ORIGINAL ARTICLE

Influence of Posterior Condylar Offset on Maximal Flexion and Outcome Scales Following TKA in Asian Patients

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Abstract

Background: Infection complicates traditional joint reconstruction prostheses in up to 7% of cases, with Background: Alteration in femoral posterior condylar offset (PCO) after total knee arthroplasty (TKA) has been reported to influence maximal flexion angle after TKA. However, there are contradictory reports about its influence on clinical outcome, and the effects of PCO alterations may vary with implant type.

Question / purposes: The purpose of this study was to determine whether PCO alterations affect maximal flexion after TKA and other functional outcomes, and whether the effects of PCO alterations differ by implant type.

Patients and Methods: Fifty consecutive cases of TKAs in each of four implant types, namely, fixed bearing (FB) cruciate retaining (CR) or posterior stabilized (PS), mobile bearing (MB) CR or PS were included in the study. Patients were evaluated for maximal flexion and clinical outcome scales. The PCO alteration was measured using pre- and postoperative true lateral knee radiographs. Correlations between PCO alterations and functional outcomes including maximal flexion were compared among the four implant types.

Results: No significant correlation was found between PCO alterations and maximal flexion achieved in any of the four implant groups (Correlation Coefficient [CC]=-0.03, 0.14, -0.14, 0.04; $p > 0.05$). The mean maximal postoperative flexion was greater in PS implants than in CR implants ($p < 0.05$). In MB-CR implanted knees, a greater PCO alteration was correlated with worse anterior knee pain score as measured by the PF scoring system (CC=-0.44, $p=0.003$) and worse WOMAC pain score (CC=-0.41, $p=0.007$).

Conclusions: Our findings indicate that PCO alterations have no effect on maximal postoperative flexion after TKA regardless of the implant type. Whether the implant is of PS or CR type is a better predictor of the final flexion achieved. However, increased PCO is correlated with worse pain score in MB-CR implants.

Level of Evidence: Level III, Retrospective comparative study

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Introduction

Pain relief and functional restoration are the fundamental goals of total knee arthroplasty (TKA). Various factors, including maximal postoperative flexion, are thought to influence the functional outcomes of TKA [15,28]. After Bellemans et al. [5] reported that alterations in posterior condylar offset (PCO) influences the maximal flexion achieved after TKA, numerous studies have evaluated the effect of these alterations [1,3,11,14,17,20,23,24,29]. However, these studies reported contradictory results regarding the effect of PCO on maximal postoperative flexion. Therefore, the role that PCO alterations play in functional outcomes including maximal flexion remains uncertain.

The effect of PCO alteration on functional outcomes may differ by the characteristics of the implant, specifically the type of bearing mobility (fixed bearing [FB] versus mobile bearing [MB]) [30] and whether the implant sacrifices PCL or not (cruciate retaining [CR] versus posteriorly stabilized [PS]) [1]. Several studies reported a definite correlation between PCO alteration and maximal flexion in CR knees [1,5,23,24], whereas two recently published studies did not find this association in MB-CR knees [17,29]. This association was not found in several studies involving PS prosthesis [1,3,14,17]. In addition, other studies reported that flexion kinematics and thus the ultimate flexion achieved differ between CR and PS TKAs [2,8,13,31]. These varied findings in studies conducted with different prostheses by various authors suggest the need for studies using different representative cohorts using relevant prostheses to determine whether the effect of PCO alteration varies by implant type. Moreover, little information is currently available for the influence of PCO alteration on outcome scales, such as American Knee Society (AKS) scores, Patellofemoral scores and the Western Ontario and McMaster Universities Arthritis (WOMAC) Index scores. On the other hand, it is well established that Asian patients have greater preoperative and postoperative maximum flexion than Western patients do [8,9,21,22,27,31]. Therefore, it is conceivable that the effects of PCO alteration on maximal flexion and other functional outcomes may be different between Asians and Westerners. However, few studies have been performed to investigate the effects of PCO alteration on functional outcomes of TKA in Asian patients.

Therefore, the present study aimed to determine whether PCO alterations that follow TKA influence functional outcomes including maximal postoperative flexion in an Asian population. We were particularly interested in determining whether the effects of PCO alterations vary by the following implant types: (1) FB-CR, (2) FB-PS, (3) MB-

CR and (4) MB-PS. We hypothesized that alteration in PCO influences maximal postoperative flexion angle and other functional outcomes, and that the effects differ by implant type.

Patients and Methods

This study was approved by the Institutional Review Board of our institution, and informed consent was obtained from all patients. To determine sample size, power analysis was performed a priori using the two-sided hypothesis test at an alpha level of 0.05. The test indicated that the sample size of 50 in each of 4 groups would provide power of 80% or higher with an alpha level of 0.05 to detect a difference of 5% in the radiographic measurements and functional scores, and a correlation coefficient greater than 0.3. To select 50 cases consecutively in each implant group, we retrospectively reviewed the records of 1,300 consecutive TKAs performed using four implant types (FB-CR, FB-PS, MB-CR and MB-PS) between October 2003 and January 2007. Inclusion criteria were the following: a diagnosis of primary osteoarthritis, no postoperative complications affecting postoperative outcomes, no systemic comorbidities that interfered with the benefits of the replaced knee, and an available record of clinical outcomes evaluated 12 months after surgery. Fifty cases were selected for each of the four implant types. The four groups did not differ in demographic characteristics or preoperative functional status including maximal flexion angle (Table 1).

All surgical procedures were performed by a single surgeon (one of the authors) via the medial parapatellar approach, and similar rehabilitation protocols were given. The patella was routinely resurfaced. All implants were fixed with cement (Palacos; Heraeus Kulzer GmbH, Hanau, Germany). The four prosthesis types were (1) FB-CR, Genesis II (Smith & Nephew, Memphis, U.S.A.), (2) FB-PS, Genesis II, (3) MB-CR, e.motion-FP (B.Braun-Aesculap, Tuttlingen, Germany), and (4) MB-PS, e.motion-PS (B.Braun-Aesculap). All of the devices mentioned above were approved by the United States Food and Drug Administration for use. After surgery, a compressive dressing was applied with immobilization for the first 24 hours. Knees were then placed in a continuous passive-motion machine. On the second postoperative day, all patients began walking with crutches or a walker, and started active and passive range-of-motion (ROM) exercises. Knee ROM exercises and weight bearing were gradually increased.

All clinical information was prospectively collected using pre-designed datasheets and maintained in our database

Table 1. Comparison of preoperative demographic characteristics and functional status among the four groups divided by types of implants*

Parameter	FB-CR (n=50)	FB-PS (n=50)	MB-CR (n=50)	MB-PS (n=50)	p-value (ANOVA)
Age (years)	68.4 (5.9)	68.0 (6.6)	67.7 (6.1)	68.0 (4.8)	0.959
Men / Women	1 / 49	1 / 49	3 / 47	4 / 46	0.383
BMI (kg/m ²)	26.1 (3.6)	26.9 (4.1)	26.4 (3.8)	25.9 (3.6)	0.612
Maximal flexion (°)	141.4 (12.2)	135.8 (14.2)	139.7 (12.8)	141.1 (13.6)	0.136
PF score					
Anterior knee pain	11.4 (5.0)	11.4 (5.1)	10.7 (5.6)	11.5 (4.2)	0.851
AKS					
Knee score	49.2 (11.0)	44.9 (7.8)	47.7 (9.5)	44.7 (10.8)	0.070
Function score	53.8 (9.7)	53.5 (12.0)	53.5 (8.5)	57.7 (14.2)	0.191
WOMAC					
Pain	10.8 (3.8)	11.6 (3.7)	10.7 (4.5)	11.3 (4.5)	0.683
Stiffness	4.7 (1.8)	5.1 (2.1)	4.4 (2.1)	4.8 (2.1)	0.424
Function	39.2 (10.6)	42.9 (12.0)	38.7 (11.3)	40.3 (14.2)	0.326

* Data are presented as means with standard deviations in parentheses.

Abbreviation: FB, fixed bearing; MB, mobile bearing; CR, posterior cruciate ligament retaining; PS, posterior cruciate ligament sacrificing; ANOVA, Analysis of variance; PF, patellofemoral; BMI, body mass index; AKS, American knee society score; WOMAC, Western Ontario McMaster Universities Osteoarthritis index

by an independent investigator (one of authors). Our clinics have a regular follow-up schedule (2 weeks, 6 weeks, 3 months, 6 months, 12 months after surgery, and yearly thereafter), and we evaluated the outcomes at 12 months after surgery for postoperative functional outcomes. Relevant preoperative and postoperative outcomes collected were knee range of motion (ROM), the patellofemoral score [10], the AKS score [16] and the WOMAC index score [4]. The knee ROM was calculated by subtracting the angle of flexion contracture from the angle of maximal flexion. An independent investigator (one of authors) measured the flexion contracture and maximal flexion angles

to the nearest 5° by using a standard (38 cm) clinical goniometer, with the patients in supine position. The lateral femoral condyle was used as the landmark to center the goniometer with the proximal limb directed towards the greater trochanter and the distal limb towards the lateral malleolus.

An independent investigator (one of authors) performed the radiographic measurements of PCO, joint line elevation, and postoperative posterior tibial slope. The PCO was measured pre- and postoperatively on true lateral knee radiographs by determining the shortest distance between the line tangent to posterior femoral cortex and

the most posterior point of the femoral condyle (preoperatively) or femur prosthesis (postoperatively) respectively (Figure 1). After correcting for radiographic magnification using a reference measurement of the tibial shaft diameter at the level of tibial tubercle, PCO alteration was calculated from the respective measurements. PCO alteration was defined as the value obtained by subtracting the amount of preoperative PCO from the amount of postoperative PCO. Joint line distance from tibial tuberosity was also measured preoperatively and postoperatively (Figure 2). Preoperatively, it was defined as the perpendicular distance from the most anteriorly prominent point of tibial tuberosity to a

Figure 1. Radiographs showing the method for measuring the posterior condylar offset (PCO) on a true lateral radiograph, pre-operatively (A) and post-operatively (B). PCO alteration was calculated by subtracting preoperative value from postoperative value.

Figure 2. Radiographs showing the method for measuring the joint line distance from tibial tuberosity on a true lateral radiograph, pre-operatively (A) and post-operatively (B). Joint line elevation was calculated by subtracting preoperative value from postoperative value.

line parallel to the weight-bearing surface of the tibial plateau, which was defined as the line passing the midpoint between the medial femoral condyle and the medial tibial plateau. Postoperatively, it was defined as the perpendicular distance from the same point of tibial tuberosity to a line parallel to the weight-bearing surface of the polyethylene insert, which is tangent to the most distal point of the femoral component. After adjusting for magnification, joint line elevation was calculated by subtracting preoperative joint line distance from postoperative joint line distance. Posterior tibial slope was measured in postoperative images. It was defined as the angle between the line parallel with the upper surface of the tibial tray and the line perpendicular to the anatomical axis of the proximal tibia, which was defined as the line connecting the midpoints of the two lines 5 cm and 15 cm distal and parallel to the joint line, respectively (Figure 3). In order to assess the reliability of the measurements using the methods described above,

two orthopedic surgeons (two of the authors) and one clinical investigator (one of the author) performed the measurements twice within an interval of one week in 30 knees randomly selected from the 200 knees. The degree of measurement reliabilities was assessed using the intraclass correlation coefficient (ICC). The ICCs for intra- and inter-rater agreement were greater

than 0.85 for all radiographic measurements. As no significant differences were found among the measurements by the three examiners, the measurements performed by a single investigator were used in the following analyses.

Statistical analyses were conducted using SPSS for Windows (version 15.0; SPSS, Chicago, Illinois), and p values of < 0.05 were considered significant. Kolmogorov-Smirnov test was used to evaluate whether the scores of the clinical outcome scale were normally distributed. As all variables showed normal distribution, parametric methods were used for all statistical analyses. Analysis of variance

(ANOVA) was performed to make comparisons among the four implant groups to determine whether any difference exists among the groups regarding PCO alteration, joint line elevation and posterior tibial slope, maximal flexion, and other functional outcomes. If ANOVA showed significant differences among the 4 groups, post hoc test was conducted with Bonferroni method. Subsequently, we conducted correlation analyses in each of four groups to investigate the correlations between 1) PCO alteration and maximal flexion angle, and 2) PCO alteration and other functional outcomes. To control the effect of joint line elevation or posterior tibial slope, partial correlation analyses were performed with joint line elevation and posterior tibial slope set as covariates. Additionally, preoperative knee ROM was also set as a covariate in the analysis between PCO and maximal postoperative flexion. In the analysis of the correlation between PCO alteration and WOMAC subscale scores, WOMAC score was converted to a 100 point system where 0 indicates the worst score and 100 indicates the best score for consistency with other functional scores. Four implant groups were compared to determine whether the prosthesis type influenced how postoperative PCO alteration affected the functional outcomes including maximal flexion.

Results

No significant association was found between the degree of PCO alterations and the maximal flexion angle achieved in any of the four implant groups. The mean maximum flexion angle after TKA was greater after PS implants than after CR implants (FB-PS 137.0° vs. FB-CR 130.1°, $p = 0.008$ and MB-PS 136.4° vs. MB-CR 130.1°, $p = 0.020$) (Table 2). However, correlation analyses discovered no significant associations between PCO alterations and maximum flexion in any of the four groups ($p > 0.05$).

The influence of PCO alterations on functional outcomes varied by the type of implant. In knees implanted with the MB-CR design, increased PCO was associated with a worse anterior knee pain score based on the PF scoring system (correlation coefficient [CC] = -0.44, $p = 0.003$) and a worse WOMAC pain score (CC = -0.41, $p = 0.007$) (Table 3). Increased PCO also tended to be associated with worse WOMAC function score (CC = -0.30, $p = 0.054$). Likewise, in the FB-PS group, the increased PCO tended to be associated with a worse AKS knee score (CC = -0.34, $p = 0.063$). In contrast, in both the FB-CR and MB-PS types, no significant associations were found between the PCO alteration and functional outcomes.

Figure 3. A radiograph showing the method for measuring the postoperative posterior tibial slope on a true lateral radiograph.

Table 2. Comparison of PCO alteration, posterior tibial slope, joint line elevation and functional outcomes among the four groups divided by types of implants*

Parameter	FB-CR (n=50)	FB-PS (n=50)	MB-CR (n=50)	MB-PS (n=50)	p-value (ANOVA)
PCO alteration (mm)	0.2 (1.9)	0.7 (2.1)	0.3 (1.7)	1.3 (2.3)	0.066
Posterior tibial slope (°)	6.1 (2.9)	5.6 (2.4)	5.0 (2.2)	4.6 (3.7)	0.052
Joint line elevation (mm)	-0.3 (4.1)	1.3 (3.8)	-0.1 (3.9)	2.0 (3.8)	0.011+
Maximal flexion (°)	130.1 (10.0)	137.0 (9.6)	132.2 (9.0)	136.4 (10.8)	0.001#
PF score					
Anterior knee pain	13.9 (2.6)	14.7 (1.2)	14.9 (0.7)	14.3 (2.5)	0.042§
AKS					
Knee score	95.4 (5.1)	96.2 (4.6)	95.6 (5.3)	95.2 (6.5)	0.802
Function score	96.8 (7.0)	94.5 (11.7)	97.4 (7.2)	95.2 (10.3)	0.359
WOMAC					
Pain	2.6 (3.0)	1.4 (2.2)	1.8 (2.1)	2.4 (2.9)	0.073
Stiffness	1.7 (1.4)	1.2 (1.2)	1.2 (1.2)	1.7 (1.4)	0.120
Function	17.2 (10.4)	13.3 (9.9)	14.9 (8.1)	14.3 (9.3)	0.226

* Data are presented as means with standard deviations in parentheses.

+ There was significant difference between FB-CR group and MB-PS group. #There were significant differences between FB-CR group and FB-PS group, and between FB-CR group and MB-PS group. §There was significant difference between FB-CR group and MB-CR group.

Abbreviation: PCO = posterior condylar offset; FB = fixed bearing; MB = mobile bearing; CR = posterior cruciate ligament retaining; PS = posterior cruciate ligament substituting; ANOVA = Analysis of variance; PF = patellofemoral; AKS = American knee society score; WOMAC = Western Ontario McMaster Universities Osteoarthritis index

Table 3. Correlations between the PCO alterations and functional outcomes among the four groups divided by types of implants*.

Parameter	FB-CR	FB-PS	MB-CR	MB-PS
Maximal flexion+	-0.07 (0.712)	0.11 (0.557)	-0.18 (0.253)	0.16 (0.308)
PF score				
Anterior knee pain	-0.24 (0.185)	-0.05 (0.808)	-0.44 (0.003)	0.14 (0.351)
AKS				
Knee score	0.03 (0.880)	-0.34 (0.063)	-0.18 (0.255)	0.12 (0.440)
Function	-0.02 (0.937)	0.19 (0.299)	0.02 (0.891)	0.05 (0.755)
WOMAC§				
Pain	-0.08 (0.648)	0.14 (0.448)	-0.41 (0.007)	0.27 (0.074)
Stiffness	-0.07 (0.706)	0.08 (0.668)	-0.12 (0.441)	0.12 (0.442)
Function	-0.18 (0.317)	0.05 (0.802)	-0.30 (0.054)	0.11 (0.461)

* Data are presented as partial correlation coefficients between PCO alteration and each functional outcome variable with posterior tibial slope and joint line elevation set as covariates, and respective p-values are presented in parentheses.

+ Preoperative maximum flexion, posterior tibial slope, and joint line elevation, which potentially influenced maximum flexion, were entered as covariates for the partial correlation analysis between PCO alteration and postoperative maximal flexion.

§ To make correlation coefficients indicate the same direction, WOMAC scores were converted to a 0-100 point system where 0 point indicates the worst score and 100 point indicates the best score scores, and the converted scores were used in the partial correlation analyses.

Abbreviation: PCO = posterior condylar offset; FB = fixed bearing; MB = mobile bearing; CR = posterior cruciate ligament retaining; PS = posterior cruciate ligament substituting; PF = patellofemoral; AKS = American knee society score; WOMAC = Western Ontario McMaster Universities Osteoarthritis index

Maximal flexion is one of the major determinants of the ultimate functional outcome of TKA, and PCO has been a subject of substantial research partly because it may be one of the surgeon-controlled factors that influence knee flexion. Indeed, multiple authors reported that the magnitude of PCO alteration affects maximal postoperative flexion achieved after TKA [1,5,23,24]. However, our careful literature review found that the effects of PCO alteration on maximum flexion vary with the implant design [1,12,14,22]. Thus, the present study was conducted to determine the influence of PCO alteration on functional outcomes including maximal postoperative flexion in knees replaced with four different types of implant.

The findings of this study need to be interpreted in context of several limitations. First, our patient population was predominantly female, which should be considered when extrapolating our findings to populations with a different gender composition. Nonetheless, it should be noted that the female gender dominance reflects the actual gender balance of patients undergoing TKA in Korea [7,19]. Thus, findings of the present study are generalizable to Asian female patients. Second, knee ROM was measured as non-weight-bearing passive motion arc in this study. However, most activities of daily living are performed under weight-bearing condition and therefore measurement of knee ROM under weight-bearing condition may be more appropriate [9,31]. Third, the clinical data were obtained 12 months after surgery. Although clinical status after TKA typically plateaus after 1 year, somewhat different results may have been found after a longer follow-up. Fourth, although we took into account the effect of posterior tibial slope and joint line elevation when evaluating the effect of PCO alteration, the combined effects among other kinematic parameters such as anteroposterior translation and axial femorotibial rotation were not evaluated. Future studies are warranted to elucidate the confounding effects of the other kinematic factors.

Our findings do not support our hypothesis that PCO alteration after TKA correlates

Discussion

with maximal postoperative flexion angle. No significant association was found between PCO alteration and maximal flexion in any of the four implant groups. As mentioned above, contradictory findings regarding the effects of PCO alterations on maximum flexion have been reported in previous studies [1,5,14,17,23,24,29]. In a videofluoroscopic study of knees replaced with FB-CR prosthesis, Bellemans et al. [5] found that in deep flexion, the tibial insert directly impinged against the back of the femur, blocking further flexion, and that accordingly PCO was correlated with maximum flexion. Several subsequent studies echoed the proposed correlation between PCO alteration and maximum flexion in knees replaced with CR prosthesis [1,23,24]. In contrast, other studies found no correlation in knees with MB-CR prosthesis [17,29], with FB-PS prosthesis [1,20,32], and with MB-PS prosthesis [3,14,17]. Our findings agree with these latter studies denying the correlation between PCO alteration and maximum flexion. Several interpretations are possible as to why no correlation was found in the current study. First, differences might have existed in the extent of PCO alteration and other factors influencing maximum flexion. For example, in the study by Bellemans et al. [5], the mean PCO alteration was -2.2 mm and mean posterior tibial slope was 3° whereas in the FB-CR group of our study, the mean PCO alteration was 0.2 mm and the mean posterior tibial slope was 6.1°. Previous studies found that other kinematic parameters including posterior tibial slope and condylar roll back affected maximal flexion in CR knees [6,23,24]. Second, Asian patients may have different kinematic patterns that minimize the effects of PCO alterations on maximum flexion. Previous studies reported that compared to Caucasian knees, earlier and more backward movement of the medial femoral condyle in full flexion was observed in Asian knees [18,25]. These may mask the postoperative effect of alterations in PCO on maximal flexion in Asian patients. In addition, preoperative maximal flexion in Asian patients is typically greater than that in Western patients [2,5,27,28], and the degree of preoperative knee flexion is the strongest predictor for postoperative knee flexion [27,28]. The profound contribution of greater preoperative knee flexion may negate the effects of PCO alteration on maximum flexion. On the other hand, in the present study, the knees replaced with PS prosthesis whether FB or MB, had greater postoperative maximum flexion than the knees with corresponding CR prosthesis. This finding, taken together with the lack of a correlation between PCO alteration and maximum flexion angle, suggests that the choice of prosthesis type in terms of PS versus CR is a more important surgeon-controlled factor to increase postoperative knee flexion.

Our findings support our hypothesis that the effects of

PCO alterations on the functional outcomes of TKA vary by implant type. Only the MR-CR group had inverse correlations between PCO alteration and two outcome scales (anterior knee pain and WOMAC pain score), and no other three groups had significant correlations. In the knees replaced with MB-CR prosthesis, PCO increase was associated with a worse anterior knee pain score and worse WOMAC pain score. It is also worthy of note that PCO increase had a marginally significant correlation with worse WOMAC function score ($CC=-0.03$, $p=0.054$). Our findings of no correlation between PCO alteration and outcome scales in the knees replaced with PS prosthesis corroborate the previous studies reporting no effect of PCO alterations on maximum flexion in knees replaced with FB-PS prosthesis [1,20,32] or with MB-PS prosthesis [3,14,17]. These findings are also intuitively explainable by the fact that the kinematics in knees replaced with PS prosthesis are more profoundly dictated by the post-cam mechanism, which may minimize the kinematic effects of PCO alterations. On the other hand, it is not clear why such correlation does not exist in the knees replaced with FB-CR prosthesis, for which the kinematic effects of PCO alteration should be similar to the MB-CR prosthesis. We speculate that the presence of the correlation only in the knees replaced with MB-CR is attributed to the bearing mobility in conjunction with the retention of PCL. It is conceivable that PCO increase causes tightness across the anterior portion of the knee and subsequently leads to impinge on anterior soft tissue. These kinematic scenarios consequently result in anterior knee pain or knee discomfort when boosted by the soft tissue irritation with mobile polyethylene insert. Relatedly, a previous study reported that synovitis and recurrent effusion occurred in 60% of patients with MB-CR prosthesis (anterior-posterior-glide LCS TKA prosthesis) [26]. However, our interpretations are purely speculative and certainly future studies are recommended.

In conclusion, the alterations in PCO have no effect on maximal postoperative flexion angle regardless of the implant type used. Rather than PCO alteration, whether the implant is either PS or CR type is a better predictor of the final flexion achieved. However, PCO increase is associated with worse outcome in MB-CR prosthesis, and thus surgeons should take caution not to significantly increase the PCO when implanting MB-CR systems.

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