# *Are undesirable contact kinematics minimized after kinematically aligned total knee arthroplasty? An intersurgeon analysis of consecutive patients*

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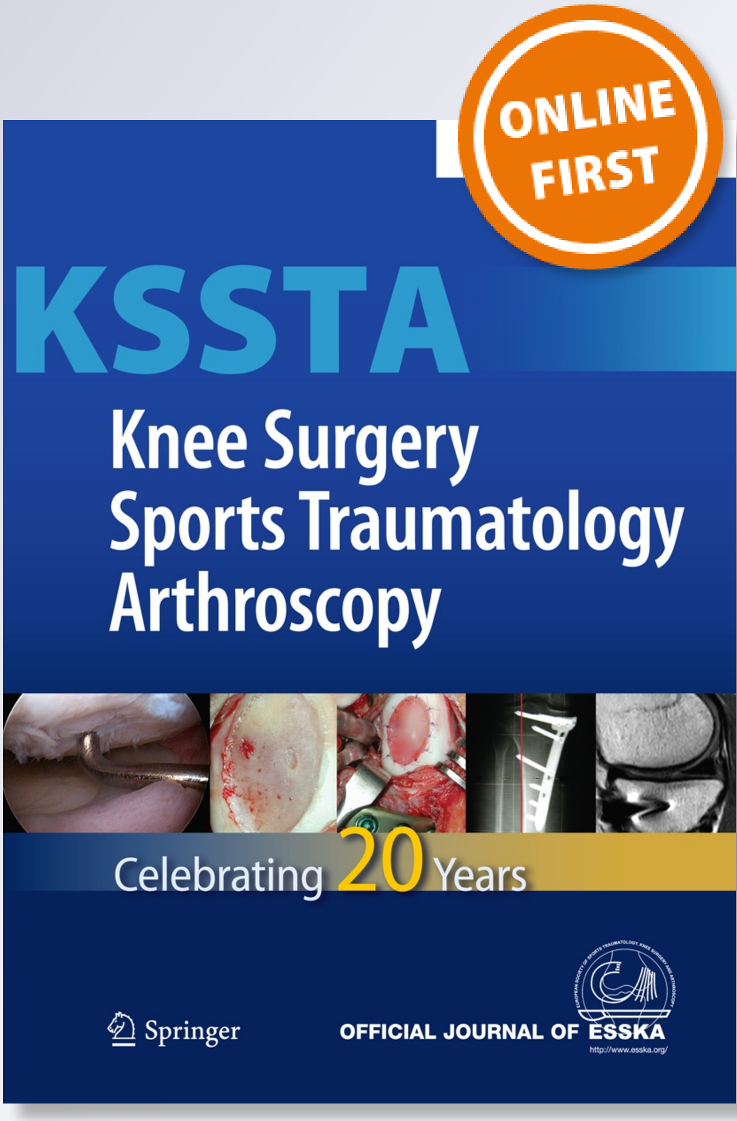

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# Are undesirable contact kinematics minimized after kinematically aligned total knee arthroplasty? An intersurgeon analysis of consecutive patients

Stephen M. Howell · Esther E. Hodapp · Joseph V. Vernace · Maury L. Hull · Thomas D. Meade

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**Abstract**
*Purpose* Tibiofemoral contact kinematics or knee implant motions have a direct influence on patient function and implant longevity and should be evaluated for any new alignment technique such as kinematically aligned total knee arthroplasty (TKA). Edge loading of the tibial liner and external rotation (reverse of normal) and adduction of the tibial component on the femoral component are undesirable contact kinematics that should be minimized. Accordingly, this study determined whether the overall prevalence of undesirable contact kinematics during standing, mid kneeling near 90 degrees and full kneeling with kinematically aligned TKA are minimal and not different between groups of consecutive patients treated by different surgeons.
*Methods* Three surgeons were asked to perform cemented, kinematically aligned TKA with patient-specific guides in a consecutive series of patients with their preferred cruciate-retaining (CR) implant. In vivo tibiofemoral contact positions were obtained using a 3- to 2-dimensional image registration technique in 69 subjects (Vanguard CR–TKA $N = 22$, and Triathlon CR–TKA $N = 47$).
*Results* Anterior or posterior edge loading of the tibial liner was not observed. The overall prevalence of external rotation of the tibial component on the femoral component of 6 % was low and not different between surgeons (n.s.). The overall prevalence of adduction of the tibial component on the femoral component of 4 % was low and not different between surgeons (n.s.).
*Conclusions* Kinematically aligned TKA minimized the undesirable contact kinematics of edge loading of the tibial liner, and external rotation and adduction of the tibial component on the femoral component during standing and kneeling, which suggests an optimistic prognosis for durable long-term function.
*Level of evidence* III.

**Keywords** Total knee arthroplasty · Kneeling · Kinematic alignment · Kinematics

Ethical Board Review statement: Approved by the BioMed IRB, San Diego, CA.

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## Introduction

Kneeling is an integral part of daily life, work and sport after total knee arthroplasty (TKA) during which undesirable contact kinematics or patterns of motion consisting of anteroposterior (AP) edge loading of the tibial liner, and external (reverse of normal) rotation and adduction of the tibial component on the femoral component may occur. Kneeling on the tibial tubercle displaces the tibia posterior with respect to the femur and can edge load the tibial liner and predispose to wear [3, 9]. External rotation of the tibial component with knee flexion is a pattern of motion opposite to that of the normal knee that might limit knee flexion, alter patellofemoral tracking, increase patellar contact forces and cause patellar failure [4, 5, 20, 23, 27]. Adduction, or lift-off of the lateral tibial condyle, can

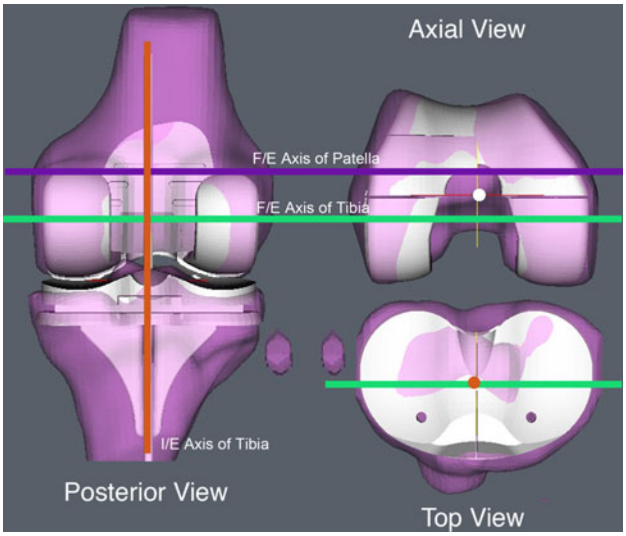


**Fig. 1** Kinematically aligned TKA matches the surfaces of the best-fitting femoral and tibial components to the articular surface of the normal knee model. Matching the surfaces restores the two parallel transverse axes in the femur about which the tibia (*green line*) and patella (*magenta line*) flex and extend (*F/E*), and restores the longitudinal axis in the tibia (*orange line*) about which the tibia internally and externally rotates (*I/E*) on the femur

overload the medial compartment and may cause asymmetrical polyethylene liner wear, tibial component loosening and mechanical failure [18, 28, 29]. Therefore, minimizing these undesirable contact kinematics should be an important objective of any alignment strategy for TKA.

A new alignment strategy that strives to restore prearthritic knee alignment and avoid release of the collateral and retinacular ligaments is a kinematic alignment [10–14, 26]. The principle step in kinematically aligned TKA is co-aligning the transverse axis of the femoral component about which the tibial component flexes and extends to the femur's transverse axis (Fig. 1). The soft tissues are handled by removing marginal osteophytes to restore the length of the collateral and retinacular ligaments [11–14, 26]. It is unknown whether the use of an alignment strategy that avoids release of the collateral and retinacular ligaments minimizes undesirable contact kinematics.

The primary purpose of this study was to determine whether the overall prevalence of undesirable contact kinematics during standing, mid kneeling near 90 degrees of flexion and full kneeling with kinematically aligned TKA are minimal and not different between groups of consecutive patients treated by different surgeons with the cruciate-retaining (CR) implant they prefer. The secondary purpose was to report the overall patient function as measured by the Oxkord Knee Score and determine whether the function is different between consecutive patients treated by different surgeons at 6 months.

## Materials and methods

A multi-centre study involving three surgeons (*A*, *B*, and *C*) was instituted in 2008, which considered all patients requiring a TKA considered for inclusion in the study. Included were patients with osteoarthritis of the knee with or without previous open or arthroscopic meniscectomy or ligament reconstruction, with any degree of motion loss and varus/valgus deformity, and who lived within a 50-mile radius of the treating surgeon. Excluded were patients with chronic PCL or collateral ligament insufficiency, inflammatory arthritis, neuropathic knee, fracture and osteotomy about the knee, and internal fixation of the femur and tibia. The study consisted of 66 patients with 69 TKAs (3 bilateral) with Surgeon *A* contributing 22 patients, Surgeon *B* contributing 21 patients and Surgeon *C* contributing 26 patients. Surgeon *A* preferred one brand of a fixed-bearing, cruciate-retaining implant (Vanguard; Biomet, Inc, Warsaw, IN) and Surgeon *B* and *C* preferred another brand (Triathlon; Stryker, Mahwah, NJ). In both brands, the sagittal and coronal radii of the bearing surfaces of the two prostheses were symmetric and the tibial bearings were fixed. An institutional review board approved the study (Protocol Number SMH-S58, BioMed IRB, San Diego, CA.)

Each patient was treated with a kinematically aligned TKA with patient-specific, six degree-of-freedom, femoral and tibial cutting guides that were created preoperatively from a 3-D surface model of the knee made from an MRI of the knee with the use of a previously described technique [10, 14, 26]. Proprietary software generated a 3-D model of the arthritic knee from an MRI (OtisMed Corp, Alameda, CA). The 3-D arthritic knee model was transformed into a normal knee model by filling in worn areas, removing osteophytes and approximating the joint surface. The best-fitting 3-D model of the femoral component (Fig. 1) was selected and shape fitted to the restored articular surface of the femur from 15 to 115 degrees. In theory, kinematic alignment restores the normal parallel and perpendicular interrelationships between the three kinematic axes of the prearthritic knee [12–14]. The planes of the bone cuts were transferred from the normal to the arthritic 3-D model and then to the patient-specific cutting guides.

Intraoperatively, the femoral guide was seated, pinned, and the distal cut was made. The four remaining femoral cuts were made with a 4-in-1 chamfer guide. The posterior cruciate ligament (PCL) was retained. The tibial guide was seated, pinned, and the proximal cut was made. Flexion contractures were corrected with removal of posterior osteophytes and a release of the posterior capsule [25]. Medial or lateral tightness was corrected by the removal of marginal osteophytes. Release of the collateral ligaments was not performed. The internal–external rotation of the tibial component was aligned to the articular tibial drill holes made to secure the tibial cutting guide by Surgeons *A* and *B*. Surgeon *C* used the range-of-motion technique in which the femoral component rotates the 'floating' tibial trial and baseplate into position as the knee is passively flexed and extended. The components were cemented, and the patella was resurfaced in all cases.

One observer measured the patterns of motion of the tibial component on the femoral component using a previously described method [2, 3, 6, 10, 17]. Three lateral radiographs of the subject's knee were taken in the following positions: standing, mid kneeling (approximately 90° of flexion) and full kneeling. The patient knelt on a padded stool with the opposite leg behind them and out of the field of view. The centre of the knee, X-ray beam and film cassette were co-aligned. The focal distance was standardized at 40 inches [3, 17].

The radiographs were digitized with the use of a high-resolution flatbed scanner and processed to delineate the components from the surrounding tissues. The in vivo component relationships were then ascertained from a comparison with manufacturer-supplied, computer-generated geometric models of each knee arthroplasty design. The in vivo position and orientation of the components at each knee position were determined from computer matching the silhouette of the geometric model of the femoral and tibial baseplate with the radiographic silhouette on the digitized radiograph. Rotation was determined by matching the two-dimensional projection of the metal with the known projection of geometric models. The image-matching programme tracks the 3D motion of the tibial baseplate and the femoral component. Because the polyethylene insert is rigidly attached to the tibial baseplate, the 3D motion of the insert is determined from referencing the tibial baseplate [2, 6, 17, 27]. Computer modelling studies and controlled mechanical tests assessed the accuracy of the technique. The reported results indicate that knee rotations are measured with an accuracy of approximately one degree and that sagittal plane translations are measured with an accuracy of approximately 0.5 mm [2]. The computer-aided design models and the measured 3D positions and orientations of the components were used to determine the locations of closest proximity or contact between the components. Contact between the components was determined by evaluating the minimum distance between the 2 surfaces, with any distance <1.0 mm taken as representing contact. The flexion angle between the femoral and tibial components was measured. The AP movement of the contact position of the medial and lateral condyles of the tibial component on the femoral component was referenced to the centre of the tibial liner and measured in millimetres [2, 3, 6, 17, 27]. Four dependent variables were measured: anterior (+)–posterior (−) contact position of the medial and lateral condyles of the tibia on the femoral component, and internal (+)–external (−) rotation and abduction (+)–adduction (−) of the tibial component on the femoral component.

Pre-operatively and at 6-month follow-up, function was determined with a hand-held computerized device that the patient filled out, which reduced interviewer and non-responder bias (MedTrak, Conshohocken, Pennsylvania) [15]. Function was determined by the Oxford Knee Score (best 48, worst 0) and the Knee Society Score (best 100, worst 0). Varus and valgus deformity, extension, and flexion were measured with a long-arm goniometer.

### Statistical analysis

A power analysis was performed to determine the minimum number of subjects required to achieve an a priori statistical power of 0.80 with an alpha of 0.05. Based on a standard deviation of 2.0° for abduction–adduction rotation [22, 24], 4° for internal–external rotation [7, 24], and 3 mm for the anterior–posterior contact positions of the lateral and medial femoral condyles on the tibial component [9], and a clinically meaningful difference of 3° for abduction–adduction rotation, a 4° difference in internal–external rotation, and a 3 mm difference in the anterior–posterior contact positions of the lateral and medial femoral condyles on the tibial component, each surgeon needed to treat a minimum of 21 subjects.

The arithmetic mean and standard deviation (SD) were used to describe the overall contact kinematics (anterior–posterior position of the tibial component on the medial and lateral femoral condyles, and internal–external rotation and abduction–adduction of the tibial component on the femoral component), demographic data [sex, age, body mass index (BMI)] and function (varus–valgus alignment, extension, flexion, Oxford Score and Knee Society Score). A two-factor repeated-measures ANOVA and a Tukey post hoc test were performed to determine whether the contact kinematics at each flexion angle were different between patients grouped by surgeon. A single factor analysis of variance (ANOVA) and a Tukey post hoc test were used to determine whether the demographic and function were different between patients grouped by surgeon. The level of significance was set at $p < 0.05$.

## Results

The study consisted of 42 females and 24 males with a mean age of 65 ± 11 years (range, 36–85 years). There were no significant differences in age, BMI, preoperative flexion and preoperative varus/valgus deformity between patients grouped by surgeon (Table 1).

**Table 1** Demographic and preoperative information for all patients and patients grouped by surgeon

| Group | Number of subjects | Number of TKAs | Age (years) | Body mass index (kg/m$^2$) | Preoperative extension (degrees) | Preoperative flexion (degrees) | Preoperative varus (−)/ valgus (+) (degrees) |
|---|---|---|---|---|---|---|---|
| All TKA's | 66 | 69 | 65.0 ± 11.4 (36–85) | 30.4 ± 5.3 (18–43) | 6 ± 6.2 (0–25) | 113 ± 12.1 (78–135) | 1.1 ± 5.3 (−10 to 15) |
| Surgeon *A* | 22 | 22 | 64.1 ± 12.2 (36–85) | 31.2 ± 5.1 (23–42) | 9 ± 7.4 (0–25) | 108 ± 14.2 (78–125) | 0.8 ± 5.7 (−10 to 15) |
| Surgeon *B* | 21 | 21 | 69.2 ± 9.1 (48–82) | 29.3 ± 6.4 (18–43) | 7 ± 5.2 (0–16) | 116 ± 12.2 (95–135) | 3.8 ± 4.5 (−5 to 15) |
| Surgeon *C* | 23 | 26 | 62.2 ± 11.7 (39–85) | 30.6 ± 4.3 (21–40) | 1.7 ± 2.1 (0–5)* | 114 ± 8.9 (90–125) | 0.5 ± 4.9 (−8 to 7) |

Values outside the parentheses are the means ± standard deviations. Values inside parentheses are the range. Means with * indicate they are significantly different between patients grouped by surgeon ($p < 0.05$)

**Table 2** Change in the AP contact position of the medial and lateral tibial condyles on the femoral component between knee movements of standing to mid kneeling and mid kneeling to full kneeling for all patients and patients grouped by surgeon

| Group | Component | Change in contact position on medial tibial condyle (+ anterior, −posterior) | | Change in contact position on lateral tibial condyle (+ anterior, −posterior) | |
|---|---|---|---|---|---|
| | | Standing to mid kneeling (mm) | Mid kneeling to full kneeling (mm) | Standing to mid kneeling (mm) | Mid kneeling to full kneeling (mm) |
| All TKA's | | 5.7 ± 5.0 (−11 to 16) | −1.4 ± 5.0 (−13 to 14) | 2.0 ± 5.5 (−11 to 16) | −4.0 ± 4.0 (−12 to 15) |
| Surgeon *A* | Vanguard CR | 6.7 ± 4.7 (−3 to 16) | 1.3 ± 3.3 (−7 to 9) | 2.0 ± 5.4 (−10 to 10) | −3.6 ± 2.9 (−10 to 3) |
| Surgeon *B* | Triathlon CR | 5.0 ± 4.8 (−6 to 13) | 2.1 ± 5.6 (−7 to 14) | 3.2 ± 5.6 (−6 to 13) | −2.1 ± 5.0 (−11 to 15) |
| Surgeon *C* | Triathlon CR | 5.6 ± 5.4 (−11 to 16) | −4.2 ± 3.9 (−13 to 5)* | 1.0 ± 5.4 (−7 to 16) | −6.0 ± 3.2 (−12 to 3)* |

Values outside the parentheses are the mean ± standard deviation of the change in AP contact position on the tibial condyle (+ anterior/− posterior). Values inside parentheses are the range. For a knee movement, means with * indicate they are significantly different between patients grouped by surgeon ($p < 0.05$)

In terms of the AP contact position of the medial and lateral tibial condyles on the femoral component, the mean contact remained fairly centred on the tibial liner with no edge loading when standing (medial 3.6 ± 3.1; lateral 4.4 ± 3.1), mid kneeling (medial 2.1 ± 4.2; lateral 2.5 ± 4.5) and full kneeling (medial 0.7 ± 4.5; lateral −6.5 ± 4.6) for all subjects (Table 2). The contact position of the medial and lateral tibial condyle moved posterior from standing to mid kneeling and the pattern of motion was not different between patients grouped by surgeon. The contact position of the medial tibial condyle moved anterior from mid kneeling to full kneeling and the pattern of motion was not different between patients grouped by surgeon. The contact position of the lateral femoral condyle of Surgeon *A* and *C* moved posterior from mid kneeling to full kneeling, whereas the contact position of the group by Surgeon *B* did not move posterior.

In terms of internal/external rotation of the tibial component on the femoral component, the tibial component internally rotated on the tibia from standing to mid kneeling and from mid kneeling to full kneeling (Table 3). The pattern of axial rotation was not different between patients grouped by surgeon, was greatest from standing to mid kneeling, was least from mid kneeling to full kneeling and was similar to the normal knee.

In terms of abduction/adduction of the tibial component on the femoral component, adduction was infrequent and was observed in 2.8 % of patients when standing and full kneeling and 4 % of subjects when mid kneeling (Table 4). The pattern of abduction/adduction was not different between patients grouped by surgeon.

In terms of function, the mean Oxford Knee Score, standing to kneeling range-of-motion and active flexion were not different between patients grouped by surgeon (Table 5). The Knee Society Score was significantly lower in the group by Surgeon *C*.

## Discussion

The most important finding in this in vivo study of a consecutive series of kinematically aligned TKAs treated by three surgeons is that the anterior–posterior contact position of the medial and lateral femoral condyles remains

**Table 3** Mean axial rotation of the tibial component on the femoral component between knee movements and number (percentage) of TKAs with a normal pattern and various amounts of axial rotation for all patients and patients grouped by surgeon

| Group | Component | Average axial rotation standing to mid kneeling (degrees) | Average axial rotation from mid kneeling to full kneeling (degrees) | TKA with a normal pattern of external femoral rotation between standing and full kneeling | TKA with axial rotation > 5° | TKA with axial rotation > 15° |
|---|---|---|---|---|---|---|
| All TKA's | | 6.3 ± 6.9 (−18 to 23) | 1.9 ± 3.9 (−12 to 14) | 65 (94 %) | 58 (84 %) | 11 (16 %) |
| Surgeon *A* | Vanguard CR | 5.9 ± 6.7 (−10 to 23) | 2.4 ± 3.6 (−3.4 to 14) | 22 (100 %) | 17 (77 %) | 1 (5 %) |
| Surgeon *B* | Triathlon CR | 7.4 ± 4.1 (0 to 17) | 1.5 ± 2.8 (−3 to 8) | 21 (100 %) | 18 (86 %) | 2 (10 %) |
| Surgeon *C* | Triathlon CR | 5.8 ± 8.7 (−18 to 22) | 1.7 ± 4.9 (−12 to 12) | 22 (85 %) | 21 (81 %) | 7 (27 %) |

Values outside the parentheses are the mean ± standard deviation of the axial rotation of the tibial component on the femoral component (+ internal rotation/− external rotation). Values inside parentheses are the range. For a knee movement, means with * indicate they are significantly different between patients grouped by surgeon ($p < 0.05$)

**Table 4** Mean abduction/adduction (AB/AD) of the tibial component on the femoral component and number (percentage) of TKAs with adduction greater than 1 degree for different knee positions for all patients and patients grouped by surgeon

| Group | Component | Average AB/AD standing (degrees) | Average AB/AD at mid kneeling (degrees) | Average AB/AD at full kneeling (degrees) | TKA with adduction > 1° at 0° | TKA with adduction > 1° at 0° at mid kneeling | TKA with adduction > 1° at full kneeling |
|---|---|---|---|---|---|---|---|
| All TKA's | | 0.4 ± 1.1 (−1 to 7) | 0.9 ± 1.2 (−2 to 4) | 1.1 ± 1.5 (−2 to 6) | 2 (2.8 %) | 3 (4 %) | 2 (2.8 %) |
| Surgeon *A* | Vanguard CR | 0.0 ± 0.6 (−1 to 2) | 1.0 ± 1.2 (−2 to 4) | 1.5 ± 1.8 (−2 to 6) | 1 (5 %) | 1 (5 %) | 0 (0 %) |
| Surgeon *B* | Triathlon CR | 0.4 ± 0.7 (−1 to 2) | 1.0 ± 1.0 (−1 to 3) | 1.3 ± 1.0 (−1 to 3) | 0 (0 %) | 0 (0 %) | 0 (0 %) |
| Surgeon *C* | Triathlon CR | 0.7 ± 1.5 (−1 to 7) | 0.7 ± 1.2 (−1 to 3) | 0.8 ± 1.5 (−2 to 5) | 1 (4 %) | 2 (8 %) | 2 (8 %) |

Values outside the parentheses are the mean ± standard deviation of abduction/adduction of the tibial component on the femoral component (+abduction/− adduction). Values inside parentheses are the range. For all TKA's, means with * indicates a significant difference in abduction/adduction between knee positions ($p < 0.05$)

well centred on the tibia, undesirable contact kinematics are minimal, and these kinematics are not different between patients grouped by surgeon. Of secondary importance is that knee function, as measured by the Oxford Knee Score and restoration of knee flexion, is high and not different between patients grouped by surgeon

The ability to kneel is a function that most patients want to resume after TKA. Kneeling is deemed 'safe' when the anterior–posterior contact position between the medial and lateral femoral condyles and the tibial component remains within the intended articulation range of the implants when mid kneeling and full kneeling [3]. The present study showed that the anterior–posterior contact position of the medial and lateral femoral condyles had no edge loading and was more centred on the tibial liner than a selected series of well-functioning, mechanically aligned Advance Medial-Pivot TKAs (Wright Medical Technology, Arlington TX) and the Advance Double-High TKAs (Wright Medical Technology) [3]. For the Advance Medial-Pivot knee with PCL retention, the maximum change in the contact position of the medial femoral condyle was 3.4 times more anterior, and the maximum change in the contact position of the lateral femoral condyle was 1.8 times more posterior than in the present study. For the Advance Medial-Pivot knee with PCL resection, the maximum change in the contact position of the medial femoral condyle was 3.4 times more anterior, and the maximum change in the contact position of the lateral femoral condyle was 4.7 times more anterior than in the present study. Accordingly, the tibial liner of the kinematically aligned TKA is centrally loaded during standing and kneeling.

It is important to minimize the external rotation of the tibial component on the femoral component during knee

**Table 5** Function and motion determined at 6 months postoperatively for all patients and patients grouped by surgeon

| Group | Function measured by Oxford Knee Score (48 best) | Function measured by Knee Society Score (100 best) | Standing to full kneeling range-of-motion (degrees) | Active flexion (degrees) |
|---|---|---|---|---|
| All TKA's | 42 ± 4.8 (28–48) | 93 ± 6.1 (70–100) | 107 ± 13.4 (68–137) | 119 ± 8.0 (105–140) |
| Surgeon *A* | 41 ± 5.5 (29–48) | 97 ± 4.4 (80–100) | 107 ± 16.5 (68–137) | 118 ± 8.3 (105–135) |
| Surgeon *B* | 41 ± 5.5 (29–48) | 94 ± 7.1 (70–100) | 106 ± 12.2 (78–125) | 120 ± 8.0 (116–120) |
| Surgeon *C* | 43 ± 3.4 (34–48) | 89 ± 3.3 (85–100)* | 109 ± 11.7 (79–129) | 123 ± 7.2 (110–140) |

Values outside the parentheses are the means ± standard deviations. Values inside parentheses are the range. Means with * indicate they are significantly different between patients grouped by surgeon ($p < 0.05$)

flexion because it alters patellofemoral tracking, increases patellar contact forces and may cause patella failure [4, 5, 20, 23, 27]. We observed a normal pattern of internal rotation of the tibial component on the femoral component with knee flexion in 100 % of the patients treated by Surgeon *A* and *B*. In contrast, we observed an abnormal pattern of external rotation of the tibial component in 15 % of the patients treated by Surgeon *C*, which we attribute to Surgeon *C* setting the axial rotation of the tibial component by range-of-motion technique in which the femoral component rotates the 'floating' tibial trial and baseplate into position as the knee is passively flexed and extended instead of the patient-specific tibial guide. The range-of-motion technique tends to leave the tibial component internally rotated [16] and may explain why a higher percentage of Surgeon *C*'s patients had external rotation of the tibial component with knee flexion.

Adduction, or lateral lift-off of the tibial condyle, overloads the medial compartment and may cause asymmetrical polyethylene liner wear, tibial component loosening and mechanical failure [18, 28, 29]. Adduction was minimal in the present study and occurred in 2.8 % of patients when standing and 4 % of patients when mid kneeling and full kneeling.

In the present study, the mean Oxford Knee Score for patients grouped by surgeon ranged from 41 to 43 and the mean active knee flexion for patients grouped by surgeon ranged from 118 to 123°, which indicates high and consistent function and flexion 6-month postoperatively. The mean Oxford Knee Score of 42 for all kinematically aligned TKAs in the present study is comparable if not higher than the mean Oxford Knee Score of 35 for mechanically aligned TKA reported at 1 year by the National Joint Registry for England and Wales [1], and the mean Oxford Knee Score of 37 for mechanically aligned TKA reported at 6 months by the New Zealand Joint Registry [21]. Because a unit decrease in the Oxford Score at 6 months increases the revision rate 10 % at 2 years [21], the relatively high Oxford Knee Score of the kinematically aligned TKAs suggests that the revision rate for kinematically aligned TKA might be relatively low at 2 years.

One concern of surgeons interested in kinematically aligned TKA is whether the postoperative alignment of the limb, knee and components predisposes the knee to a higher rate of wear, loosening and aseptic revision than a mechanically aligned TKA [19]. A prospective, double blind, randomized clinical trial of 82 subjects showed that both the hip–knee–ankle angle of the limb and the femoral–tibial angle of the knee of the kinematically aligned TKAs were similar to those of mechanically aligned TKA with conventional instruments; however, the obliquity of the joint line was more anatomic in the kinematically aligned TKA. The more anatomic joint line in the kinematically aligned TKAs was associated with a 7-point better Oxford Knee Score (mean 42) and 5 degrees more knee flexion (mean 120 degrees) than those of mechanically aligned TKA at 6 months. Because limb and knee alignment is similar for the kinematically and mechanically aligned TKA, the rate of wear, loosening and aseptic revision might be similar as well [8, 12].

The study has some limitations. First, the present study provided a limited evaluation of kinematics, namely kneeling, and did not evaluate squatting, lunging and other daily activities, which are of equal interest to the patient and surgeon. Second, the analysis and clinical follow-up at 6 months is too short to determine the effects of contact kinematics on wear and long-term survival. However, a study of 215 kinematically aligned TKAs showed a zero incidence of catastrophic failure and a high mean Oxford knee and WOMAC Scores at a minimum of 31 months regardless of whether the alignment of the tibial component, knee and limb was categorized as either in range, varus outlier or valgus outlier. Furthermore, their 1.4 % incidence of reoperation for any reason (except deep infection) was comparable to, if not lower than, the 2.8 % incidence of reoperation for mechanically aligned TKA with the same component design reported in the Australian registry at 3 years [11]. Third, the surgeon's judgment determined whether the TKA was balanced and aligned without release of the collateral ligaments. Although the three surgeons in this study did not perform a collateral ligament release on their patients, another surgeon treating these same patients or patient with more severe deformities might have preferred to perform a collateral ligament release.

## Conclusion

In conclusion, the use of kinematically aligned TKA, in a consecutive series of patients treated by three surgeons, resulted in consistent findings of desirable contact kinematics, minimization of undesirable kinematics, high function and high flexion, which collectively suggest an optimistic prognosis for durable long-term function.

**Conflict of interest** No authors have signed any agreement with a commercial interest related to this study which would in any way limit publication of any and all data generated for the study or to delay publication for any reason. One of the authors (S.M.H.) is a paid consultant and receives royalties from Biomet Sports Medicine, Inc, and is a consultant and receives research support from Stryker Orthopaedics. One author (M.L.H.) receives research support from Stryker Orthopaedics. One author (J.V.V.) is a consultant for Stryker Orthopaedics. One author (T.D.M.) is a consultant and receives royalties from Arthrex, Inc.

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