and the line perpendicular to the posterior tibial base plate measures 26° internal rotation, this is called the tibial rotation angle (green angle, figure 2 d). The normal value for this angle is 18° internal rotation (yellow angle, figure 2 e), this has to be subtracted from 26° resulting in 8° internal malrotation (red angle, figure 2 f).
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**Polyethylene bearing rotation**
The polyethylene bearing rotation was determined by measuring the angle between the polyethylene posterior borderline and the tibia tubercle axis. This angle was obtained by adding the angle formed by the polyethylene posterior borderline and the axis of the tibial base plate posterior borderline to the angle of the tibial base plate formed with the tibia tubercle (figure 3b). The combined tibial component rotation was measured by adding the polyethylene component rotation to the tibial base plate rotation.

**Combined component rotation**
As defined by Berger et al. [6] the combined component rotation was determined by adding the femoral component rotation angle and the tibial base plate component rotational angle for each patient. Internal rotation was added as a negative (-) angle and external rotation was added as a positive (+) angle.

**Conventional Radiology**
The standard long-leg X-ray was used to determine the mechanical axes of each leg. Following Bindelglass the skyline view was used to measure the amount of patellar tilt and/or subluxation [8]. Lateral tilt and subluxation were defined as positive, and medial tilt and subluxation were defined as negative [8].

**Results**
The mean age of the patients in the study group at enrolment was 74 years (SD 6.9). The mean length of follow-up was 69 months (SD 11). The ratio between female and male was 7:3.
The mean femoral component rotation in the study group was 0.95° (SD 2.4°) external rotation. The mean tibial base plate rotation in the study group was 1.2° (SD 10°) external rotation. The rotation of the polyethylene mobile bearing was 1.2° (SD 6.5°) external rotation. The mean combined component rotation was 2.1° (SD 11°) external rotation (Table 1).
Figure 3. Angle between mobile PE bearing and posterior tibial base plate illustrates a case example of the same right knee, measuring the difference between the mobile PE and the posterior tibial base plate. In figure 3 a the posterior edge of the mobile PE is drawn (blue line). Afterwards this line is transposed to the line of the posterior tibial base plate (figure 3 b) (this is the same red line as figure 2 b). The measured angle of 13° external rotation shows the correction of the mobile bearing PE. This angle can be measured as the line between tibial tubercle axis and the line perpendicular to the posterior line of the mobile PE (blue line figure 3 c). The normal value for this angle is 18° internal rotation (yellow angle, this is the same angle as figure 2 e), this has to be subtracted and measures 5° external rotation (blue angle, figure 3 d). The difference between the red angle, showing 8° internal rotation, and the blue angle showing 5° external rotation can be seen as the difference between a "mobile" (blue angle) and a "fixed bearing" (red angle) (figure 3 e).
The mean mechanical axis in the study group was 0.9° valgus (range 3.1° varus to 9.5° valgus). Tangential radiographs and skyline view measurements resulted in a mean patellar tilt within the group of 1.4 lateral tilt, with a range of -3.1° to 5.3°. The patellar subluxation in the study group was 1 mm lateral, with a range of 0 to 7 mm. There was a statistically significant correlation coefficient of 0.85 (p<0.001) - between the rotation of the mobile PE and the fixed base plate of the tibial component (Figure 4; Table 2). In 5 out of 6 cases with internal rotation the PE corrected the malrotation. In 3 patients with excessive external rotation the PE corrected with internal rotation (Table 1).

Table 1: Detailed rotation:
Most important finding, red column, showing what the Polyethylene rotation does compared with the Tibial Component Rotation

<table>
<thead>
<tr>
<th>Subject number</th>
<th>Femur component rotation</th>
<th>Tibial component rotation</th>
<th>PE component rotation</th>
<th>PE component Rotation - Tibial Component Rotation</th>
<th>component rotation (femur + tibia)</th>
<th>component rotation (femur + PE)</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>-1.5</td>
<td>-6.7</td>
<td>-2.3</td>
<td>4.4</td>
<td>-8.2</td>
<td>-3.8</td>
</tr>
<tr>
<td>2</td>
<td>0.7</td>
<td>3.3</td>
<td>-4.4</td>
<td>-7.7</td>
<td>4.0</td>
<td>-3.7</td>
</tr>
<tr>
<td>3</td>
<td>6.7</td>
<td>14.3</td>
<td>16.3</td>
<td>2.0</td>
<td>21.0</td>
<td>23</td>
</tr>
<tr>
<td>4</td>
<td>-0.6</td>
<td>-3.0</td>
<td>-3.6</td>
<td>-0.6</td>
<td>-3.6</td>
<td>-4.2</td>
</tr>
<tr>
<td>5</td>
<td>-0.7</td>
<td>-8.3</td>
<td>-0.5</td>
<td>7.8</td>
<td>-9.0</td>
<td>-1.2</td>
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<tr>
<td>6</td>
<td>-0.1</td>
<td>-7.1</td>
<td>-0.8</td>
<td>6.3</td>
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<tr>
<td>7</td>
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<td>-3.5</td>
<td>0.0</td>
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<td>-3.6</td>
</tr>
<tr>
<td>8</td>
<td>3.1</td>
<td>-8.0</td>
<td>3.2</td>
<td>11.2</td>
<td>-4.9</td>
<td>6.3</td>
</tr>
<tr>
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<td>18.2</td>
<td>9.4</td>
<td>-8.8</td>
<td>20.3</td>
<td>11.5</td>
</tr>
<tr>
<td>10</td>
<td>-0.1</td>
<td>12.8</td>
<td>9.9</td>
<td>-2.8</td>
<td>12.7</td>
<td>9.8</td>
</tr>
<tr>
<td>Mean</td>
<td>0.9</td>
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<td>2.4</td>
<td>1.2</td>
<td>2.2</td>
<td>3.3</td>
</tr>
<tr>
<td>SD</td>
<td>2.4</td>
<td>10.2</td>
<td>7.1</td>
<td>6.5</td>
<td>11.7</td>
<td>9.1</td>
</tr>
</tbody>
</table>

Table 2: Bivariate correlation analysis (Spearman’s rho) of the PE-rotation relative to the base plate and the rotation of the base plate.

<table>
<thead>
<tr>
<th>Tibia component rotation angle</th>
<th>Correlation</th>
<th>P-value</th>
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<tbody>
<tr>
<td>Polyethylene</td>
<td>rho = -0.85;</td>
<td>p&lt;0.001</td>
</tr>
</tbody>
</table>
The inter- and intraobserver reliability coefficient (ICC) for the component rotation was 0.98 (p < 0.001) and 0.98 (p < 0.001) respectively. The inter- and intraobserver reliability coefficient (ICC) for the tibial component rotation was 0.97 (p < 0.001) and 0.99 (p < 0.001) and PE rotation was 0.76 (p < 0.027) and 0.99 (p < 0.001) respectively. The median Knee Society Score – knee score – was 97.0 points (range 58-100) and the Knee Society Score – function score – was 70.0 points (range 10-100). The VAS showed a median score of 5 points (range 0-60). Furthermore, the median score for physical functioning and bodily pain were 55 and 52 points respectively. Finally, the Oxford 12-item knee questionnaire had a median score of 17.5 points (range 14-36) (Table 3). No significant correlations were observed between the rotations of the components and any of the clinical scores.
Table 3 Patient reported outcome measures: VAS= visual analog scale for pain; Q1= physical functioning; Q2= role limitation due to physical problems; Q3= role limitations due to emotional problems; Q4= social functioning; Q5= mental health; Q6= energy vitality; Q7= pain; Q8= general health perception.

AKSS, American Knee Society Score

<table>
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<th>Characteristics</th>
<th>Median</th>
<th>Range</th>
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<td>Study group (n=10)</td>
<td></td>
<td></td>
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<tr>
<td>VAS</td>
<td>5</td>
<td>0-60</td>
</tr>
<tr>
<td>Oxford 12- item questionnaire</td>
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<td>14-36</td>
</tr>
<tr>
<td>SF-36 Q1</td>
<td>55</td>
<td>25-90</td>
</tr>
<tr>
<td>SF-36 Q2</td>
<td>37.5</td>
<td>0-100</td>
</tr>
<tr>
<td>SF-36 Q3</td>
<td>100</td>
<td>0-100</td>
</tr>
<tr>
<td>SF-36 Q4</td>
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<td>50-100</td>
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<td>SF-36 Q5</td>
<td>84</td>
<td>68-96</td>
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<td>SF-36 Q6</td>
<td>62.5</td>
<td>35-90</td>
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<td>SF-36 Q7</td>
<td>52</td>
<td>22-100</td>
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<td>SF-36 Q8</td>
<td>69.5</td>
<td>35-97</td>
</tr>
<tr>
<td>AKSS Knee score</td>
<td>97.0</td>
<td>58-100</td>
</tr>
<tr>
<td>AKSS Function score</td>
<td>70.0</td>
<td>10-100</td>
</tr>
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</table>

Discussion

This study showed that the PE-component of the mobile bearing TKA corrects for malrotation of the fixed tibial base plate. When the tibial base plate is internally rotated, the PE bearing will turn more towards external rotation, bringing the rotation of the combined components back towards neutral position. In addition, greater malrotation of the tibial base plate was not significantly correlated with physical function in our study population.

Rotational alignment of the components of the TKA remains a topic of debate. Bargren emphasized the importance of tibial component rotation, showing that knee dislocation attributed to a tibial base-plate malrotation [2]. Different authors suggested that malrotation is an important issue but visualization techniques, to measure this malrotation, were not accurate enough. Using CT scans to visualize malrotation after TKA Berger et al reported that combined component internal rotation is associated with lateral tracking followed by patellar tilting and potential patellar subluxation [6]. In a case of severe malrotation a dislocation and component failure were reported [6]. Barrack et al also used CT scans to study the influence of malrotation on AKP [4]. They showed that patients with a combined internal rotation had a relative risk of AKP, which was five times higher than those without combined component internal rotation [4]. It is thought that
a femoral component placed in internal rotation shifts and tilts the patella medially and this can have a negative influence on AKP[4,6,18-19]. The results found in our study with respect to the PE-component rotation and malrotation of the fixed tibial base plate are in concordance with the previous reported literature[15,22-23]. Using a mobile bearing knee Komistek et al showed that in flexion the PE bearing rotation could vary from 8.5 to 9.8 degrees and in extension from 1.9 until 1.0 degrees at 3 and 15 months[23]. This is confirmed by Kessler in a cadaver study, that in the presence of femoral component malrotation, a mobile bearing could help maintain axial rotational alignment of the mobile PE bearing with the femoral component[22]. They indicated that the PE bearing could rotate up to 21 degrees[22]. However, they suggested that the PE bearing has minimal influence in reducing patellofemoral maltracking induced by femur malrotation due to the patella following the trochlear groove and the attachment to the tibial tubercle[22]. Garling et al analysed a mobile bearing PS knee and found limited movement of the PE bearing compared to the tibial component[15]. The femur component showed more axial rotation than the mobile bearing indicating that the femur component was sliding on the PE bearing[15].

Although this study did not reveal a significant relationship between malrotation and physical function in the absence of AKP, it is thought that avoiding malrotation plays an important role in preventing AKP[4,6,18-19,26]. A complicated issue associated with preventing malrotation is finding the ‘perfect’ placement of the components. It is unclear what the most ideal alignment for the femoral and tibial components is[4,6,18-19,26,34]. Four different techniques to determine correct rotational placement of the femur component are commonly used, i.e. posterior condylar line, anterior-posterior line or Whitesides line, surgical epicondylar axis and the gap technique. Of these four techniques the surgical epicondylar axis is the only technique that can be measured post operatively. On the tibial side intra-articular landmarks include the tibial tubercle, the patellar tendon and the posterior tibial axis. Additionally extra-articular landmarks (the transmalleolar axis of the ankle and the metatarsus of the foot) can be used to accurately place your tibial component.

Preventing malrotation could also have an impact on reducing health costs and improving patient’s well being since AKP is said to be one of the main reasons for early revision[4,6,12-13,18-19,26,31,33]. Mockford and Beverland reported that 0.4% of their patients had a secondary patella resurfacing in a study population of...
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2950 mobile bearing TKA\cite{24}. In a study by Stiehl et al 4743 patients treated with a mobile bearing TKA only 2 had a secondary resurfacing. They reported 0.5% patella related failures (AKP was not mentioned)\cite{32}.

This study should be considered in light of its shortcomings, including that the results were limited to 10 patients and only one type of mobile bearing was used. Another limitation was that the measurements of the tibial and femoral components were carried out using the technique described by Berger et al\cite{6-7}. Although this is the most used and reported technique in the literature regarding component rotation, there are some concerns. The result of the measured component rotation is dependent on the chosen location of the geometrical centre. All measurements, including anatomical landmarks, are influenced by the interpretation of the observer. This remains a concern despite the good inter- and intraobserver reliability of the measurement of the component rotation. A further concern is the fact that the reference values used, the ones described by Berger, are from 75 embalmed anatomic specimen femurs\cite{7}. Of these 75 specimens, the gender was known in 35 femurs and unknown in 40\cite{7}. Nevertheless, the CT technique described by Berger can be seen as the gold standard for measuring (mal)rotation after a TKA today\cite{4,6,26}.

Although this technique has its imperfections it can be useful in detecting patients with a clinically relevant malrotation after their TKA\cite{18-19}. Future studies may address the impact of different types of mobile bearing TKA. Patellofemoral complications, including AKP, seem to be rare in some types of mobile bearing TKA \cite{24,32}, especially in the first years after placement \cite{12,29}. A small but clinically significant short term advantage was reported, regarding pain, in favour of the mobile bearing design as compared the fixed bearing design\cite{29}. In the longer follow-up of this study, the reported difference was no longer seen\cite{5}. Kim et al described more pain in a fixed bearing knee at a mean follow-up of 2.6 years \cite{31}. Similarly, findings in a previous study, support the finding that the posterior stabilized mobile (PSM) bearing TKA demonstrates a clinically significant reduction in the reported incidence of AKP compared to a posterior stabilized fixed bearing TKA (PS)\cite{12}. The longer follow-up study does not support this difference anymore\cite{13}. Others researchers did not report any difference between a fixed and a mobile bearing\cite{1,27,31,33}. 
Conclusion

This pilot study demonstrated in a small group of patients the ability of the mobile PE to correct the malrotation of the fixed tibial base plate. This ‘forgiving’ feature may help to prevent anterior knee pain, but this remains to be proven in a prospective study. Greater attention to and understanding of anterior knee pain will lead to pain relief and overall patient satisfaction after TKA.
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References


