

In-vivo kinematics of high-flex posterior-stabilized total knee prosthesis designed for Asian populations

Toshifumi Watanabe¹ · Takeshi Muneta¹ · Hideyuki Koga¹ · Masafumi Horie¹ · Tomomasa Nakamura¹ · Koji Otabe¹ · Yusuke Nakagawa¹ · Mai Katakura¹ · Ichiro Sekiya¹

Received: 21 November 2015 / Accepted: 16 March 2016 / Published online: 2 April 2016
© SICOT aisbl 2016

Abstract

Purpose The purpose of this study was to determine in-vivo kinematics of our developed posterior-stabilized (PS) total knee prosthesis for Asian populations in comparison with a popular high-flexion PS prosthesis.

Methods We analyzed 62 osteoarthritic knees: 31 knees with the new PS prosthesis (group A) and 31 knees with a popular high-flexion PS prosthesis (group B). Radiographic knee images were taken during standing, lunge, and kneeling activities. The three-dimensional position and orientation of the implant components were determined using model-based shape matching techniques.

Results Group A showed slightly greater implant flexion angles compared with knees with conventional prosthesis at maximum lunge (average: 119 vs. 110°, $p=0.001$), and at maximum kneeling (121 vs. 114°, $p=0.004$), although the range of motion was not significantly different. The femoral centre positions were more posterior in group A at standing, at 90° lunge, at maximum lunge (-9 and -7 mm, $p=0.004$), at 90° kneeling, and at maximum kneeling (-9 vs. -7 mm,

$p=0.016$), and posterior translations of the femoral center were greater at 90° knee flexion postures. The femoral centre positions had a strong negative correlation with implant flexion angles at maximum lunge in group B ($r=-0.893$, $p<0.001$), but not in group A ($p=0.242$).

Conclusions The new PS prosthesis designed for Asian knee morphology achieved flexion angles and range of motion at least comparable to that of conventional high-flexion PS prosthesis. The femoral roll-back pattern, however, is different from a conventional knee, reflecting the post/cam design.

Keywords Asian populations · Implant design · In-vivo kinematics · Posterior-stabilized · Total knee arthroplasty

Introduction

In spite of increasing functionality and long-term survivorship [1, 2], there is still room for improvement in total knee

✉ Toshifumi Watanabe
watanabe.orj@tmd.ac.jp

Takeshi Muneta
muneta.orj@tmd.ac.jp

Hideyuki Koga
koga.orj@tmd.ac.jp

Masafumi Horie
horie.orj@tmd.ac.jp

Tomomasa Nakamura
nakamura.orj@tmd.ac.jp

Koji Otabe
otabe.orj@tmd.ac.jp

Yusuke Nakagawa
ynakagawa.orj@tmd.ac.jp

Mai Katakura
mai-mm@hotmail.co.jp

Ichiro Sekiya
sekiya.orj@tmd.ac.jp

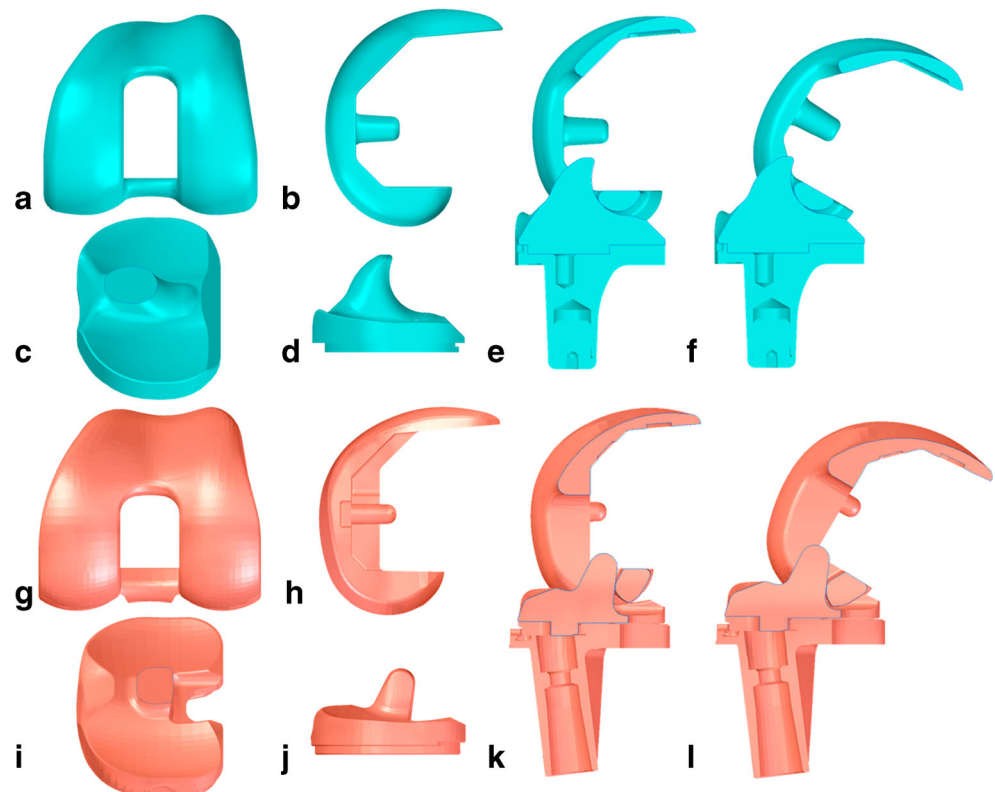
¹ Department of Orthopaedic Surgery, Tokyo Medical and Dental University Hospital of Medicine, 1-5-45 Yushima, Bunkyo-ku, Tokyo 113-8510, Japan

arthroplasty (TKA), and efforts to create better implants and to refine surgical techniques are continuing [3, 4]. The design of prostheses for Asian populations should take into account the morphological differences in knee geometry between races to optimize function, because Asian knees have different morphological features from Caucasian knees [5, 6]. Normal knee kinematics is also different between races [7]. Over time, various prostheses have been developed to achieve better clinical outcomes. Obtaining a smooth functional range of motion [8, 9], stability in daily activities [10, 11], and durability are key factors [12, 13]. To achieve these factors, a prosthesis should fit the cutting surface of the distal femur and proximal tibia to allow smooth tibio-femoral motion. It is reported that current implant designs are not able to achieve enough deep flexion in vivo [14, 15]. High-flexion prostheses have gained popularity; however, early loosening [16] and dislocation [17] have been reported, which brings to question both stability and durability. Extra bone cutting in the posterior condyle for the smaller radii in high-flexion prostheses is also a concern, because bone stock preservation is increasingly important with the rising demand for revision arthroplasty.

Because of this situation, we have developed a high-flexion posterior-stabilized (PS) total knee prosthesis for Asian populations, and have applied it clinically since November 2010 (Fig. 1a–f). The component design was based on CT images of Japanese osteoarthritic knees, aiming to cover most of the size variation in Asian patients. The prosthesis is designed to

achieve functional range of motion with smaller radii in the posterior condyle, but preserves more bone compared with the conventional high-flexion system. The reasons for choosing the PS type were its wide application to various knees including severely deformed knees with a contracted or non-functional posterior cruciate ligament (PCL), and easier surgical maneuvers for surgeons without adding procedures for PCL [18]. Now that the system has a post/cam mechanism, in-vivo kinematics will exhibit guided motion. However, we did not want to force excessive femoral posterior translation that would increase anterior soft tissue tension and may result in anterior knee pain or limited flexion angle. We also wanted to respect the conditions of each knee, and adopted a round-shape post and a slightly concave symmetrical polyethylene insert without extreme constraint to allow smooth femoral rotation and translation. The broad base of the post and lower contact point of the post/cam provide sufficient jumping height to make this implant more stable and durable. The femoral components are made of zirconia ceramics, which exhibited low friction and high durability when used in conjunction with a polyethylene insert in knee simulator tests [19]. Ceramic materials generally provided a harder, more hydrophilic, and more polished surface compared with cobalt-chrome alloy [20], and zirconia ceramics are softer than alumina ceramics with less fracture risk. Although clinical advantages of ceramic component in TKA remain unclear [19, 21], we chose zirconia ceramic materials for femoral

Fig. 1 Implant design of the new posterior-stabilized (PS) total knee prosthesis (a–f) and a popular high-flexion PS prosthesis (g–l) are shown (a, g) Anterior views of the femoral components (b, h) Lateral views of the femoral components (c, i) Oblique supero-lateral views of the polyethylene inserts with the posts being cut at the base (d, j) Lateral views of the polyethylene inserts (e, f, k, l) Sagittal cross-sectional views of the systems at the center at 90° flexion and deep flexion



component, aiming to achieve longer survivorship. Ceramic materials have other advantages of avoiding metal allergies or hypersensitivity, which is generally caused by cobalt-chrome alloy for femoral components [22]; ceramic materials also allow for clear magnetic resonance images to detect post-operative lesions with fewer artifacts compared with metal components [23]. The purpose of this study was to determine the in-vivo kinematics of this new prosthesis in comparison with a popular high-flexion PS prosthesis to understand how the design features of the new prosthesis affect post-operative knee kinematics.

Methods

We analyzed a total of 62 osteoarthritic knees in 43 Japanese patients for this study: 31 knees in 19 patients with the new PS prosthesis (Actiyas, Kyocera Medical, Japan; group A, Fig. 1a-f), and the other 31 knees in 24 patients with a popular high-flexion PS prosthesis as a control group (NexGen LPS-Flex, Zimmer, USA; group B, Fig. 1g-l). Patients in group A underwent TKA from November 2010 to November 2011 at our university hospital. Patients in group B underwent TKA from February 2006 to August 2008 at one of our related institutions where the first author worked. Originally, we performed 99 primary TKAs in 66 patients using Actiyas and 71 primary TKAs in 65 patients using LPS-Flex during the above-mentioned periods. We did not use any cruciate-retaining prostheses during these periods, and all the primary TKAs, except those for knees with severe instability or deformity requiring constrained prosthesis, were performed using Actiyas or LPS-Flex, respectively. We recruited these patients for kinematic analysis. In this step, patients with low activity levels because of other co-existing diseases or aging were excluded at outpatient clinics for safety reasons, and patients who agreed to participate in this study were included. As a result, we obtained in-vivo kinematic data of 38 knees in 23

patients with the new prosthesis and 42 knees in 32 patients with the popular high-flexion PS prosthesis. We excluded knees with rheumatoid arthritis, pre-operative valgus deformity, and pre-operative flexion angle less than 90°. Adapting these exclusion criteria left 31 knees in each group. A sample of 62 knees was computed to produce 83 % power ($1-\beta$) for comparing kinematic values between group A and B using an effect size of 0.75. All patients gave informed consent to participate in this institutional review board approved study. Pre-operative background data were not significantly different (Table 1). Postoperative clinical results at radiographic examination for kinematic study and component angles assessed based on the knee society radiographic assessment were not significantly different, either (Table 2).

The two high-flexion fixed-bearing PS prostheses have similar features and have a few differences (Fig. 1). The similarities are as follows: (1) several radii that become smaller in the posterior condyle to achieve deep flexion without edge loading until 155° flexion, (2) delayed post/cam engagement at 75° of knee flexion when the femoral component is located at the Antero-posterior (AP) center, (3) a symmetrical femoral component, and (4) a slightly concave symmetrical polyethylene insert to allow free translation and rotation. The main design differences of two prostheses that may affect in-vivo knee kinematics are as follows: (1) the shapes of the post and cam. The new prosthesis has a round-shape post in order to allow smooth rotation. The round post has a concave posterior aspect and gentle ridge behind it. The sagittal cross-sectional surface of the cam has an oval shape with the long axis in a proximo-distal direction. These features allow smooth posterior translation of the femur after the post/cam engagement and then restrain increasing posterior translation in deep flexion. On the other hand, the conventional prosthesis has a square-shape post with a straight posterior aspect and a cam of larger volume in the posterior side of the femur, which appears to work well in deep flexion rather than at 90° knee flexion. (2) The new prosthesis has a lower profile in the

Table 1 Pre-operative demographic data between the two groups

Demographic and clinical variables	Group A (n = 31)	Group B (n = 31)	P-value
Age at surgery (years)	74 ± 4	73 ± 5	0.299
Sex (female/male)	28 / 3	26 / 5	0.354
Body mass index (kg/m ²)	27 ± 4	27 ± 5	0.920
Femoro-tibial angle (°)	186 ± 5	188 ± 8	0.357
Extension (°)	-4 ± 6	-4 ± 6	0.984
Flexion (°)	125 ± 14	124 ± 15	0.725
Knee Society knee score	45 ± 10	40 ± 11	0.098
Function score	50 ± 17	48 ± 11	0.560
Follow-up period (years)	2.4 ± 0.5	2.5 ± 0.4	0.426

Data are shown as mean ± standard deviation or as numbers

Table 2 Post-operative clinical results at radiographic examination for kinematic study and component positions assessed using the Knee Society roentgenographic evaluation system

Clinical results	Group A (n = 31)	Group B (n = 31)	P-value
Femoro-tibial angle (°)	174 ± 3	174 ± 2	0.221
Extension (°)	-1 ± 3	0 ± 2	0.244
Flexion (°)	126 ± 12	123 ± 9	0.211
Knee Society knee score	95 ± 7	95 ± 4	0.984
Function score	79 ± 18	75 ± 14	0.279
α (°)	96 ± 3	97 ± 1	0.247
β (°)	90 ± 1	90 ± 1	0.338
γ (°)	1 ± 3	1 ± 2	0.187
δ (°)	84 ± 2	85 ± 2	0.267

Data are shown as mean ± standard deviation.

anterior part of the femoral component, increased intercondylar opening space, and an anterior cut of the tibial component, in order to reduce anterior soft tissue tension.

The same surgical procedure was applied to all knees. A midvastus approach and measured bone cuts based on the anatomical landmarks were utilized for all knees. The distal femur was cut perpendicular to its mechanical axis, using intramedullary instruments, removing bone to match the femoral component thickness. The proximal tibia was cut perpendicular to its mechanical axis in the coronal plane and with 5 to 7° posterior tibial slope in the sagittal plane using extramedullary instruments, depending on the individual's posterior tibial slope. The posterior femoral condyles were cut parallel to the epicondylar axis and perpendicular to the Whiteside line with 3 to 5° external rotation from the posterior condylar line depending on the individual's epicondylar axis. The soft tissues were released to achieve adequate mediolateral balance and all components were fixed with cement after trial reduction.

Static radiographic knee images were taken in the same way for both groups at 2 to 3 years after surgery at the following five postures: (1) full extension standing, (2) lunge at 90° flexion, (3) lunge at maximum flexion, (4) kneeling at 90° flexion, and (5) kneeling at maximum flexion (Fig. 2). For the lunge, each patient put their foot on a 15 to 35 cm box and bent their 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 finished at maximum comfortable flexion.

The three-dimensional position and orientation of the implant components were determined using model-based shape matching techniques [24] (Fig. 3). Implant flexion angles between the femoral and tibial components (a positive value means flexion), femoral rotation angles (a positive value means femoral external rotation), and valgus angles (a positive value means valgus) were evaluated based on the implant axes. AP positions 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). The femoral condylar center was defined as the midpoint of lowest points of both condyles. The rotational and translational changes of kinematic values at lunge and kneeling with respect to those at standing were also evaluated: the range of motions, the femoral rotations, the valgus rotations, and the AP translations of each femoral condyle and the center. 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 [24].

We compared these kinematic values between group A and B. We also evaluated the correlations between the AP

Fig. 2 Static radiographic knee images were taken in the same way for both groups (a) at full extension standing, (b) lunge at 90° flexion, (c) lunge at maximum flexion, (d) kneeling at 90° flexion, and (e) kneeling at maximum flexion

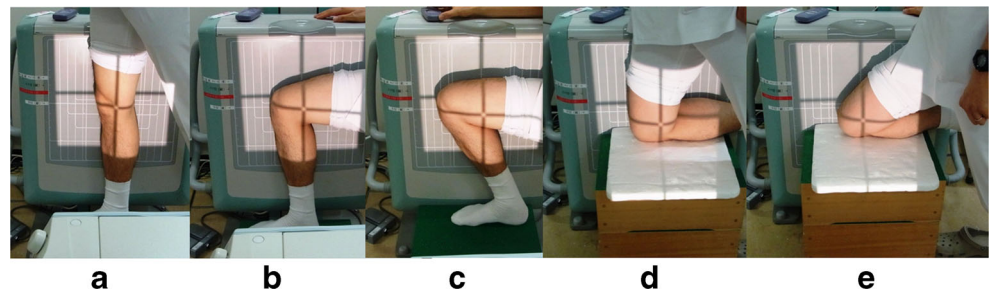
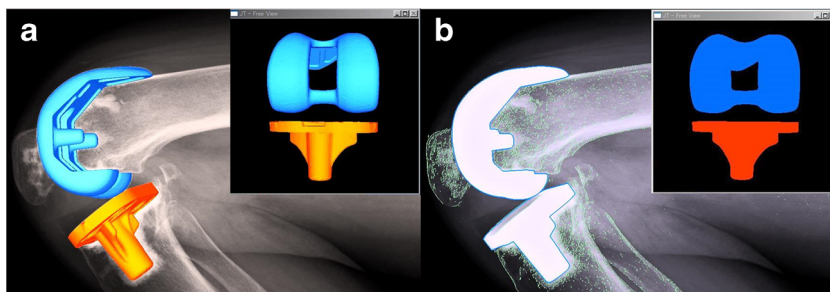


Fig. 3 Three-dimensional model mode (a) and edge detection mode (b) during shape-matching are shown



positions of femoral center and implant flexion angles, and femoral rotation angles and implant flexion angles at maximum lunge.

Unpaired t-tests were used to compare kinematic values between the two groups. Pearson’s tests were applied to examine correlations. Preoperative demographic data were compared using unpaired t-tests and chi-square tests. A probability value (p) less than 0.05 was considered significant.

Results

The implant angles and positions at each knee posture and the total amount of rotations and translations are shown in Fig. 4.

The maximum implant flexion angles were greater in group A than group B at maximum lunge and at maximum kneeling (Fig. 4a). However, the range of motion did not differ significantly in both groups (Fig. 4b). The medial condylar positions were more posterior in group A than group B at 90° lunge, at maximum lunge, and at 90° kneeling (Fig. 4c). These differences were also observed in the AP translations of the medial condyle (Fig. 4d). The lateral condylar positions were also more posterior in group A than group B at every knee position (Fig. 4e). In contrast, the AP translation of the lateral condyle was greater in group B than group A at maximum lunge (Fig. 4f). Resulting from medial and lateral condylar positions, the femoral center positions were more posterior in group A than group B at every knee position (Fig. 4g).

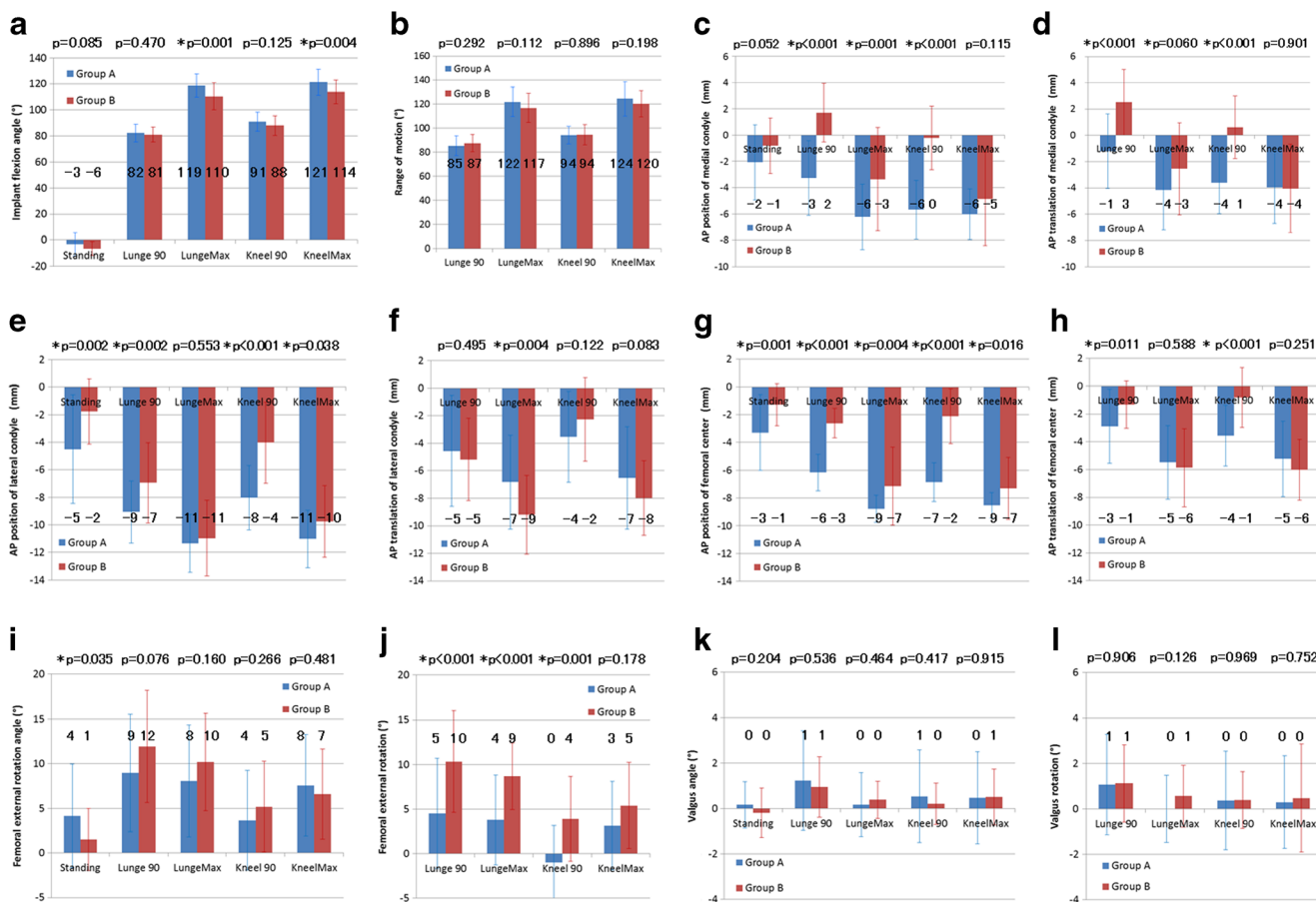


Fig. 4 Kinematic values between the two groups were compared at each pose * p < 0.05

The AP translations of the femoral centre were greater in group A than group B at 90° knee flexion postures (Fig. 4h). The femoral external rotation angles were not significantly different between the two groups except at standing (Fig. 4i). The femoral external rotations (amount of rotations) were, however, greater in group B than group A at 90° lunge, at maximum lunge, and at 90° kneeling (Fig. 4j). The valgus angles were small and not significantly different between the two groups (Fig. 4k). Similar findings were observed in the valgus rotations (amount of rotations) (Fig. 4l).

Correlations between the femoral center positions and the implant flexion angles, and the femoral external rotation angles and the implant flexion angles at maximum lunge are shown in Fig. 5. Strong negative correlation was found between the femoral centre position and implant flexion angles in group B (Fig. 5b) and moderate negative correlation in both groups combined (Fig. 5c), but not in group A (Fig. 5a). Weak correlations were found between the femoral external rotation angles and implant flexion angles in group A (Fig. 5d), group B (Fig. 5e), and in both groups combined (Fig. 5f).

Discussion

We compared in-vivo knee kinematics between the new PS total knee prosthesis for Asian patients and a popular high-flexion PS prosthesis during standing, lunge, and kneeling activities. Knees with a new prosthesis showed slightly greater implant flexion angles compared with knees with a conventional prosthesis, although the range of motion was not significantly different. The femoral centre positions were more

posterior in group A, and the posterior translations of the femoral centre were greater at 90° knee flexion postures. On the other hand, the femoral external rotation angles were not significantly different between the two groups except at standing, and the femoral external rotations (amount of rotations) were greater in group B. The femoral centre positions had a strong negative correlation with implant flexion angles at maximum lunge in group B, but not in group A. The femoral external rotation angles had weak negative correlations with implant flexion angles in both groups.

Several limitations should be acknowledged. First, the subjects are not a single surgeon series. Different surgeons performed arthroplasties for each experimental group. It is reported that surgical maneuvers influence the post-operative kinematics [25]. However, the surgeons belong to the same university group and the surgical procedures including bone cutting, soft tissue balancing, and implant fixation were the same. Furthermore, we used the same analysis methods. Second, we analyzed static radiographic images, not serial images during activities. However, these kinematic values at five weight-bearing knee positions including full flexion demonstrated significant differences between the similar high-flexion PS prostheses, which gave us hints to consider the influence of implant design characteristics on in-vivo knee kinematics.

Group A showed slightly greater implant flexion angles and similar range of motion, which means one of the design goals, deep flexion, was achieved with this prosthesis. Both implants are designed to achieve deep flexion, preventing edge loading until 155° flexion. Adding femoral bowing (5°) and posterior tibial slope (5–7°) [26], maximum skeletal flexion angles of the knees with a new prosthesis and the

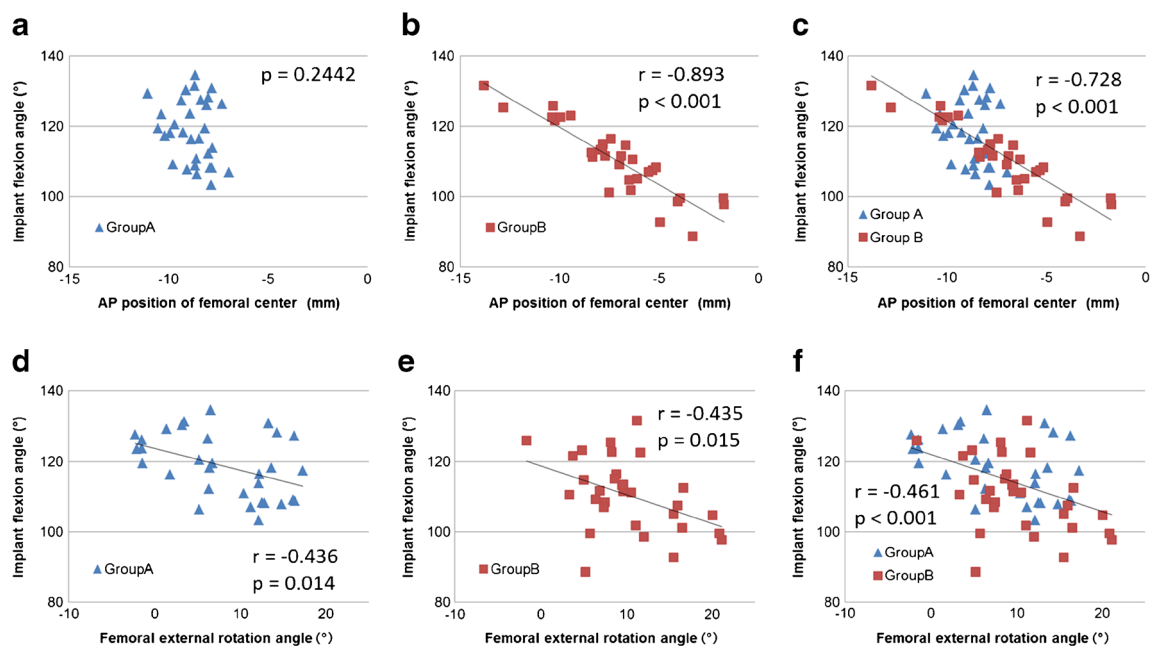


Fig. 5 Correlations between the femoral center positions and the implant flexion angles (a–c), and the femoral external rotation angles and the implant flexion angles at maximum lunge (d–f) are shown

knees with a conventional prosthesis calculated from implant flexion angles would be around 120 to 130°, which is comparable with previously reported flexion angles after TKA with high-flexion prosthesis [27–29].

Group A demonstrated more posterior positions of the femoral centre compared with knees from group B, and more posterior translations of the femoral center at 90° knee flexion postures. At maximum lunge, the femoral centre of the new implant located approximately 9 mm posterior within a relatively narrow range from 7 to 11 mm, while the conventional implant had wide variability from 2 to 14 mm (Fig. 5a and b). It is considered that these kinematic differences reflect design characteristics of both prostheses. The new implant has a round post with a wide base and a concave posterior aspect, and a cam with an oval shape of a sagittal cross-sectional surface in a proximo-distal direction, which induces steady femoral posterior translation soon after the post/cam engagement, but after a certain degree of translation, the post/cam mechanism does not force increasing posterior translation. Together with the low profile in the anterior portion of the components, the new prosthesis allows most knees to achieve around 9 mm posterior position of the femoral centre. However, it restricts excessive posterior translations of femoral condyles beyond that area. This steady femoral posterior translation may play an important role in achieving deep flexion [30]. On the other hand, the conventional implant has a square post with a straight posterior aspect and a cam with a larger volume in the distal side of the femur. These design features in the conventional prosthesis keep moving the femoral component posteriorly after post/cam engagement, especially in deep flexion. However, it seems that this posterior translation depends on the flexibility of soft tissue around the knee, represented by the extensor mechanism. Knees with flexible soft tissue allow this femoral posterior translation, but knees with inflexible soft tissue do not.

Group A showed similar femoral external rotation angles and smaller femoral external rotations (amount of rotations) compared with group B. Axial rotations were designed to allow 20° in each direction for the new prosthesis and 12° or more in each direction for the conventional prosthesis. The new implant is designed to allow free rotation with a relatively flat insert and rounded post [31]; however, it exhibited less femoral axial rotations than expected. We think that because of the above mentioned steady bicondylar femoral translations, the new prosthesis did not achieve great femoral external rotation. It seems to be challenging to achieve both great femoral posterior translation and great external rotation with knee flexion solely by the post/cam mechanism with a symmetrical insert. An asymmetrical anatomical insert with a concave medial surface and convex lateral surface would solve this problem; however, more guided motion may lead to other issues [32].

Group A showed no correlation between the femoral posterior positions and the implant flexion angles at maximum

lunge, while group B exhibited a strong correlation. This difference in both groups would result from the above-mentioned different post/cam design in both systems. The new system allows about 9 mm posterior position of the femoral centre at maximum knee flexion, regardless of the soft tissue flexibility, but does not force further translation beyond that point. On the other hand, the conventional system provides increasing femoral posterior translation in deep flexion if the soft tissue around the knee, represented by the extensor mechanism, allows. Therefore, strong correlation was observed between the femoral centre posterior position and the knee flexion angle in the conventional group. Positive correlations have been reported between femoral posterior position and greater maximum knee flexion in the knees with TKA [30], which is applied to our results in the conventional prosthesis. However, this theory is not exactly applicable to the new prosthesis. The post/cam design of the new implant is configured to provide approximately 9 mm of femoral posterior position at 120° implant flexion, which, on average, was slightly greater than that observed in the control knees. Slightly greater lunge and kneeling flexion in knees with the new design may be a manifestation of this steady posterior femoral position.

Both groups showed weak negative correlations between femoral external rotation angles and the maximum implant flexion angles. The reason for these paradoxical correlations in this study can be explained by bicondylar posterior translations in deep flexion. In lunge activities, femoral external rotation angles were the greatest at 90° flexion in the two groups, and then because of the post/cam mechanism, both condyles moved posteriorly together in deep flexion, resulting in reduced femoral external rotation angles.

Conclusions

The new PS prosthesis designed for Asian knee morphology achieved flexion angles and range of motion at least comparable to that of a conventional high-flexion PS prosthesis. The femoral roll-back pattern, however, is different from a conventional knee, reflecting the post/cam design.

Acknowledgments The authors thank Scott A. Banks, PhD for his continuous support on kinematic analysis. We also thank Bryan P. Conrad, PhD for his careful review of the manuscript and for giving us useful suggestions, and Tomoyuki Mizuguchi for his valuable advice on image processing. We received research support from Kyocera Medical and Zimmer.

References

1. Rand JA, Ilstrup DM (1991) Survivorship analysis of total knee arthroplasty. Cumulative rates of survival of 9200 total knee arthroplasties. *J Bone Joint Surg Am* 73(3):397–409

2. Whiteside LA (1994) Cementless total knee replacement. Nine- to 11-year results and 10-year survivorship analysis. *Clin Orthop Relat Res* 309:185–192
3. Fujimoto E, Sasashige Y, Tomita T, Sasaki H, Touten Y, Fujiwara Y, Ochi M (2016) Intra-operative gaps affect outcome and postoperative kinematics in vivo following cruciate-retaining total knee arthroplasty. *Int Orthop* 40(1):41–49. doi:10.1007/s00264-015-2847-y
4. Hohmann E, Tetsworth K (2016) Do manual cutting guides for total knee arthroplasty introduce systematic error? *Int Orthop* 40(2):277–284. doi:10.1007/s00264-015-2963-8
5. Li P, Tsai TY, Li JS, Zhang Y, Kwon YM, Rubash HE, Li G (2014) Morphological measurement of the knee: race and sex effects. *Acta Orthop Belg* 80(2):260–268
6. Mahfouz M, Abdel Fatah EE, Bowers LS, Scuderi G (2012) Three-dimensional morphology of the knee reveals ethnic differences. *Clin Orthop Relat Res* 470(1):172–185. doi:10.1007/s11999-011-2089-2
7. Leszko F, Hovinga KR, Lerner AL, Komistek RD, Mahfouz MR (2011) In vivo normal knee kinematics: is ethnicity or gender an influencing factor? *Clin Orthop Relat Res* 469(1):95–106. doi:10.1007/s11999-010-1517-z
8. Devers BN, Conditt MA, Jamieson ML, Driscoll MD, Noble PC, Parsley BS (2011) Does greater knee flexion increase patient function and satisfaction after total knee arthroplasty? *J Arthroplasty* 26(2):178–186. doi:10.1016/j.arth.2010.02.008
9. Park KK, Chang CB, Kang YG, Seong SC, Kim TK (2007) Correlation of maximum flexion with clinical outcome after total knee replacement in Asian patients. *J Bone Joint Surg (Br)* 89(5):604–608. doi:10.1302/0301-620x.89b5.18117
10. Sharkey PF, Hozack WJ, Rothman RH, Shastri S, Jacoby SM (2002) Insall Award paper. Why are total knee arthroplasties failing today? *Clin Orthop Relat Res* (404):7–13
11. Noble PC, Gordon MJ, Weiss JM, Reddix RN, Conditt MA, Mathis KB (2005) Does total knee replacement restore normal knee function? *Clin Orthop Relat Res* 431:157–165
12. Meneghini RM, Russo GS, Lieberman JR (2014) Modern perceptions and expectations regarding total knee arthroplasty. *J Knee Surg* 27(2):93–97. doi:10.1055/s-0033-1348408
13. Heyse TJ, Ries MD, Bellemans J, Goodman SB, Scott RD, Wright TM, Lipman JD, Schwarzkopf R, Figgie MP (2014) Total knee arthroplasty in patients with juvenile idiopathic arthritis. *Clin Orthop Relat Res* 472(1):147–154. doi:10.1007/s11999-013-3095-3
14. Jacobs CA, Christensen CP (2014) Factors influencing patient satisfaction two to five years after primary total knee arthroplasty. *J Arthroplasty* 29(6):1189–1191. doi:10.1016/j.arth.2014.01.008
15. Kim SJ, Bamne A, Song YD, Kang YG, Kim TK (2015) Patients still wish for key improvements after total knee arthroplasty. *Knee Surg Relat Res* 27(1):24–33. doi:10.5792/ksr.2015.27.1.24
16. Han HS, Kang SB, Yoon KS (2007) High incidence of loosening of the femoral component in legacy posterior stabilised-flex total knee replacement. *J Bone Joint Surg (Br)* 89(11):1457–1461. doi:10.1302/0301-620X.89B11.19840
17. Amout N, Vandenneucker H, Bellemans J (2011) Posterior dislocation in total knee replacement: a price for deep flexion? *Knee Surg Sports Traumatol Arthrosc* 19(6):911–913. doi:10.1007/s00167-010-1258-2
18. Watanabe T, Ishizuki M, Muneta T, Banks SA (2013) Knee kinematics in anterior cruciate ligament-substituting arthroplasty with or without the posterior cruciate ligament. *J Arthroplasty* 28(4):548–552. doi:10.1016/j.arth.2012.06.030
19. Oonishi H, Ueno M, Kim SC, Iwamoto M, Kyomoto M (2009) Ceramic versus cobalt-chrome femoral components; wear of polyethylene insert in total knee prosthesis. *J Arthroplasty* 24(3):374–382. doi:10.1016/j.arth.2007.10.021
20. Innocenti M, Civinini R, Carulli C, Matassi F, Villano M (2010) The 5-year results of an oxidized zirconium femoral component for TKA. *Clin Orthop Relat Res* 468(5):1258–1263. doi:10.1007/s11999-009-1109-y
21. Majima T, Yasuda K, Tago H, Aoki Y, Minami A (2008) Clinical results of posterior cruciate ligament retaining TKA with alumina ceramic condylar prosthesis: comparison to Co-Cr alloy prosthesis. *Knee Surg Sports Traumatol Arthrosc* 16(2):152–156. doi:10.1007/s00167-007-0435-4
22. Innocenti M, Carulli C, Matassi F, Carossino AM, Brandi ML, Civinini R (2014) Total knee arthroplasty in patients with hypersensitivity to metals. *Int Orthop* 38(2):329–333. doi:10.1007/s00264-013-2229-2
23. Panfili E, Pierdicca L, Salvolini L, Imperiale L, Dubbini J, Giovagnoni A (2014) Magnetic resonance imaging (MRI) artefacts in hip prostheses: a comparison of different prosthetic compositions. *Radiol Med* 119(2):113–120. doi:10.1007/s11547-013-0315-6
24. Banks SA, Hodge WA (1996) Accurate measurement of three-dimensional knee replacement kinematics using single-plane fluoroscopy. *IEEE Trans Biomed Eng* 43(6):638–649. doi:10.1109/10.495283
25. Nozaki H, Banks SA, Suguro T, Hodge WA (2002) Observations of femoral rollback in cruciate-retaining knee arthroplasty. *Clin Orthop Relat Res* 404:308–314
26. Banks SA, Harman MK, Bellemans J, Hodge WA (2003) Making sense of knee arthroplasty kinematics: news you can use. *J Bone Joint Surg Am* 85-A(Suppl 4):64–72
27. Hosaka K, Saito S, Ishii T, Mori S, Sumino T, Tokuhashi Y (2011) Asian-specific total knee system: 5-14 year follow-up study. *BMC Musculoskelet Disord* 12:251. doi:10.1186/1471-2474-12-251
28. Huang HT, Su JY, Wang GJ (2005) The early results of high-flex total knee arthroplasty: a minimum of 2 years of follow-up. *J Arthroplasty* 20(5):674–679. doi:10.1016/j.arth.2004.09.053
29. Malik A, Salas A, Ben Ari J, Ma Y, Gonzalez Della Valle A (2010) Range of motion and function are similar in patients undergoing TKA with posterior stabilised and high-flexion inserts. *Int Orthop* 34(7):965–972. doi:10.1007/s00264-009-0865-3
30. Banks S, Bellemans J, Nozaki H, Whiteside LA, Harman M, Hodge WA (2003) Knee motions during maximum flexion in fixed and mobile-bearing arthroplasties. *Clin Orthop Relat Res* 410:131–138. doi:10.1097/01.blo.0000063121.39522.19
31. Lin KJ, Huang CH, Liu YL, Chen WC, Chang TW, Yang CT, Lai YS, Cheng CK (2011) Influence of post-cam design of posterior stabilized knee prosthesis on tibiofemoral motion during high knee flexion. *Clin Biomech (Bristol, Avon)* 26(8):847–852. doi:10.1016/j.clinbiomech.2011.04.002
32. Digennaro V, Zambianchi F, Marcovigi A, Mugnai R, Fiacchi F, Catani F (2014) Design and kinematics in total knee arthroplasty. *Int Orthop*. doi:10.1007/s00264-013-2245-2