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Matched comparison of kinematics in knees with mild and severe varus deformity using fixed- and mobile-bearing total knee arthroplasty

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ABSTRACT

Background: We examined knee kinematics in three 16-knee cohorts with the same implant design to clarify the influence of bearing mobility and preoperative deformity on the kinematics of posterior-stabilized knee arthroplasty. Compared to knees with mild deformity and a fixed-bearing implant, we hypothesized that a matched group of knees with mobile-bearing prostheses would show greater tibial axial rotation. We hypothesized that knees with the same fixed-bearing implant, but severe preoperative deformity, would have less axial rotation.
Methods: A total of 58 knees in 48 patients were involved in this study from a consecutive single-surgeon total knee arthroplasty series. Sixteen knees received mobile-bearing prostheses, and a best-matched cohort of knees with fixed-bearing implants was selected. The 16 fixed-bearing knees with most severe preoperative deformity were selected as a third group. All knees were examined at least 1.5 years after surgery. Flexion, femoral external rotation, anteroposterior translation of both femoral condyles during squatting and deep knee flexion activities were evaluated using model-image registration techniques.
Findings: We found some statistically significant, but small differences among the three groups in dynamic and static knee kinematics. In squatting, total femoral rotation for knees with fixed- and mobile-bearing implants, and knees with fixed-bearing implants after severe preoperative varus deformity, was not significantly different. [7° (SD3°), 9° (SD3°), 8° (SD3°), respectively, $P=0.08$].
Interpretation: Similar kinematic results for knees with different tibial bearing surfaces and preoperative deformities indicate a robust treatment with this posterior stabilized implant. However, knees did not exhibit normal femoral rotations or functional flexion ranges.

1. Introduction

Mobile-bearing prostheses for total knee arthroplasty (TKA) were introduced in the late 1970s to provide high conformity and low contact stress between the femoral component and the polyethylene insert (Buechel and Pappas, 1986; Goodfellow and O'Connor, 1978; Minns and Campbell, 1978). Mobile-bearing prostheses have theoretical advantages over fixed bearing prostheses in terms of reducing shear forces on the polyethylene insert and the bone-cement prostheses interface, minimizing polyethylene wear, self-aligning, and preventing losses in range of motion. Previous in vitro studies have confirmed the advantages of these design concepts in terms of contact stress, contact area, and polyethylene wear (Bottlang et al., 2006; Matsuda et al., 1998; McEwen et al., 2005). However, clinical studies have not proven the superiority of mobile-bearing prostheses over fixed-bearing prostheses with regard to range of motion, clinical score, or long-term survival rates (Bhan et al., 2005; Chiu et al., 2001; Harrington et al., 2009; Matsuda et al., 2010) .

Several in vivo studies using fluoroscopic imaging and shape-matching techniques have examined knee kinematics after mobile-bearing TKA, but have not contrasted kinematics with similar fixed-bearing implants (Banks and Hodge, 2004a, 2004b; Banks et al., 1991; Futai et al., 2011; Garling et al., 2007; Komistek et al., 2004; Nakamura et al., 2009). Several in vivo studies have compared tibiofemoral rotations of mobile- and fixed-bearing variants of posterior stabilized prostheses and found greater femoral external rotations in the mobile-bearing knees (Delport et al., 2006; Ranawat et al., 2004; Shi et al., 2008). However, these studies involved implants with different articular geometries, or the patients were studied in non-weightbearing postures. We believe that the weightbearing kinematic characteristics of mobile-bearing implants should be contrasted with identical fixed-bearing designs to elucidate any actual in vivo kinematic differences, preferably in single-surgeon, matched patient series.

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Similarly, there have been reports comparing clinical outcomes of knee arthroplasty with mild and severe varus deformity (Karachalios et al., 1994; Teeny et al., 1991), but very little quantitative study contrasting how knees with severe preoperative varus move compared to those with mild preoperative varus. It is easy to assume that knees with more severe preoperative deformity will demonstrate less femoral external rotation and anteroposterior (AP) translation after arthroplasty, but it remains possible that modern surgical techniques and implants provide equivalent kinematic results for the typical range of preoperative deformities.

Therefore, we have analyzed in vivo kinematic patterns of mobile- and fixed-bearing posterior stabilized knee prostheses in a single-surgeon series using the same implant design. We sought to address two questions: First, do matched knees with fixed- and mobile-bearing variants of the same implant show different kinematics? Based upon the observation that mobile-bearing inserts provide little resistance to axial rotation, while fixed-bearing inserts provide increasing torsional resistance with increasing weight-bearing internal/external rotation, we hypothesized that mobile-bearing prostheses would show greater femoral axial rotation compared to fixed bearing prostheses. Second, does preoperative deformity affect knee kinematics during functional tasks with posterior-stabilized fixed-bearing arthroplasty? Based upon the observation that severely deformed knees often have contractures and limited joint mobility, we hypothesized that the knees with preoperative severe deformities would have less femoral axial rotation and less tiobiofemoral translation than those with mild preoperative deformity.

Table 1
Pre- and post-operative basic data on 3 groups.

Demographic variables		MB (n = 16)	FB (n = 16)	SFB (n = 16)
Age at surgery (years)		70 (SD 6)	71 (SD 7)	74 (SD 7)
Sex (male/female)		5/11	5/11	1/15
Body mass index		26 (SD 4)	27 (SD 6)	26 (SD 4)
Diagnosis (OA/RA)		12/4	12/4†	16/0‡
Preop	FTA	180 (SD 4)	181 (SD 8)†	195 (SD 5)‡
	Extension (°)	−8 (SD 8)	−6 (SD 9)	−10 (SD 13)
	Flexion (°)	128 (SD 18)	128 (SD 16)†	108 (SD 23)‡
	KS Knee score	46 (SD 14)	37 (SD 10)	33 (SD 14)‡
	KS Function score	45 (SD 14)	41 (SD 19)	41 (SD 18)
Postop	FTA	174 (SD 2)	174 (SD 2)	175 (SD 2)
	Extension (°)	−1 (SD 2)	−1 (SD 2)	−2 (SD 4)
	Flexion (°)	122 (SD 10)	128 (SD 14)	122 (SD 12)
	KS Knee score	93 (SD 5)	94 (SD 5)	93 (SD 7)
	KS Function score	76 (SD 14)	76 (SD 21)	69 (SD 13)
Follow-up period (years)		3.4 (SD 1.1)*	2.4 (SD 0.7)	2.0 (SD 0.3)‡

MB: Mobile-bearing group, FB: Fixed-bearing group.
SFB: Severe deformity fixed bearing group.
OA: Osteoarthritis, RA: Rheumatoid Arthritis, FTA: Femoro-tibial Angle.
KS: Knee Society.
* Significant difference between the MB and FB group.
† Significant difference between the FB and SFB group.
‡ Significant difference between the SFB and MB group.

2. Methods

A total of 58 knees in 48 patients were involved in this study from a consecutive TKA series. We recruited patients who underwent primary TKA using a posterior stabilized prosthesis (NexGen LPS Flex, Zimmer, Warsaw, IN, USA) from August 2004 to July 2008 and had at least 1.5 years post-surgical follow-up. Every patient satisfying these criteria was asked to take part in this study, and all patients willing to participate were included. A single surgeon (TW) performed all surgeries using a mini-midvastus approach (Watanabe et al., 2009) at the same institution. From August 2004 to May 2007, a mobile-bearing prosthesis was used for patients with femoro-tibial angles less than 190°, while fixed-bearing implants were used for more severely deformed knees. After May 2007, fixed-bearing prostheses were used for all patients. All patients gave informed consent to take part in the study, which was approved by the relevant institutional review boards.

All knees received femoral components of an identical design. Sixteen knees received mobile-bearing tibial prostheses (mobile-bearing group) and 42 knees received fixed-bearing tibial prostheses. From the 42 fixed-bearing knees, we selected the 16 knees which were best matched to the mobile-bearing group in terms of age at surgery, sex, diagnosis, preoperative deformity, range of motion, and Knee Society Score (fixed-bearing group). We also selected 16 knees with severe preoperative deformity from the remaining fixed-bearing knees as a third group (severe deformity group). The pre- and post-operative demographic data show no significant differences between the mobile- and fixed-bearing groups except for follow-up period, while there were significant differences between the severe deformity group and the other two groups (Table 1).

For the study, a series of dynamic radiographs and 5 static lateral radiographs were taken for each patient. For dynamic radiographs, we selected a proper height box (15 cm, 25 cm, and 35 cm) for each patient and determined foot position so the patient could stand up with full knee extension and sit down with maximum knee flexion. A series of continuous sagittal X-ray images of sitting down and standing up on the box were taken using a flat panel detector (Sonialvision Safire II, Shimadzu, Kyoto, Japan: 7.5 frames/s, 367.20 mm × 367.20 mm image area, 3.922 pixels/mm resolution.) We used images of the sitting down phase, from extension to flexion, for this study.

Static radiographs were taken using the same detector (365.76 mm × 365.76 mm image area, 7.874 pixels/mm resolution) in the following 5 positions: (1) straight-leg standing, (2) lunge at 90° flexion, (3) lunge at maximum flexion, (4) kneeling at 90° flexion and (5) kneeling at maximum flexion. For lunge each patient puts their foot on a 15 to 35 cm box and bent the knee to approximately 90° and to maximum comfortable flexion. For kneeling each patient put their shin on a padded 15 to 35 cm box with their foot hanging freely. The motion started with the knee at 90° flexion and concluded at maximum comfortable flexion. An investigator (TW) was always available to hold the patient's hands or forearms as a safety measure to prevent the patient from losing balance.

The radiographs were digitized and analyzed according to published techniques (Banks and Hodge, 1996). Briefly, the three-dimensional position and orientation of the implant components were determined using model-based shape matching techniques, applying nonlinear least-squares minimization to refine an initial manual solution. A manufacturer-supplied implant surface model was projected onto the digitized image, and its three-dimensional pose was iteratively adjusted to match its silhouette with the silhouette of the patient's knee arthroplasty components. The results of this shape-matching process have standard errors of approximately 0.5 to 1.0° for rotations and 0.5 to 1.0 mm for translations in the sagittal plane (Banks and Hodge, 1996).

Implant flexion angles between the femoral and tibial components (a negative value means extension), femoral rotation angles (a positive value means femoral external rotation), and varus/valgus angles (a positive value means valgus) were evaluated based on the implant axes. AP locations of each femoral condyle were estimated as the lowest point on each femoral condyle relative to the transverse plane of the tibial baseplate (a negative value means posterior to the centerline of the baseplate).

Analysis of variance (ANOVA) and Chi square tests were used to compare the pre- and post-operative demographic data for the three groups. ANOVA and post hoc tests (Tukey) were used for comparisons of the kinematic data of the three groups. Probabilities (*P*-values) less than 0.05 were considered significant.