Chapter 6

Mobile-bearing kinematics change over time
A fluoroscopic study in rheumatoid arthritis patients

Nienke Wolterbeek¹, Eric H. Garling¹, Bart J.A. Mertens², Edward R. Valstar¹,³, Rob G.H.H. Nelissen¹

¹Department of Orthopaedics, Leiden University Medical Center
²Department of Medical Statistics and Bioinformatics, Leiden University Medical Center
³Department of Biomechanical Engineering, Delft University of Technology

Clinical Biomechanics 2009; 24:441-445
Abstract

In a previous fluoroscopy study the motion of a mobile-bearing total knee prosthesis was evaluated. That study showed that the axial rotation of the insert was limited. Three possible explanations are given for the limited rotation: low conformity between the femoral component and insert, the fixed anterior position of the insert-tibia pivot point leading to impingement and fibrous tissue formation. While the effect of the conformity on the axial rotation will not change over time, the effect of impingement and fibrous tissue is likely to increase, and thereby further decreasing the axial rotation.

In order to accurately assess changes in axial rotation over time in a mobile-bearing total knee prosthesis rheumatoid arthritis patient group, patients were evaluated 8 months and 3 years postoperatively using fluoroscopy.

In comparison with the 8 months evaluation, the rotation of the femoral component (range: $-10.8^\circ$ to $2.8^\circ$) and the insert (range: $-5.9^\circ$ to $1.4^\circ$) were further limited at 3 years (respectively, $-5.9^\circ$ to $4.9^\circ$ and $-2.8^\circ$ to $5.4^\circ$). Patterns of axial rotation for the femoral component and insert varied considerably between the trials within patients while at the 8 months evaluation no significant difference within patients was observed.

This study shows the importance of re-evaluating knee kinematics over time. The axial rotation of both the femoral component as the insert decreased over time, indicating a kinematic change caused by intrinsic factors. The decline in rotation of the insert could be explained by increased impingement and the formation of fibrous tissue.
6.1 Introduction

During the last decade, mobile-bearing (MB) knee prosthesis designs have become increasingly popular. In theory, the mobility of a MB permits increased articular conformity between the femoral and tibial components, reducing contact stresses and thus reducing polyethylene wear compared to fixed-bearing (FB) total knee prosthesis (TKP) (Cheng et al., 2003; Henricson et al., 2006; Li et al., 2006). There are many studies that evaluate the performance of MB TKP (Banks et al., 2003a; Bhan et al., 2005; Callaghan, 2001; Catani et al., 2003; Delport et al., 2006; Dennis et al., 2005; Garling et al., 2007b; Jones and Huo, 2006). Most kinematic studies focus on osteoarthritis patients.

The underlying pathology is of importance as it may have an effect on knee kinematics. For example, patients suffering from osteoarthritis may have different kinematic and coordination patterns compared to TKP patients suffering from rheumatoid arthritis (RA) (Chmell and Scott, 1999). RA causes degenerative loss of skeletal muscle mass and strength and selective muscle atrophy may have occurred (Chmell and Scott, 1999; Keenan et al., 1991; Meireles et al., 2002; Tjon et al., 2000). It is also reported that RA patients have an increased postural sway and that the quality of sensory information from the lower limbs is affected (Tjon et al., 2000). In most cases, RA has also affected other joints. All these factors influence the knee function of the patient.

In a previous fluoroscopy study the motion of a mobile-bearing TKP in 10 RA patients was evaluated 8 months postoperatively (Garling et al., 2007b). That study showed that the axial rotation of the insert was limited - or even absent - and that in all cases the femoral component rotated more than the insert. In Garling et al. (2007b), three possible explanations are given for the limited rotation. Firstly, the low conformity between the femoral component and insert of this specific design allows the femoral component to rotate and translate with respect to the insert without forcing the insert to rotate. Secondly, the fixed anterior position of the insert-tibia pivot point may lead to torsion forces at the cam-insert articulation, because the
pivot point does not coincide with the actual tibiofemoral rotation point, resulting in polyethylene on metal impingement. The third explanation is that fibrous tissue formation between the tibial plateau and the insert limits the freedom of motion of the insert. While the effect of the conformity on the axial rotation will not change over time, the effect of impingement and fibrous tissue is likely to increase, and thereby further decreasing the axial rotation.

Knowledge about the kinematic changes of knee prostheses over time in patients is very limited. It is important to measure the kinematics of patients over times to assess possible changes in kinematics. Two studies have been published, but they focus on FB prostheses and not on MB prostheses (Collopy et al., 1977; Steiner et al., 1989). Therefore, in this study patients with a mobile-bearing total knee prosthesis that have been evaluated 8 months postoperatively in a previous fluoroscopy study are now re-evaluated 3 years postoperatively in order to accurately assess changes in axial rotation over time.

### 6.2 Methods

Ten rheumatoid arthritis patients were selected from a prospectively randomized Roentgen stereophotogrammetric analysis (RSA) study in our specialized rheumatoid arthritis clinic. Patients were measured using fluoroscopy while performing a step-up task 8 months after total knee arthroplasty (Garling et al., 2007b). From the original group of patients, seven patients were able to participate with the second follow-up (six females and one male). The mean follow-up time was 8 months (range: 2 – 13) for the first follow-up and 43 months (range: 33 – 51) for the second. The mean age during surgery was 67 years (range: 51 – 73) and the mean body mass index (BMI) was 30 (range: 26 – 35) at both follow-ups (Table 6.1). Three patients were lost to follow-up. One patient died, one was not able to participate because of psychological reasons and one patient could not be tracked down. Inclusion criteria were the ability to walk more than 500 m and to perform a step-up task without the help of bars. Exclusion criteria were the use of walking aids, functional impairment at any other
Table 6.1: Patient Characteristics: mean, standard deviation ($\sigma$) and range ($n = 7$).

<table>
<thead>
<tr>
<th>Age at surgery (years)</th>
<th>Follow-up time (months)</th>
<th>BMI (kg/m$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>8 months</td>
<td>3 years</td>
</tr>
<tr>
<td>Mean</td>
<td>67</td>
<td>8</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>8.2</td>
<td>4.4</td>
</tr>
<tr>
<td>Range</td>
<td>51-73</td>
<td>2-13</td>
</tr>
</tbody>
</table>

lower extremity joint besides the operated knee and pain during activity according to the knee society pain score (KSS) (Ewald, 1989). All patients gave informed consent and the study was approved by the local medical ethics committee.

In all patients, a NexGen legacy posterior stabilized (LPS) mobile-bearing prosthesis was implanted (Zimmer Inc., Warsaw, USA). All components were fixed using cement. The tibial-articular surfaces are made of compression moulded polyethylene. During surgery 1 mm tantalum markers were inserted in predefined non-weight bearing areas of the insert to visualize the polyethylene (Garling et al., 2005a). The insert has an anterior-central located trunnion and allows for $25^\circ$ internal-external rotation on the tibia limited by an anterior bar. The curvature of the femoral component permits internal-external rotation to $12^\circ$ in maximum flexion. In the NexGen LPS mobile-bearing knee, there is a limited degree of conformity of the insert surface. The conformity of the insert of the MB and the FB design of this prosthesis are the same, the only difference between the designs is the additional point of rotation in the MB design.

The patients were asked to perform a step-up task (height 18 cm) with bare feet in front of a fluoroscope (super digital fluorography (SDF) system, Toshiba Infinix-NB: Toshiba, Zoetermeer, The Netherlands). At the start of the step-up motion, the leg with the TKP was positioned on top of the riser. The step-up motion was finished when the contra-lateral leg was on top of the riser. The patient was asked to perform the step-up motion in a controlled manner without the use of holding bars. The patient performed five step-ups in total, the first two were used to gain comfort with
the experimental set-up and during the last three runs data was collected. Prior to the measurements, the fluoroscopic set-up was calibrated using a specially designed calibration box (BAAT Engineering B.V. Hengelo, The Netherlands) (Garling et al., 2005a). In order to assess accurate three-dimensional (3D) models of the markers of the insert, two RSA radiographs of the subjects were used. These marker models of the insert were used to assess position and orientation of the insert in the fluoroscopic images. Reverse engineered 3D models of the tibia component and the femoral component were used to assess the position and orientation of the femur and the tibia. Contours of the implants were detected and the 3D models of the implants were projected onto the image plane and a virtually projected contour was calculated (Kaptein et al., 2003).

All images are processed using a commercially available software package (Model-based RSA, Medis specials b.v., The Netherlands). With the assessed 3D position and orientation of the femoral and tibial components and the markers in the insert both the relative rotation of the insert with respect to the tibial component and the relative rotation of the femoral component with respect to the tibial component were calculated. This technique showed to have an axial rotation accuracy of 0.3° (Garling et al., 2005a). In this study, motions smaller than 0.6° (95% confidence interval) were denoted as measurement error. The coordinate system was defined by the local coordinate system of the tibial component (internal rotation is defined as negative; 0° is extension). At maximal extension the axial rotation is set to zero. For both follow-ups this is done separately. This means that ‘zero’ axial rotation in the first follow-up might not be the same as in the second follow-up. To overcome possible differences in relative positions of the insert and femur component with respect to the tibia component, the relative change in rotation is presented.

6.2.1 Statistical analysis

A linear mixed-effects model for longitudinal data was used to compare the differences between the axial rotation of the femoral component and the insert at both follow-ups. The model assumes a linear trend of axial rotation of the predicted means
of axial rotation versus knee angle within each follow-up. A patient random effect as well as a trial-within-patient nested random effect was incorporated in the model for both the intercept and slope coefficients of the linear trend. The first random effect was included to account for between-patient heterogeneity in observed differences, while the latter effect was included to take into account differences in the number of analysable trials per patient between follow-ups. It is a key characteristic of the model that differences in range of motion between trials are taken into account with respect to the fitting of the population linear effect within each follow-up. The model was fit using a fully Bayesian formulation via Markov chain Monte Carlo within the package WinBUGS (Lunn et al., 2000). Model-based residuals were investigated to detect potential mismatch between the observed data and the assumed model, which could adversely affect conclusions. Based on the model, the fitted mean population linear trends were calculated for the rotation of the insert, the femoral component and the difference between them versus knee angle, together with standard errors for each follow-up. Similarly, the probabilities were calculated of mean differences at the 8 months follow-up being larger than those at 3 years, for each knee angle within the range of the data. In interpreting those numbers, it should be noted that a probability of 0.5 means that the axial rotation at both follow-ups is the same. A probability between 0.5 and 1 indicates that the mean axial rotation of follow-up one is larger than the mean axial rotation of follow-up two.

6.3 Results

Clinical parameters determined with the KSS did not change between follow-ups (respectively, 155 ($\pm$46.8) and 161 ($\pm$44.5) points of the 200). At both follow-up moments patients were able to perform complete knee extension ($0^\circ$). The range of knee flexion during the step-up task was the same at both follow-ups (mean $40^\circ$ ($\pm11^\circ$) versus $43^\circ$ ($\pm14^\circ$)). All axial rotation patterns were erratic and in most cases the axial rotations of the insert were smaller than the measurement error ($\pm0.6^\circ$). A remarkable observation at the 3 years follow-up was that patterns of axial rotation for
**Table 6.2:** Maximal axial rotations and range for follow-up one and two \((n = 7)\).

<table>
<thead>
<tr>
<th></th>
<th>8 months</th>
<th>3 years</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Femoral component</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal rotation</td>
<td>-10.8°</td>
<td>-5.9°</td>
</tr>
<tr>
<td>External rotation</td>
<td>2.8°</td>
<td>4.9°</td>
</tr>
<tr>
<td>Range</td>
<td>13.6°</td>
<td>10.8°</td>
</tr>
<tr>
<td><strong>Insert</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal rotation</td>
<td>-5.9°</td>
<td>-2.8°</td>
</tr>
<tr>
<td>External rotation</td>
<td>1.4°</td>
<td>5.4°</td>
</tr>
<tr>
<td>Range</td>
<td>7.3°</td>
<td>8.2°</td>
</tr>
</tbody>
</table>

Both the femoral component and insert varied considerably between the trials within patients (Figure 6.1) while at the 8 months evaluation no significant difference within patients was observed. At both follow-ups, in all subjects, the femoral component showed more axial rotation than the insert (Table 6.2, Figures 6.2, 6.3).

The 8 months results show that the axial rotation of the insert was limited. In comparison with the 8 months evaluation, the 3 years rotation of the femoral component \((-10.8°\) to \(2.8°\)) and the insert \((-5.9°\) to \(1.4°\)) was further decreased (respectively, \(-5.9°\) to \(4.9°\) and \(-2.8°\) to \(5.4°\)) (Table 6.2, Figures 6.2, 6.3). The large external rotation of the insert at the second follow-up is caused by one deviant trial (Figure 6.2) and gives a distorted picture of the range of axial rotation. The other two trials of this patient were not atypical. The trial was not excluded. The decrease in axial rotation of the femoral component and insert at 3 years is also presented in figures 6.4. In these figures, the predicted mean \((\pm \sigma)\) according to the mixed-model approach is shown for the axial rotation of the femoral component and insert for both follow-ups. Also the probability that the mean axial rotation of the second follow-up is smaller than the mean axial rotation at the 8 months evaluation is visualized. The probabilities are above 0.5, which indicates that the mean axial rotation after 8 months is larger compared to the mean axial rotation at 3 years.
Figure 6.1: Example of variation in axial rotation patterns at the 3 years follow-up between trials of the femoral component (solid) and the insert (dotted) within one subject.

6.4 Discussion

In order to accurately assess changes in axial rotation over time in a mobile-bearing total knee prosthesis RA patient group, knee kinematics of seven patients were evaluated 8 months and 3 years postoperatively using fluoroscopy. The rotation of the polyethylene insert proved to be limited at 8 months postoperatively and even decreased over time. It seems that the insert becomes more fixed after a few years. The experimental set-up was exactly the same at both follow-ups, assuming no influence of extrinsic factors. Therefore, all differences found can be interpreted as differences caused by intrinsic factors. The effect of the underlying pathology is
limited by excluding patients with functional impairment of any other lower extremity joint besides the operated knee. In this study, the maximum knee extension did not change over time, but axial rotation of the femoral component and the insert decreased. The decrease in femoral axial rotation indicates a kinematic change over time. A remarkable observation at the 3 years follow-up was that patterns of axial rotation for both the femoral component and insert varied considerably between the trials within patients (Figure 6.1) while at the 8 months evaluation no significant difference within patients was observed. The increase in variability at 3 years may imply a decrease in muscle control.

The high variability and the observed reversed patterns might be caused by the
Fig. 6.3: Rotation of the femoral component of all individual trials of all patients ($n = 7$) at 8 months (dotted) and 3 years (solid). The grey area represents the measurement error ($\pm 0.6^\circ$).

location of the trunnion of the tibial-insert which is placed anterior in this design and does not coincide with the actual tibiofemoral rotation point. The high variability in axial rotation patterns among patients observed in this study is in accordance with the literature. Knee joint kinematics are highly unpredictable (Banks et al., 2005; Dennis et al., 1998; Huang et al., 2007; Stiehl et al., 1995, 1999) and often abnormal compared with healthy knees (Callaghan, 2001). In most studies tibiofemoral axial rotations are reduced compared to the axial rotation of the normal knee (Fantozzi et al., 2004; Haas et al., 2002; Most et al., 2003). Also reversed axial rotation patterns compared to normal kinematics are common after total knee arthroplasty (Callaghan, 2001). These reversed patterns are undesirable and can have an adverse effect on the
Figure 6.4: Predicted mean and standard deviation ($\sigma$) for the axial rotation of the femoral component (a) and for the insert (b) for 8 months follow-up (dotted) and 3 years follow-up (solid) on the left y-axis. On the right y-axis, the probability that the mean axial rotation of the second follow-up (FU2) is smaller than the axial rotation of the first follow-up (FU1) is shown.
range of motion because of reduced posterior femoral rollback of the lateral femoral condyle and patellar stability (Callaghan, 2001; Dennis et al., 2005).

In Garling’s short term follow-up study, three explanations were given for the observed limited rotations. The first is the low conformity between the femoral component and insert. The conformity is not subjected to change over time and therefore not responsible for the observed decline in axial rotation. The other two explanations, respectively, increased polyethylene on metal impingement at the cam-insert articulation and increased formation of fibrous tissue at the edge of the insert, could explain the decline in axial rotation of the insert at the latter follow-up. Until now, no revision surgery was necessary in our patient group. However, retrieval data could clarify possible fibrous tissue formation and also show the effect on wear of the observed sliding phenomenon of the femoral component with respect to the insert (Harman et al., 2001).

Several studies show that ‘normal’ knees have a smooth motion during knee flexion, while implanted knees produce erratic, discontinuous motions (Sakauchi et al., 2001; Stiehl et al., 1995). This erratic motion is also visible in this study. In most trials, at both follow-ups, the femoral component and the insert rotate in the same direction but the rotation of the insert is much smaller. This indicates sliding of the femoral component over the insert during flexion. In two other fluoroscopic studies comparable results are found using different designs (Dennis et al., 2005; Fantozzi et al., 2004). If this sliding occurs without rotating the insert, a MB TKP becomes a FB TKP. In the NexGen LPS mobile-bearing knee, there is a limited degree of conformity of the insert surface. This allows for sliding of the femoral component with respect to the insert (±12° of rotation). However, the philosophy behind a MB design is that axial rotation occurs at the tibial-insert interface to reduce multidirectional wear on the superior (i.e. femoral) aspect of the insert (Dennis et al., 2005). The mobility of a MB permits increased articular conformity between the femoral and tibial components. If the conformity is not increased but kept the same as the conformity of a FB prosthesis, as is the case for the NexGen LPS mobile-bearing knee, this will result in minimal or no rotation at the tibial-insert interface. In this
non-conforming prosthesis, the effect of limited axial rotation will be compensated for with sliding of the femoral component on the insert. Therefore, the patient might not experience any functional limitations in daily living. However, the theoretical advantages of having a rotating platform which should lead to reduced contact stresses and wear will not be accomplished and could even lead to longevity problems.

The conformity of the femoral-tibial contact area should be high enough to make sure that the insert is following the motion of the femoral component thereby facilitating the philosophy of the MB design. The only theoretical advantage remaining of this MB design over a FB design seems to be the assumed forgiveness for surgical rotational misalignment. In this study, the exact positions of the markers in the insert are not known, In future studies it would be interesting to place the markers with a submillimetre accuracy to evaluate the actual axial rotation instead of the relative axial rotations. This would also provide more insight in the theory that MB inserts find their own optimal position and correct for femoral component misalignment.

A limitation of this study is the small patient group. For the first evaluation, an 80% power analysis in combination with an expected measurement error of 0.3° showed that relative motions of 0.3° could be detected when ten patients were included in the study. Unfortunately, three patients were lost to follow-up which has a negative effect on the power of this study. Patients included in fluoroscopic studies are surgeon-selected and therefore kinematic results in general biased. Although this is the first study presenting changes in mobile-bearing knee kinematics of RA patients, one has to be careful generalizing these findings to other patient groups and/or other implant designs. The characteristics of this NexGen design will result in implant specific tibiofemoral and insert kinematics.

**Conclusion**

It is important to assess knee kinematics for the most frequently encountered daily activities, as functional capabilities of patients and survival of TKP are affected by
knee kinematics. This study shows the importance of re-evaluating knee kinematics over time, as knee kinematics continue to adapt to intrinsic factors and physiological changes. In an identical experimental set-up the axial rotation of both the femoral component as the insert decreased over time, indicating a kinematic change caused by intrinsic factors. The decline in rotation of the insert could be explained by increased impingement and the formation of fibrous tissue.