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Comparison of *In Vivo* Knee Kinematics between Fixed-Bearing and Mobile-Bearing Total Knee Arthroplasty during Deep Knee Bending Activities

Nobukazu Okamoto[1], Eiichi Nakamura[2], Tetsuro Masuda[1], Hitoshi Ito[1], Satoshi Hisanaga[1] and Takeshi Miyamoto[1]*

[1]*Department of Orthopedic Surgery, Kumamoto University, Japan*

[2]*Kumamoto Kaiseikai Hospital, Japan*

Abstract

Mobile-bearing Total Knee Arthroplasty (TKA) is associated with high conformity and low-contact stress. The rotation of the polyethylene insert better replicates natural motion. Improvement in daily activities, such as squatting and kneeling, that require high knee flexion, has reportedly resulted in increased patient satisfaction after TKA. The purpose of this study was to determine whether a mobile-bearing TKA improved functional knee flexion better than a fixed-bearing TKA. We compared the difference in weight-bearing knee kinematics in patients with mobile-bearing and fixed-bearing TKA by performing lunging or kneeling activities. We randomly allocated 40 knees (37 patients) to mobile-bearing TKA (n=20) or fixed-bearing TKA (n=20). Using fluoroscopic imaging, we evaluated knee kinematics during these activities one year postoperatively. There were no differences in maximum knee flexion during lunging or kneeling, or in the total extent of rotation. Due to the external rotation of the polyethylene insert, patients with mobile-bearing TKA had a wider range of absolute external rotation. The position of the medial and the lateral condyles was not different between the two TKAs. The motion of the polyethylene insert in the mobile-bearing TKA did not contribute to an increase in maximal flexion and kinematics during the aforementioned activities. Further comparative research evaluating long-term clinical outcomes is required.

Keywords: Total knee arthroplasty; Kinematics; Mobile-bearing; Fixed-bearing

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***Correspondence:**
*Nobukazu Okamoto, Department of Orthopedic Surgery, Kumamoto University, 1-1-1 Honjo, Kumamoto, Japan, Tel: +8196-373-5226; Fax: +8196-373-5228;
E-mail: nobuoka9999@yahoo.co.jp*

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Introduction

Mobile-bearing Total Knee Arthroplasty (TKA) is a procedure that is associated with high conformity and low contact stress. These features reduce polyethylene wear and lower the risk of component loosening [1-3]. In addition, the rotation of the polyethylene inserts better replicates natural motion and corrects the rotational mismatch between the femoral and tibial components [4]. This feature enables the placement of polyethylene insert in the most appropriate position and facilitates better patellar tracking [1,5,6], leading to improved kinematics and clinical outcomes. However, clinical differences between mobile-bearing and fixed-bearing TKA, in terms of range of motion, clinical scores, and survival rates, remain to be documented [7-14].

We recently reported a comparison between the knee kinematics for mobile-bearing and fixed-bearing TKA designs during step-up activity [15]. The kinematics was not significantly different in terms of the total amount of the rotation and AP translation. However, the polyethylene insert in the mobile-bearing TKA showed a wider range of rotation. As with the step-up activity, improvement in daily activities that require high knee flexion, such as squatting and kneeling, has reportedly resulted in increased patient satisfaction after TKA [16,17]. Several studies have suggested that high knee flexion is associated with joint kinematics [18-20]. Greater knee flexion is reportedly correlated with increased posterior femoral translation. Femoral external rotation increases with knee flexion in normal and replaced knees, and a causal relationship was suggested but not proven [21,22]. Recently, it was reported that the kinematics of normal knees during high flexion exhibited femoral rotation, but the pattern and amount rotation were variable according to the activity [23]. A mix of studies reported mobile-bearing and fixed-bearing TKA kinematics during deep knee-bending activities [20,24-26].

Few studies have assessed the kinematics of the mobile-bearing polyethylene insert. It was

Table 1: Patient demographic data.

	Group 1 (n=20)			Group 2 (n=20)			P
	Mean	SD	Range	Mean	SD	Range	
Patient age (years)	76	7	65-88	77	4	70-84	0.58
Sex (female/man)	(18/2)			(16/4)			
Height (cm)	151	8	140-170	151	8	136-170	0.82
Weight (kg)	59	10	48-81	59	10	46-91	0.99

Table 2: Knee position during maximal flexion lunging.

	Implant Maximal Flexion (°)	Tibial External Rotation (°)	Medial AP (cm)	Lateral AP (cm)
MB	118 ± 18	-5.0 ± 5.0	-0.4 ± 0.4	-0.7 ± 0.4
FB	119 ± 15	-3.6 ± 3.8	-0.6 ± 0.3	-0.6 ± 0.4
P value	0.9	0.3	0.6	0.8

Values are expressed as mean ± SD

AP: Anterior-Posterior; MB: Mobile-Bearing; FB: Fixed-Bearing

difficult to analyze the insert motion because the polyethylene insert was radiolucent, so it was challenging to obtain a three-dimensional (3-D) model for model-based image registration techniques. To determine whether the motion of the inserts in the mobile-bearing TKA contributes to knee kinematics, including maximum flexion during weight-bearing deep knee bending activities, we compared kinematics in patients with mobile-bearing and fixed-bearing TKA.

Patients and Methods

We enrolled 37 patients with osteoarthritis (40 knees), who had knee flexion greater than 120°, in this prospective, randomized study, as previously described [15]. All patients provided informed consent to participate. The study protocol was approved by the Institutional Review Board.

Using randomization envelopes, 20 knees (18 women, 2 men) were assigned to undergo mobile-bearing TKA (NexGen LPS Flex Mobile, Zimmer, Warsaw, IN; Group 1), and the other 20 knees (16 women, 4 men) received fixed-bearing TKA (NexGen LPS Flex Fixed, Zimmer; Group 2).

All TKAs were performed by the same surgeon using a measured resection technique. The patella was not resurfaced. In Group 1, a device was employed intraoperatively to place four 0.8 mm tantalum beads at predefined sites in a polyethylene insert (Figure 1A and B) [27]. The Hospital for Special Surgery (HSS) score was used for pre- and post-operative clinical evaluation. Radiographic evaluation was performed using standing AP radiographs for the tibiofemoral angle and the Knee Society rating system for component alignment [28].

One year after surgery, knee motions were recorded by lateral fluoroscopy on a 17-inch flat-panel detector (SonialVision Safire, Shimadzu, Kyoto, Japan). For kneeling and lunging, subjects were observed while they performed a weight-bearing lunge and partial weight-bearing kneeling to maximum comfortable flexion [21,24]. Lateral fluoroscopic images were recorded at 5 frames per second (Figure 2A, 2B).

The 3-D position and orientation of the tibial and femoral components were determined using model-based image registration techniques, manual matching, and image space optimization routines [28]. The fluoroscopic images were digitized and analyzed [28]. The optical geometry of the fluoroscopy system (principal distance, principal point) was determined from images of a calibration target [29]. The implant surface model was projected onto the geometry-

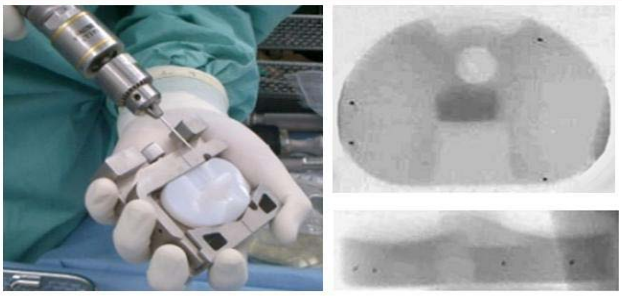

Figure 1: A plate for inserting the beads (left) and X-ray images of the polyethylene strategically inserted with four tantalum beads (right).

corrected image, and its 3-D pose was iteratively adjusted to match its silhouette with the silhouette of the subject's knee components. The 3-D models of the beads positioned in the mobile-bearing insert were adjusted to the beads in the radiograph as above. The standard errors of this shape-matching process are approximately 0.5° to 1.0° for rotations, and 0.5 mm to 1.0 mm for translations in the sagittal plane [27,28].

Knee flexion angles, anterior-posterior condylar positions, and external rotation between femoral and tibial components were evaluated. In patients with mobile-bearing TKA, we also assessed external rotation of the polyethylene inserts relative to tibial components using CAD models of the four inserted tantalum beads. The location of the medial and lateral condylar contacts was estimated as the lowest point on each femoral condyle relative to the transverse plane of the tibial baseplate. The distance between each contact point and the Anterior-Posterior (AP) center of the tibial baseplate was measured, and a negative value indicated a position posterior to the centerline of the baseplate. Tibial external rotation relative to the femur was defined as positive rotation.

Student's t-test was used for comparisons between the two groups. We used a two-way repeated measure ANOVA to determine whether there were study-design effects (Group 1 or Group 2) on the AP tibiofemoral translations and rotation. Post-hoc pair-wise comparisons were performed using Tukey's Honestly Significant Difference. The F-test was used to compare variations of the range of the absolute external rotation between the two groups. P-values <0.05 were considered significant. We performed a power analysis to determine the sample size. A sample size estimation showed that 20 knees in each group would be required to show a difference in the

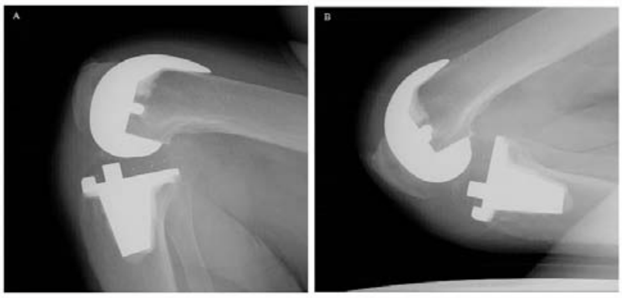

Figure 2: Images showing deep knee bending activities in mobile-bearing total knee arthroplasty. At least three tantalum beads are shown. (A) Lunging activity; (B) Kneeling activity.

flexion angle with a power level of 80% by G* power 3.1.7 (Heinrich Heine, Universitat Düsseldorf, Dusseldorf, Germany).

Results

There were no significant differences in any preoperative and postoperative data between Group 1 and Group 2 (Table 1). Three patients with bilateral TKA were included. One had undergone mobile-bearing TKA in one knee and fixed-bearing TKA in the other. Another had fixed-bearing TKA in both knees, and the third had mobile-bearing TKA in both knees.

During lunging activity, there were no significant differences in terms of the AP position of the medial and lateral condyles and the tibial external rotation between the two groups (Figure 3). In maximum flexion lunging, there were no significant differences in implant flexion 118° ± 18° for the mobile-bearing TKA (Group 1) and 119° ± 15° for the fixed-bearing TKA (Group 2, Table 2). In maximum flexion kneeling, there were no significant differences in implant flexion 129° ± 14° for the mobile-bearing TKA (Group 1), and 126° ± 14° for the fixed-bearing TKA (Group 2, Table 3). There were no significant differences in terms of the total amount of tibial external rotation and the location of both condyles from extension to flexion during lunging and kneeling activities (Table 2 and 3). Group 1 patients had a significantly wider range of absolute external rotation in both extension (mean 0.03° ± 6.0°; range, -8.95° to 11.03°) and maximal flexion (mean -5.0° ± 5.9°, range -12.7° to 5.7°) during lunging activity than Group 2 (extension: mean -1.3° ± 3.2°, range -9.62° to 2.0° and maximal flexion: mean -4.9° ± 3.5°, range -12.7° to 5.71°; p=0.01 and p=0.02, respectively; Figure 4). Although the femoral component in this group rotated relative to the polyethylene insert, their wider range of external rotation was due to the external rotation of the polyethylene inserts relative to the tibial component (Figure 5).

There were no significant between-group differences in the post-operative range of motion, HSS score, tibiofemoral angle, and component alignment [30].

Discussion

In this study, we compared the kinematics of a fixed-bearing TKA (Group 2) and a mobile-bearing TKA (Group 1) during deep knee-bending activities to determine whether mobile-bearing TKA contributes to an increase in maximal flexion and kinematics. Fixed- and mobile-bearing TKA had the same femoral component; they demonstrated similar kinematics in terms of AP translation and external rotation during deep knee bending activities. However,

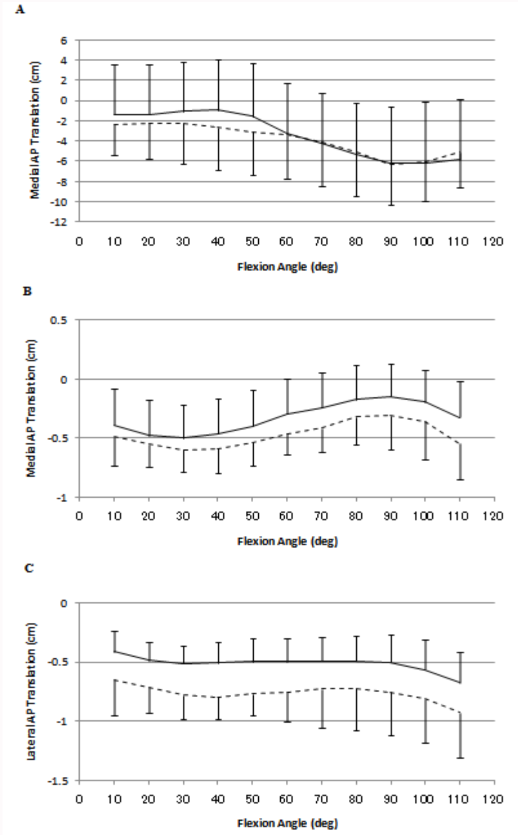

Figure 3: Tibial external rotation and AP translation of the femoral condyle for the mobile-bearing TKA (solid line) and the fixed-bearing TKA (dotted line). (A) Tibial external rotation; (B) Medial condyle AP translation; (C) Lateral condyle AP translation.

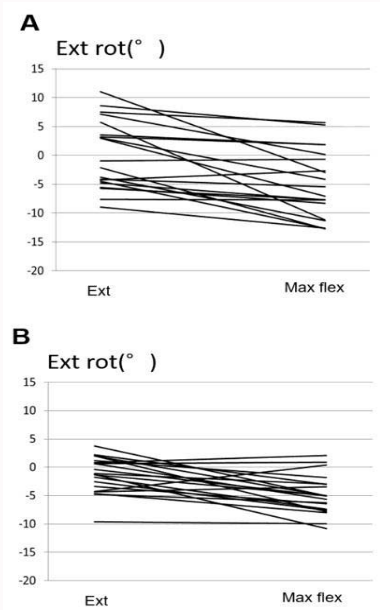

Figure 4: Tibial external rotation, from extension to maximal flexion, during the lunging activity in each patient. (A) Mobile-bearing TKA; (B) Fixed-bearing TKA.
Ext: Extension; Max flex: Maximum Flexion

among Group 1 patients, we noted a wider range of external rotation, which was attributed to the motion of the polyethylene insert on the

Table 3: Knee position during maximal flexion kneeling.

	Implant Maximal Flexion (°)	Tibial External Rotation (°)	Medial AP (cm)	Lateral AP (cm)
MB	129 ± 14	-3.4 ± 4.9	-0.6 ± 0.3	-0.9 ± 0.3
FB	126 ± 14	-3.6 ± 3.9	-0.5 ± 0.3	-0.8 ± 0.4
P value	0.5	0.9	0.5	0.7

Values are expressed as mean ± SD
AP: Anterior-Posterior; MB: Mobile-Bearing; FB: Fixed-Bearing

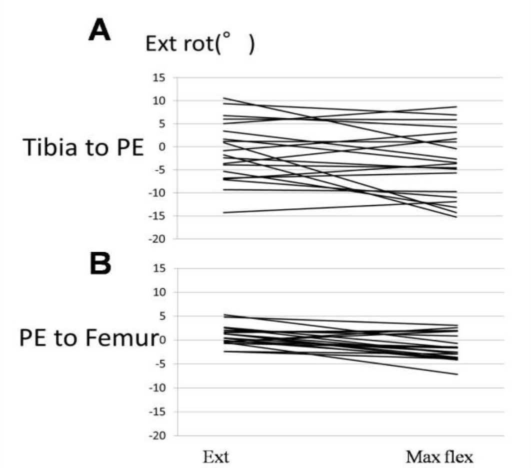

Figure 5: External rotation, from extension to maximal flexion, during the lunging activity in each patient who received mobile-bearing TKA. (A) Tibial external rotation relative to polyethylene insert; (B) External rotation of polyethylene insert relative to the femoral component.
Ext: Extension; Max flex: Maximum Flexion

tibial component.

Several clinical studies have reported the results of comparing fixed-bearing and mobile-bearing TKA during deep knee-bending activities [25,26]. For example, Shi et al. [25] compared 26 fixed- and 30 mobile-bearing TKA using the same component design we used in passive knee flexion under true lateral radiograph using fluoroscopy. The authors reported that the amount of external rotation from extension to maximum flexion was larger in patients with mobile-bearing TKA (7.9° *vs.* 5.1°). On the other hand, Watanabe et al. [26] compared 16 fixed- and 16 mobile-bearing TKA with the same design as the present study using model-based image registration techniques. These authors found no significant difference during squatting activity, and external rotation was 9° for mobile- and 7° for fixed-bearing TKA. No difference was also detected, in terms of the AP translation, during squatting activity. However, few studies have assessed the kinematics of the mobile-bearing polyethylene insert. It was difficult to analyze the insert motion using the model-based image registration techniques because the polyethylene insert was radiolucent. In our study, we compared the fixed-bearing TKA and mobile-bearing TKA, and assessed the motion of the polyethylene insert. There were no significant differences in external rotation. In the lunging activity, the mobile-bearing TKA group tended to have more external rotation than did the fixed bearing activity, as previously reported [25,26]. We demonstrated a significantly wider range of insert motion for the mobile-bearing TKA as designed during both activities, the same as in the step-up activity described in our recent report [15].

There were also no significant differences in maximum knee flexion during lunging or kneeling for both types of TKA. Daily activities such as squatting, kneeling, or sitting cross-legged require around 150° knee flexion. Greater maximum flexion is reportedly correlated with increased posterior femoral translation [18-20]. Femoral external rotation increases with knee flexion in normal and replaced knees, and a causal relationship has been suggested [23]. We demonstrated that the tibial internal rotation and AP translation was not significantly different for both designs during maximum-flexion lunging and kneeling.

Our study has some limitations. Firstly, we did not assess the rotational axis of the implanted tibial component intraoperatively. Nonetheless, all operations were performed by the same surgeon, who used a line connecting the center of the posterior cruciate ligament and the medial edge of the patellar tendon attachment as a landmark for the tibial rotational alignment [31]. Secondly, our inclusion of three patients with bilateral TKA may have affected the results. These three patients received three fixed and three mobile knees. However, the opposite knees that did not undergo TKA were functional, and there was no difference in the results in terms of the external rotation and AP translation with and without these three patients.

In our recently reported comparison of the kinematics of fixed- and mobile-bearing TKA during step-up activity, there were also no significant kinematic differences between the two types of TKA. Although the motion of the polyethylene insert in the mobile-bearing TKA may have benefits as designed, the kinematics of mobile- and fixed-bearing TKA were not significantly different. It remains unclear if the mobile-bearing mechanism corrects the rotational mismatch that affects patellar tracking. Further comparative research evaluating long-term clinical outcomes is required.

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