MOBILE-VERSUS FIXED-BEARING TKA

Arthur W. Zürcher
Kim van Hutten
Jaap Harlaar
Caroline B. Terwee
G.H. Rob Albers
Ruud G. Pöll

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Mobile-bearing total knee arthroplasty:
More rotation is evident during more demanding tasks.
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ABSTRACT

Background: Some reports showed few but significant more axial femorotibial rotation in favor of mobile-bearing (MB) versus fixed-bearing (FB) total knee arthroplasty (TKA), mostly during knee bend fluoroscopic studies. The goal of the current study was to submit a MB and FB group of TKA patients to a turning activity, in which additional rotation was to be expected.

Methods: Two consecutive cohorts of patients after TKA (10 FB and 11 MB knees in a total of 18 patients) were assessed using motion analysis five year postoperatively, while performing gait and sit-to-walk (STW) movements with and without turning steps.

Results: Mean range of rotation in the FB group increased from 9.7 degrees during gait, to 11.7 degrees during STW straight, and to 14.3 degrees during STW turning. Mean range of rotation in the MB group increased from 13.4 degrees during gait to 21.0 degrees during STW straight, and stayed at 21.1 degrees during STW turning. In comparison, in a group of healthy subjects range of rotation went from 13.5 degrees without to 20.9 degrees with turning.

Conclusions: Too many uncontrolled variables in the current study hinder a meaningful discrimination of MB from FB TKA rotation. However, the study does illustrate how more demanding task loads could be helpful in exploring the geometric constraints of TKA variants.
INTRODUCTION

A large variety exists in total knee arthroplasty (TKA), for instance regarding condylar geometry design, posterior cruciate retention versus substitution, bearing mobility, bone versus ligament referenced placement, cemented versus uncemented placement, with or without patella resurfacing etc. As far as bearing mobility concerns, fixed-bearings (FB) are most frequently used. This is probably because superior clinical results of mobile-bearing (MB) designs are still lacking,1-3 wear rate results inconclusive,4-6 and kinematic differences are small.7-9 The rationale of MB lies originally in being part of the low-contact-stress concept to reduce loosening and wear. Herein the use of a meniscal or rotating bearing element allowed both mobility and congruency, producing both low constrained forces and low contact stresses.10 Several in vivo fluoroscopic studies compared mobile- to fixed-bearing variants,7-9,11-13 half of them showing small but significant more axial femorotibial rotation (‘rotation’) in the MB group (Table 4.1). More rotation may strictly not be relevant for the functioning of the low-contact-stress concept, but the question is raised, whether it is even desirable to have a closer to natural amount of rotation in TKA.

More rotation may assist in more complex daily life activities, although beyond a certain threshold it could preclude a clinically undesirable instability. In vivo fluoroscopic analysis of normal knees showed that only 11 degrees of rotation was used during gait and around 15 degrees during higher demanding tasks, such as a deep knee bend and chair sit/rise.14 In Dennis’ multicenter knee bend study all TKA variants showed
below 10 degrees of rotation, except for anterior cruciate retaining TKA.\textsuperscript{11} It is questionable whether the possibilities and restrictions of MB and FB TKA, and their comparison to the normal knee, should not be tested while performing more challenging tasks. We demonstrated in a motion analysis study an increase of rotation from 14 to 21 degrees in the normal knee by adding turning steps to a sit-to-walk task.\textsuperscript{15}

We expected that this additional knee rotation by adding turning elements to a task load would also occur in our TKA patients. This assumption was supported by a finite element study showing that rotational load was the primary contributor to TKA mechanics.\textsuperscript{16} We also hypothesized that a MB variant would have more rotation than a typical FB variant in turning activities.
MATERIAL AND METHODS

Two consecutive cohorts of patients after TKA, 10 FB knees (in 9 patients) and 11 MB knees (in 9 patients), underwent gait analysis five years postoperatively between February 2006 and June 2008. The FB cohort was operated on in Hilversum Hospital (currently Tergooi Hospital, Hilversum, The Netherlands) receiving a NexGen® Complete Knee Solution Legacy® Posterior Stabilized TKA (Zimmer Inc, Warsaw, IN), while the MB cohort was operated on in Slotervaart Hospital (Amsterdam, The Netherlands) receiving a LCS® Complete Rotating Platform TKA (DePuy Inc, Warsaw, IN). In the Nexgen knee the posterior cruciate ligament (PCL) was substituted and the orientation of saw cuts was bone referenced. In the LCS knee the PCL was sacrificed and saw cuts were ligament balance referenced. Otherwise, surgical approach and aftercare in both hospitals were uniform. The local ethical committee in both hospitals gave permission for conducting the study.

Inclusion criteria for the study were patients successfully operated for osteoarthritis or rheumatoid arthritis with a postoperative Knee Society Knee Score of 80 points or more. Exclusion criteria were revision surgery, neurological disorders that interfered with walking and body mass index (BMI) of 30 or more. During the course of the study, the criterion of BMI was eased from 30 to 35 to secure patient enrollment. The patient characteristics regarding gender, age at surgery, side, BMI and interval from surgery to analysis are shown in Table 4.2. Gender was equally divided in the FB group, whereas the MB group consisted of mainly women. Interval from surgery to gait analysis was 74 months in the FB group an 64 months in the MB group (p = 0.001). Otherwise,
there were no statistically significant differences between both groups. Normal data were taken from a prior study, in which fifteen healthy volunteers (six females, nine males) participated. Their average age was 33.4 years (range 24-63) and average body mass index 23.3 (range 18-25).

Gait analysis took place in the Human Movement Laboratory (Department of Rehabilitation Medicine, VU University Medical Center, Amsterdam, the Netherlands). An OptoTrak motion analysis system (model 3020, Northern Digital Inc, Waterloo, Ontario, Canada) was used to record the three-dimensional position of active surface markers at a sampling rate of 50 Hz. For the tibia a cluster of three markers was strapped over the middle lateral shank. For the femur a cluster of three markers was rigidly attached to an epicondylar frame. The Femoral Epicondylar Frame is a validated tool for noninvasive tracking of femoral axial rotation with an error of 3.3 degrees.
up to 40 degrees of knee flexion. The majority of normal rotation took place between 0-45 degrees of knee flexion during knee bending and chair rising in a fluoroscopic study. We found the same in a motion analysis study in healthy patients performing chair rises with and without turns; most rotation took place at the end of stance with the knee nearly in extension. Besides that, higher flexion angles would be less relevant to study in TKA, because an increased flexion angle also means loss of condylar congruency. The error for tibial rotation using surface markers is 2 degrees. An open source Matlab software program, BodyMech (www.bodymech.nl), was used to calculate three-dimensional knee kinematics. Tibia and femur were considered to be rigid bodies with a local coordinate system, defined by anatomical points. Coordinates of the two points, where the virtual axis of the device entered the femoral epicondyles, were calculated from the frame markers. The greater trochanter instead of femoral head was used for the femoral longitudinal axis definition. The shank markers were anatomically calibrated using the tibial tuberosity and medial and lateral malleoli. Knee kinematics followed from the relative orientation of the tibia with respect to the femur, while decomposition into Euler angles was applied following the Grood and Suntay convention.

The subjects performed four tasks: gait, move from sit-to-walk (STW) straight ahead, STW crossoverstep turning and STW sidestep turning. Chair height was adjusted to 90 percent of the lower leg length. Only the prosthetic knee in the weight bearing leg was measured during stance phase, the contralateral side acting as the swing leg. The tasks were standardized and described previously in a study with healthy subjects.
The subjects practiced each task until smoothly performed in a natural pace. Three measurements per task were recorded and used for analysis.

Ranges of rotation during the various tasks were compared between the FB and MB groups. The difference between peak internal and peak external femorotibial rotation was used to define range of axial knee rotation. The difference between internal rotation during crossoverstepping and external rotation during sidestepping was used to define overall range of rotation for STW turning. An independent t-test was utilized to compare variables (ranges of rotation during gait, STW straight and STW turning) as well as patient characteristics between both groups (FB and MB). Level of significance was set at \( p=0.05 \). The original sample size calculation with power set at 0.80 had revealed a number of 16 patients per group to find a difference of 5 degrees between groups with 5 degrees of variance.

**RESULTS**

During the stance phase of normal gait, the range of rotation in the FB group was with an average of 9.7 degrees (SD 4.2) less than the range of 13.4 degrees (SD 6.7) in the MB group, albeit not to a significant level (Tables 4.3 and 4.4). The results of non-operated knees in healthy subjects in Table 4.4 were collected in a prior study.\(^{15}\)
**TABLE 4.3.** Individual peak values of internal and external knee rotation in degrees. For each value the knee flexion angle in degrees is presented between brackets.

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Gait</th>
<th>STW, straight</th>
<th>STW, crossoverstepping</th>
<th>STW, sidestepping</th>
</tr>
</thead>
<tbody>
<tr>
<td>FB1</td>
<td>5.8 (28)</td>
<td>-0.1 (19)</td>
<td>1.7 (42)</td>
<td>-6.0 (47)</td>
</tr>
<tr>
<td>FB2</td>
<td>11.8 (22)</td>
<td>-0.5 (26)</td>
<td>4.2 (36)</td>
<td>-6.2 (51)</td>
</tr>
<tr>
<td>FB3</td>
<td>6.9 (48)</td>
<td>-1.2 (25)</td>
<td>9.2 (33)</td>
<td>-1.7 (74)</td>
</tr>
<tr>
<td>FB4</td>
<td>7.3 (24)</td>
<td>-0.2 (13)</td>
<td>15.3 (21)</td>
<td>0.1 (61)</td>
</tr>
<tr>
<td>FB5</td>
<td>13.2 (42)</td>
<td>-1.2 (18)</td>
<td>12.6 (36)</td>
<td>-0.1 (69)</td>
</tr>
<tr>
<td>FB6</td>
<td>2.7 (42)</td>
<td>-4.6 (20)</td>
<td>10.5 (31)</td>
<td>1.5 (75)</td>
</tr>
<tr>
<td>MB1</td>
<td>8.4 (30)</td>
<td>-0.3 (18)</td>
<td>3.7 (40)</td>
<td>-3.1 (84)</td>
</tr>
<tr>
<td>MB2</td>
<td>9.9 (37)</td>
<td>-1.5 (19)</td>
<td>17.1 (36)</td>
<td>-0.4 (88)</td>
</tr>
<tr>
<td>MB3</td>
<td>14.8 (41)</td>
<td>-4.0 (24)</td>
<td>11.6 (40)</td>
<td>-4.1 (55)</td>
</tr>
<tr>
<td>MB4</td>
<td>2.8 (44)</td>
<td>-2.5 (17)</td>
<td>4.5 (34)</td>
<td>-5.6 (50)</td>
</tr>
<tr>
<td>MB5</td>
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<td>-3.0 (20)</td>
<td>10.9 (20)</td>
<td>-0.8 (73)</td>
</tr>
<tr>
<td>MB6</td>
<td>-2.0 (24)</td>
<td>-1.2 (20)</td>
<td>19.6 (27)</td>
<td>-1.2 (77)</td>
</tr>
<tr>
<td>MB7</td>
<td>19.3 (18)</td>
<td>-3.6 (16)</td>
<td>31.7 (19)</td>
<td>-3.8 (71)</td>
</tr>
<tr>
<td>MB8</td>
<td>10.2 (35)</td>
<td>0.0 (22)</td>
<td>15.8 (32)</td>
<td>-1.3 (85)</td>
</tr>
<tr>
<td>MB9</td>
<td>5.2 (30)</td>
<td>-6.6 (14)</td>
<td>27.1 (30)</td>
<td>-3.4 (61)</td>
</tr>
<tr>
<td>MB10</td>
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<td>-11.2 (14)</td>
<td>17.9 (33)</td>
<td>-4.8 (65)</td>
</tr>
<tr>
<td>MB11</td>
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<td>-2.4 (23)</td>
<td>8.7 (29)</td>
<td>-4.8 (60)</td>
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<td>MB12</td>
<td>25.1 (33)</td>
<td>-2.8 (26)</td>
<td>10.9 (48)</td>
<td>-7.9 (36)</td>
</tr>
<tr>
<td>MB13</td>
<td>10.9 (28)</td>
<td>-0.7 (20)</td>
<td>21.5 (24)</td>
<td>1.4 (73)</td>
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<tr>
<td>MB14</td>
<td>8.3 (36)</td>
<td>0.9 (34)</td>
<td>7.4 (31)</td>
<td>-7.1 (71)</td>
</tr>
</tbody>
</table>

*m.d.* Missing data.
**TABLE 4.4.** Mean ranges of axial knee rotation (SD).

<table>
<thead>
<tr>
<th>Task</th>
<th>FB</th>
<th>MB</th>
<th>Normal</th>
<th>p-Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gait</td>
<td>9.7° (4.2)</td>
<td>13.4° (6.7)</td>
<td></td>
<td>0.152</td>
</tr>
<tr>
<td>Sit-to-walk, straight</td>
<td>11.7° (3.6)</td>
<td>21.0° (7.3)</td>
<td>13.5° (3.9)</td>
<td>0.002</td>
</tr>
<tr>
<td>Sit-to-walk, turning</td>
<td>14.3° (5.4)</td>
<td>21.1 (8.5)</td>
<td>20.9° (7.9)</td>
<td>0.051</td>
</tr>
</tbody>
</table>

* FB versus MB

During STW straight, range of rotation in the FB group was considerably less than in the MB group (p=0.002). In the FB group the average peak internal rotation was 8.8 degrees (SD 5.5) at 90 percent of stance phase on average (SD 14) and with an average knee flexion angle of 35 percent (SD 6). External rotation was 2.9 degrees (SD 2.5) at 20 percent of stance phase (SD 16) with a knee flexion angle of 65 degrees (SD 15). This accounted for a range of rotation of 11.7 degrees (SD 3.6). In the MB group this range was 21.0 degrees (SD 7.3), with 17.9 degrees (8.0) peak internal rotation at 89 percent stance (SD 12) with 29 degrees knee flexion (SD 8) and 3.2 degrees (SD 2.9) external rotation at 20 percent stance (SD 16) with 65 degrees knee flexion (SD 15).

STW turning still resulted in less range of rotation for the FB group (p=0.051). In the FB group the average peak internal rotation was 11.8 degrees (SD 6.2), at 88 percent of stance phase (SD 12) with an average of 33 degrees knee flexion angle (SD 6), during crossoverstepping. External rotation during sidestepping was 2.5 degrees (SD 2.1) at 26 percent stance (SD 24) with 59 degrees knee flexion (SD 20). This accounted for an overall range of rotation of 14.3 degrees (SD 5.4), versus 21.1 degrees (SD 8.5).
in the MB group. In this group crossoverstepping resulted in of 19.4 degrees internal rotation (SD 8.6) at 98 percent stance (SD 7) with 30 degrees knee flexion (SD 7), and sidestepping resulted in 1.7 degrees external rotation (SD 2.7) at 24 percent stance (SD 31) with 66 degrees knee flexion (SD 20).

**DISCUSSION**

Significant but small differences in axial femorotibial rotation during knee bending activities in favor of MB TKA were shown in a number of papers. In the current study, the difference in rotation was even larger when moving from sit to walk with and without turns. We expected increased differences during a more demanding task, because in a pilot study on healthy subjects with non-operated knees range of rotation increased from 14 to 22 degrees by adding a turning element to STW. STW represents a complex transitional task, which is a merging of a discrete task (rising from a chair) and a rhythmic one (walking). In the FB group, rotation gradually increased with increased task complexity (gait, STW straight, STW turning) to 14 degrees. In the MB group, an increase to 21 degrees in rotation from gait to STW occurred, while no further increase was seen adding turns. Perhaps the low-friction articulation between bearing undersurface and tibial component is the reason for this ‘switch on-off’ pattern of rotation in MB knees. with 17.9 degrees (8.0) peak internal rotation at 89 percent stance (SD 12) with 29 degrees knee flexion (SD 8) and 3.2 degrees (SD 2.9) external rotation at 20 percent stance (SD 16) with 65 degrees knee flexion (SD 15).
STW turning still resulted in less range of rotation for the FB group ($p=0.051$). In the FB group the average peak internal rotation was 11.8 degrees (SD 6.2), at 88 percent of stance phase (SD 12) with an average of 33 degrees knee flexion angle (SD 6), during crossoverstepping. External rotation during sidestepping was 2.5 degrees (SD 2.1) at 26 percent stance (SD 24) with 59 degrees knee flexion (SD 20). This accounted for an overall range of rotation of 14.3 degrees (SD 5.4), versus 21.1 degrees (SD 8.5) in the MB group. In this group crossoverstepping resulted in of 19.4 degrees internal rotation (SD 8.6) at 98 percent stance (SD 7) with 30 degrees knee flexion (SD 7), and sidestepping resulted in 1.7 degrees external rotation (SD 2.7) at 24 percent stance (SD 31) with 66 degrees knee flexion (SD 20).

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Even without the initiation of gait, the sit-to-stand (STS) movement is an important and challenging task of daily living that requires relatively large joint torques (and consequently joint load) and accurate balance control. Interestingly, kinematic recovery in STS performance was reported at one year after TKA and the necessary coordination appeared not to be different from a control group. To our knowledge, former kinematic analysis of the STS movement after TKA was restricted to the sagittal plane only, while STW after TKA has not been studied at all.

A shortcoming in the design of the study is that the LCS and NexGen design features and surgical technique were, except for difference in bearing mobility, not otherwise identical. Also, less rotational constraint in a PCL-retained then in a PCL-substituted FB variant might have been expected. On the other hand, both prostheses were considered to be highly representative for their cohort, being amongst the most implanted artificial knees worldwide. Another possible shortcoming refers to the utilized noninvasive measurement technique, which does not make it possible to assess mobility of the bearing relative to the tibial component in the MB group. Nevertheless, since the concept of low-contact-stress TKA is based on higher congruency between femoral component and bearing uppersurface, one might assume that the larger rotation found in the MB group was due to bearing undersurface mobility. This assumption was supported by studies
utilizing highly accurate roentgen stereometric analysis. A third shortcoming is that the study design was not a randomized trial, which means that the patient groups may be different in relevant known or unknown variables. The number of females was larger in the MB group than in the FB group, but an assumable higher laxity in females could not be held to account for as large a difference as was found in this study.

The concept of higher articulating congruency combined with bearing rotational mobility has a theoretical advantage of reduced polyethylene wear and improved function. Clinical studies of the LCS knee showed excellent results with MB, but the superiority over a FB design in comparative studies remains unproven. One randomized study compared the LCS (MB) to NexGen (FB) with a minimum 10-year clinical and radiological follow-up, finding both groups were equally successful. Series of bilaterally operated patients, randomized for FB on one MB on the other side, need to provide even longer-term clinical results. Kinematic studies are necessary to find support for either concept, although higher amounts of rotation in a MB knee would not necessarily prove the benefit of its concept.

In conclusion, there are too many uncontrolled variables in this study to provide a meaningful contribution on MB versus FB TKA kinematics. A well-controlled randomized trial with MB and FB variants of the same prosthesis would be necessary to do so. We found that a difference in knee rotation between MB and FB becomes apparent, when changing from a relatively simple task to a more demanding task such as getting-up from a chair and start walking with and without turning. The study therefore illustrates that more demanding task loads could be helpful in exploring the geometric constraints of TKA variants.
CONFLICT OF INTEREST STATEMENT

This study was financially supported by an unrestricted grant from DePuy (Johnson & Johnson Medical) and Biomet. Otherwise, all authors have no financial and personal relationships with other people or organizations that could inappropriately influence (bias) their work.
REFERENCES


