Original Article
Clinics in Orthopedic Surgery 2024;16:413-421 • https://doi.org/10.4055/cios23061

Clinical Relevance of Posterior Osteophyte Formation in Ultra-congruent Total Knee Arthroplasty: Midterm Radiographic Rollback and Impingement Analysis

Ho Won Jeong, MD*, Hyun Jin Yoo, MD*,†, Seong Yun Park, MD*, Yong Seuk Lee, MD*

*Department of Orthopedic Surgery, Seoul National University Bundang Hospital, Seoul National University College of Medicine, Seongnam,
†Department of Orthopedic Surgery, Konyang University College of Medicine, Daejeon, Korea

Background: Posterior femoral condylar osteophytes were frequently observed in patients with the ultra-congruent (UC) deep-dish design prosthesis. Therefore, the purpose of the present study was to verify the clinical relevance of osteophyte formation in the UC design.

Methods: From March 2014 to February 2018, a comparative study was conducted on 96 knees using the UC design. They were divided into 2 groups (group 1: osteophyte +, group 2: osteophyte –). Intraoperative findings, indirect femoral rollback assessment using 30° flexion and active full flexion lateral radiographs, serial change of the osteophyte, and outcomes were compared.

Results: The mean follow-up period was 49.35 ± 3.47 months in group 1 and 47.52 ± 3.37 months in group 2. Posterior component coverage was significantly different between the groups: group 1 exhibited more underhang and group 2 exhibited more overhang ($p = 0.022$). On the indirect assessment of the femoral rollback, there was a statistically significant difference in deep flexion and change in distance ($p < 0.001$ and $p < 0.001$, respectively). There was no statistical difference between the 2 groups in the American Knee Society knee and function score, and group 2 showed significant improvement in pain compared to group 1 in Western Ontario and McMaster University Arthritis Index pain score ($p = 0.029$).

Conclusions: Posterior condylar osteophyte formation was related to posterior impingement. It was more frequently observed in the underhang of the femoral component and insufficient femoral rollback. In addition, it changed with time and caused negative effects, including a gradual decrease in flexion and more pain.

Keywords: *Total knee arthroplasty, Ultra-congruent, Femoral rollback, Osteophyte, Outcome*

Total knee arthroplasty (TKA) has yielded considerable improvement in knee function among patients with osteoarthritis; however, there is a limit to restoring the full range of motion (ROM) compared with the normal healthy knee. Although walking or climbing or descending stairs would be possible with 100° of knee flexion in daily life, bathing requires deeper flexion with an average of > 120°–130°.[1-3] Moreover, deep flexion of the knee is particularly important among those with lifestyles involving sitting on the floor and other similar activities, especially among Asian patients.[4] Therefore, achieving better ROM appears to be an important factor for improving satisfaction and outcomes after TKA.[5,6]

There are several factors that affect postoperative ROM after TKA, including preoperative ROM, surgical

Received March 2, 2023; Revised May 27, 2023;
Accepted May 27, 2023
Correspondence to: Yong Seuk Lee, MD
Department of Orthopedic Surgery, Seoul National University Bundang Hospital, Seoul National University College of Medicine, 82 Gumi-ro 173beon-gil, Bundang-gu, Seongnam 13620, Korea
Tel: +82-31-787-7199, Fax: +82-31-787-4056
E-mail: smcos1@snu.ac.kr

technique, prosthesis design, implant position, posterior condylar offset (PCO), posterior osteophyte, posterior impingement, overstuffing of the patella, and rehabilitation.[7-11] Among these factors, posterior impingement can be primarily related to the cam-post design or ultra-congruent (UC) deep-dish design inserts that allow femoral rollback. When the knee is deeply flexed, posterior impingement can occur between the posterior femoral cortex and the posterior borders of the tibial insert; however, proper femoral rollback could minimize this posterior impingement and improve deep flexion.[10] In addition, PCO, posterior underhang of the femoral component, excessive ROM, and posterior tibial slope (PTS) angle are also related to posterior impingement.[9]

Mechanical stimuli, such as posterior impingement, can affect posterior femoral condylar osteophyte formation.[12] Over time, we have occasionally encountered newly developed posterior femoral condylar osteophytes in patients with the UC deep-dish design prosthesis. Based on the design rationale, the UC deep-dish design insert has a prominent anterior lip that allows the femoral component to move within the deep-dish configuration, thus making the femoral rollback a posterior-stabilizing device.[13] We speculate that osteophyte formation is related to the rollback mechanism and deep flexion. Therefore, the purpose of the present study was to verify the meaning of osteophyte formation in the UC design and to evaluate the cause and effect of this on the outcome. Hypotheses of this study were that posterior femoral osteophytes may be caused by posterior impingement and that osteophytes may change serially and affect clinical outcomes, including ROM.

METHODS

This study was approved by the Institutional Review Board of Seoul National University Bundang Hospital (IRB No. B-2007/627-302). Informed consent was waived due to the retrospective nature of the study.

Patients

The operative records and serial radiological evaluation results of 156 knees that underwent primary TKA using the UC deep-dish design (Columbus, B. Braun Aesculap) from March 2014 to February 2018 were retrospectively investigated. The indication for the UC design prosthesis was a little different from that of the posterior-stabilized (PS) design and it was not allocated in severely deformed knees. The exclusion criteria were as follows: (1) severe deformity such as > 20° varus or valgus, and > 30° severe flexion contracture, (2) previous knee surgery including high tibial osteotomy, unicompartmental knee arthroplasty, and fracture surgery, and (3) patients who did not perform deep flexion x-ray in the midterm follow-up. Ultimately, 96 knees underwent the full evaluation, of which 48 exhibited osteophyte formation (group 1) and 48 did not (group 2).

Evaluation Methods

PTS, PCO, and indirect femoral rollback were measured using 30° flexion standing lateral and active full flexion lateral radiographs. All measurements were performed twice by 2 orthopedic surgeons (HWJ and HJY) with more than 6 weeks of interval. Clinical outcomes were evaluated using the American Knee Society (AKS) knee and functional scales, the Western Ontario and McMaster University Arthritis Index (WOMAC) pain, stiffness, and function scales, and ROM. For the assessment of ROM, flexion contracture and active further flexion were evaluated using a goniometer before and after surgery with the patient positioned supine. The flattened knee parallel to the horizontal line was used as a reference to define 0°. Flexion-extension gap balance and medial-lateral (M-L) balance were also measured through intraoperative assessment.

Radiological Evaluation

Lateral radiographs were reviewed to analyze factors that could affect knee ROM using PCO, PTS angle, and posterior under- or overhang of the femoral component. PCO was defined as the maximal thickness of the posterior condyle projecting posteriorly from the extension of the posterior cortex of the femur shaft.[14] The PTS angle was defined as the angle between the tibial tray slope and the line perpendicular to the tibial anatomical axis (Fig. 1). Proximal projection of the posterior condyle of the femoral component or exposed cancellous bone was evaluated to analyze the posterior over- or underhang of the femoral component (Fig. 2). Component overhang was defined when the posterior component protruded > 3 mm.[15,16]

Posterior femoral condylar osteophytes were assessed serially at 1 year, 2 years, and 3 years or more based on immediate postoperative findings. A line perpendicular to the Blumensaat line was drawn through the most anterior and posterior edges of the osteophytes on a lateral radiograph. The distance between these 2 lines was measured and defined as the thickness of the osteophyte. A line drawn perpendicular to the proximal and distal ends of the osteophyte was defined as the osteophyte length (Fig. 3).[17]

Femoral rollback was indirectly evaluated using the distance between the deepest point of the polyethylene and femoral component anterior margin in 30° flexion and active deep flexion lateral radiographs. In addition, femoral rollback was also assessed according to the distance between the deepest point of the polyethylene and the most posterior contact point of the polyethylene with the femoral component between 30° flexion and active deep flexion lateral radiographs. To correct different deep flexion angles for the femoral rollback assessment, the deep flexion angle was measured and adjusted to 130° flexion (Fig. 4). The distance from 30° flexion to active deep flexion lateral radiographs was used for the indirect assessment of femoral rollback (Fig. 5).

Surgical Technique

All operative procedures were performed by a single experienced surgeon (YSL). The medial parapatellar approach was used, and the distal femur intramedullary guide was aimed at the mechanical axis. A femoral rotation cutting block was located with an average of 3° of external rotation from the posterior condylar axis as a reference. External rotation was adjusted according to the transepicondylar axis when the femoral condyle exhibited hypoplasia or massive abrasion. After bone resection, the remaining osteophyte(s) was removed, which induced posterior capsule and medial collateral ligament (MCL) tenting. Subsequently, medial and lateral gaps were measured with the knee in full extension and at 90° of flexion using a tensor device (Aesculap) and spreader; if necessary, sequential multiple needle puncturing of the superficial MCL was performed. In particular, the extension gap was adjusted more tightly than the flexion gap to prevent anteroposterior (AP) instability and gradual hyperextension. Once gap balancing was acceptable, trial implants were placed. Following this, M-L and AP stability and passive ROM were manually verified. In all cases, patients performed standardized weight-bearing and ROM exercises on the day after surgery using crutches or walkers.

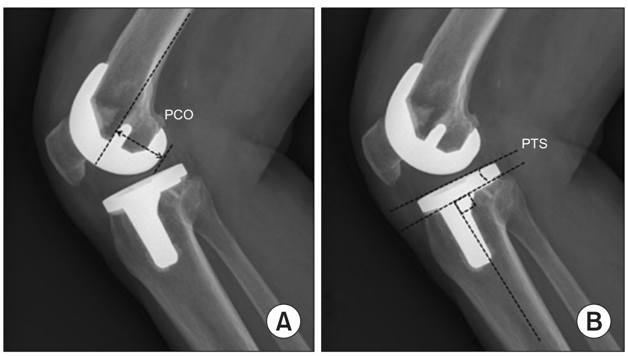

Fig. 1. Measurement of radiological parameters. (A) Posterior condylar offset (PCO); maximal thickness of the posterior condyle projecting posteriorly from the extension of the posterior cortex of the femur shaft. (B) Posterior tibial slope (PTS) angle; the angle between the tibial tray slope and the line perpendicular to the tibial anatomical axis.

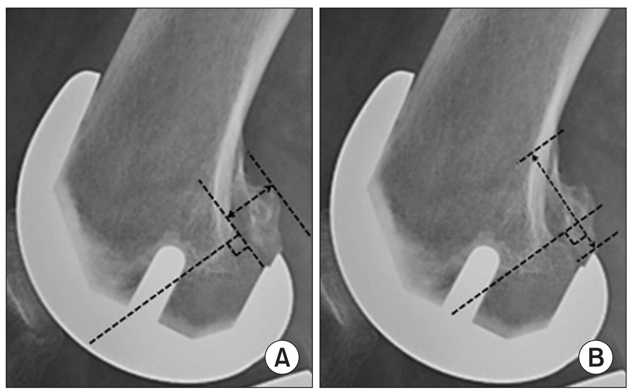

Fig. 3. Assessment of posterior femoral osteophyte formation. (A) Thickness; the distance between lines drawn anterior and posterior to the osteophyte perpendicular to the Blumensaat line. (B) Length; the distance between lines drawn perpendicular to the proximal and distal ends of the osteophyte.

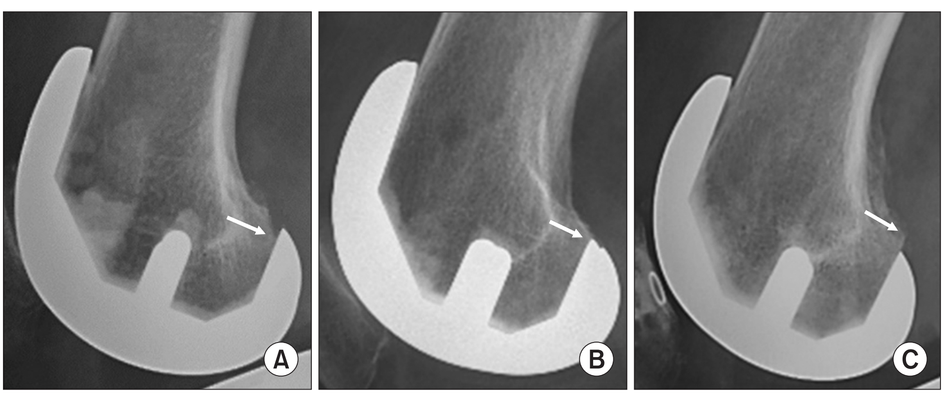

Fig. 2. Measurement of posterior component fitting. (A) Overhang was defined when the posterior component protruded > 3 mm. Good fit (B) and underhang (C) on 30° flexion lateral radiographs. The white arrows indicate the extent to which the femoral component covers the posterior condyle of the femur.

Statistical Analysis

All statistical analyses were performed using IBM SPSS version 26.0 (IBM Corp.). Intra- and interrater reliability for measurement was assessed using intraclass correlation coefficient (ICC) analysis. Priori power analysis was performed using G power version 3.1.9.4, in which at least 61 knees were required to perform Pearson's correlation analysis (effect size ρ = 0.35, α = 0.05, power [1–β] = 0.80). Data descriptions were based on mean and standard deviation (SD) for continuous variables. The chi-square and Fisher's exact tests were used to compare qualitative variables (sex, right or left side, and posterior component coverage). The Student *t*-test or Mann-Whitney test was used to compare demographics, radiological, intraoperative, and clinical outcomes between the groups. Repeated measures one-way analysis of variance (ANOVA) was performed to compare osteophyte size and ROM between each period in the serial follow-up. Repeated measures 2-way ANOVA was performed to evaluate the interaction effect of osteophyte formation on serial changes in ROM. Bonferroni post-hoc analysis was performed. Pearson's correlation analysis was performed to evaluate correlations between the final follow-up of the posterior impingement factors and ROM. Pearson's correlation analysis was used to identify statistically significant parameters in the comparison between groups 1 and 2. It was also used to analyze the correlation between deep flexion angle and posterior rollback. Differences with $p < 0.05$ were considered statistically significant.

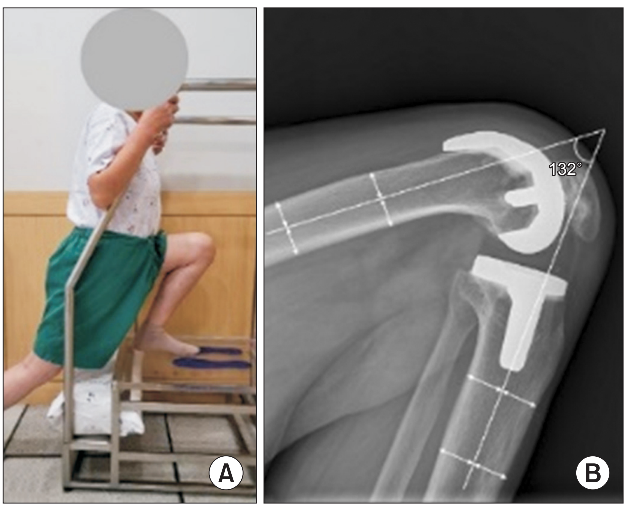

Fig. 4. Scheme of the deep flexion angle. (A) Posture to take an active deep flexion wight-bearing lateral radiograph. (B) The angle formed by lines drawn along the mid-shafts of the tibia and femur on a lateral deep flexion radiograph.

RESULTS

The intra- and interobserver agreements were excellent (ICC, 0.851–0.873) on radiographic measurements. The mean (± SD) follow-up period was 49.35 ± 3.47 months and 47.52 ± 3.37 months in groups 1 and 2, respectively. The demographic characteristics of the 2 groups were similar and are summarized in Table 1. There were no statistical differences in radiological parameters (PCO and PCO ratio [PCOR]) and PTS between the groups. However, posterior component coverage was significantly different

Table 1. Patient Demographics

Variable	Group 1 (osteophyte +)	Group 2 (osteophyte –)	*p*-value*
Age (yr)	70.3 ± 5.9	70.4 ± 6.7	0.961
Sex (male : female, %)	12.5 : 87.5	16.7 : 83.3	0.838
Site (right : left, %)	47.9 : 52.1	45.8 : 54.2	0.563
Body mass index (kg/m^2)	27.27 ± 3.65	27.13 ± 5.56	0.892
Follow-up period (mo)	49.35 ± 3.47	47.52 ± 3.37	-

Values are presented as mean ± standard deviation.
*Statistical significance, $p < 0.05$.

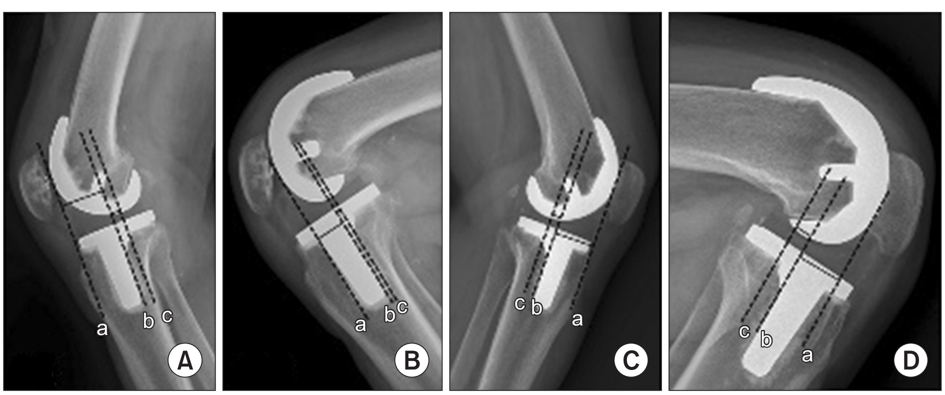

Fig. 5. Indirect femoral rollback assessment on 30° flexion (A, C) and active deep flexion (B, D) lateral radiographs. a: femoral component anterior margin, b: deepest point of polyethylene, c: most posterior contact point.

between the groups: group 1 exhibited more underhang and group 2 exhibited more overhang ($p = 0.022$). In the case of intraoperative parameters, the flexion gap was slightly larger than the extension gap in both groups, but there was no M-L imbalance in either group. In addition, there was no significant difference in polyethylene thickness (Table 2).

On the indirect assessment of the femoral rollback, in the case of the anterior margin distance, 30° flexion, deep flexion, change in distance, and corrected change distance were statistically different between the groups ($p = 0.023$, $p < 0.001$, $p < 0.001$, and $p < 0.001$, respectively), and the amount of change in the anterior margin distance was larger in group 2 than in group 1. In the case of contact point distance, there was a statistically significant difference in deep flexion, change in distance, and corrected change distance ($p < 0.001$ $p < 0.001$, and $p < 0.001$, respectively). While the contact point distance increased in group 2, it decreased in group 1 and exhibited paradoxical anterior displacement (–1.31 ± 3.03 mm and 2.83 ± 2.19 mm in groups 1 and 2, respectively) (Table 3, Fig. 5).

Final follow-up clinical outcomes, including ROM and clinical scales, improved compared to preoperative values in both groups. Flexion contracture was significantly higher in group 1 than in group 2 (3.35° ± 1.56° and 2.06° ± 2.16°, respectively; $p = 0.001$). Both groups exhibited a similar degree of active further flexion at the final follow-up ($p = 0.131$). There was no statistical difference in AKS knee and function scores between the groups, although group 2 exhibited significant improvement in pain compared to group 1 in the WOMAC pain score ($p = 0.029$). There were no significant differences in other WOMAC scores between the 2 groups (Table 4). In both groups, flexion contracture decreased over time; however, in group 1, active further flexion gradually decreased over time ($p < 0.001$) and in group 2, active further flexion increased over time ($p < 0.001$) (Table 5). When analyzing differences according to time points in each group, the

Table 2. Evaluation of Radiologic and Intraoperative Parameters

Variable	Group 1 (osteophyte +)	Group 2 (osteophyte –)	*p*-value
Radiologic parameter			
PCO (mm)	30.75 ± 7.17	32.02 ± 4.91	0.321
PCO ratio	0.50 ± 0.11	0.51 ± 0.08	0.622
PTS (°)	3.1 ± 1.21	2.97 ± 0.61	0.485
Posterior component coverage			0.022*
Overhang (knees, %)	3.90	16.00	
Good-fit (knees, %)	85.40	80.00	
Underhang (knees, %)	10.70	4.00	
Length (mm)	–1.5 ± 2.6	1.5 ± 2.2	
Deep flexion angle	130.96 ± 9.47	122.95 ± 5.09	< 0.001*
Intraoperative parameter (mm)			
Flexion-extension gap difference			
Lateral	0.88 ± 0.57	0.94 ± 0.53	0.588
Medial	0.71 ± 0.87	0.79 ± 0.78	0.643
M-L balance			
Flexion	0.54 ± 0.68	0.43 ± 0.62	0.387
Extension	0.38 ± 0.64	0.28 ± 0.54	0.420
Polyethylene thickness	12.04 ± 1.57	12.52 ± 1.64	0.154

Values are presented as mean ± standard deviation.
PCO: posterior condylar offset, PTS: posterior tibial slope, M-L balance: difference between lateral gap and medial gap.
*Statistical significance, $p < 0.05$.

Table 3. Indirect Assessment of the Femoral Rollback

Variable	Group 1 (osteophyte +)	Group 2 (osteophyte –)	*p*-value
Femoral rollback parameter			
Anterior margin distance (mm)			
30° Flexion	28.78 ± 2.68	29.91 ± 2.07	0.023*
Deep flexion	19.93 ± 3.00	17.71 ± 2.09	< 0.001*
Change distance	–8.85 ± 2.93	–12.20 ± 2.34	< 0.001*
Corrected change distance	–9.11 ± 3.16	–12.86 ± 2.90	< 0.001*
Contact point distance (mm)			
30° Flexion	5.05 ± 2.06	4.94 ± 1.33	0.254
Deep flexion	3.61 ± 3.55	6.40 ± 2.10	< 0.001*
Change distance	–1.43 ± 3.20	1.46 ± 2.01	< 0.001*
Corrected change distance	–1.31 ± 3.03	2.83 ± 2.19	< 0.001*
Deep flexion angle			
Anterior margin distance (mm)	$r = 0.510$, $p < 0.001$*		
Contact point distance (mm)	$r = –0.760$, $p < 0.001$*		

Values are presented as mean ± standard deviation.
Change distance: difference of contact point distance at deep flexion and 30° flexion, corrected change distance: the deep flexion angle was measured and adjusted to 130° flexion.
*Statistical significance, $p < 0.05$.

Table 4. Comparison of Last Follow-up Clinical Outcomes

Outcome	Group 1	Group 2	*p*-value
ROM			
FC (°)	3.35 ± 1.56	2.06 ± 2.16	0.001*
FF (°)	130.42 ± 2.49	129.48 ± 3.45	0.131
Clinical score			
AKSS knee	76.46 ± 12.08	74.09 ± 11.34	0.326
AKSS function	68.75 ± 14.64	69.49 ± 14.58	0.806
WOMAC pain	3.00 ± 2.44	1.96 ± 2.13	0.029*
WOMAC stiffness	1.50 ± 1.54	1.72 ± 1.77	0.514
WOMAC function	20.56 ± 6.59	18.98 ± 7.54	0.279

Values are presented as mean ± standard deviation.
ROM: range of motion, FC: flexion contracture, FF: further flexion, AKSS: American Knee Society Scores, WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index.
*Statistical significance, $p < 0.05$.

thickness and length of osteophytes in group 1 increased significantly over time ($p < 0.001$) (Table 5, Fig. 6).

DISCUSSION

The principal findings of this study were as follows: osteophyte formation decreased femoral rollback, which was verified by the smaller amount of change in the anterior margin distance and the change in contact point distance. Posterior condylar osteophytes also caused a gradual decrease in active further flexion with time. Osteophytes were more frequently observed when the femoral component was underhang and were also associated with pain.

It has been reported that impingement can occur and the degree of flexion can be reduced by > 10° when the posterior condylar cancellous bone is uncovered by distal placement of the femoral component.[9)] In our study, the proportion of posterior condyle underhanging components in the osteophyte group (i.e., group 1) was higher than that in the group without osteophytes (i.e., group 2). We assumed that this difference was related to the posterior impingement and the formation of an osteophyte. Walker et al.[9)] reported an increase in ROM as the PCO increased. On the other hand, some studies have reported that PCO and PCOR do not have a significant effect on ROM.[18-20)] According to the study by Mahoney and Kin-

Table 5. Serial Changes of Posterior Femoral Osteophyte Size and ROM

Variable	Postoperative 1 yr	Postoperative 2 yr	Final FU	*p*-value
Posterior osteophyte size				
Osteophyte thickness (mm)	2.72 ± 1.64	4.20 ± 1.97	5.79 ± 1.78	< 0.001*
Osteophyte length (mm)	6.62 ± 4.22	8.50 ± 4.48	11.72 ± 4.65	< 0.001*
ROM (°)				
FC				
Group 1	3.87 ± 1.82	3.48 ± 1.61	3.35 ± 1.56	0.044*
Group 2	3.08 ± 1.49	2.63 ± 1.45	2.06 ± 2.16	< 0.001*
FF				
Group 1	134.90 ± 3.92	133.96 ± 5.74	130.42 ± 2.49	< 0.001*
Group 2	122.50 ± 4.84	126.46 ± 4.25	129.48 ± 3.45	< 0.001*

Values are presented as mean ± standard deviation.
ROM: range of motion, FU: follow-up, FC: flexion contracture, FF: further flexion.
*Statistical significance, $p < 0.05$.

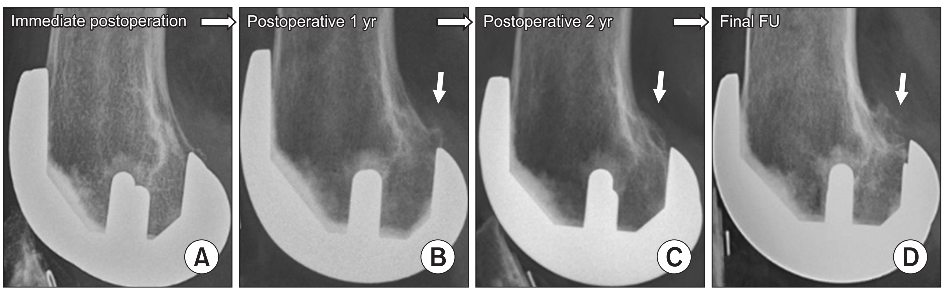

Fig. 6. Serial change in posterior femoral osteophyte formation. (A) Cleaned posterior femoral condyle immediately postoperatively. (B) Postoperative 1 year. (C) Postoperative 2 years. (D) Final follow-up (FU).

sey,[16] when the femoral component was overhanging by ≥ 3 mm, a larger size of the component may affect the reduction in ROM. In the present study, the results were somewhat contradictory, the overhang rate was higher in the group without osteophytes, and the postoperative ROM was lower in the group with osteophytes. However, there was no significant difference in further flexion between the 2 groups at the final follow-up.

In a randomized controlled trial comparing 63 UC and 64 PS TKA, Lutzner et al.[21] reported that paradoxical anterior displacement may occur in UC. It has been reported that anterior femoral translation can induce posterior impingement with decreased PCO.[22,23] Mizu-Uchi et al.[24] reported that bony impingement due to posterior osteophytes can limit flexion. Yau et al.[8] described posterior femoral condyle osteophytes as a significant independent factor affecting postoperative flexion, revealed by serial regression analysis of 92 patients at 3 months, 6 months, and 1 year. In group 1 in our study (i.e., with osteophytes), flexion contracture improved over time, but further flexion decreased, which is believed to be the effect of bony impingement due to the formation of posterior osteophytes. In addition, posterior impingement due to an osteophyte or decreased PCO may be a factor that increases pain after TKA.[25-27] In our study, it was observed that group 1 had a significantly higher WOMAC pain score than did group 2.

Massin and Gournay[10] reported that paradoxical femoral rollback could cause tibiofemoral impingement, which eventually results in a decrease in ROM. In the present study, paradoxical rollback was observed in group 1, in which the contact point distance decreased in deep flexion, and osteophytes gradually emerged and increased over time. Similarly, Carvalho et al.[28] also reported that femoral rollback and posterior impingement were related, but such impingement did not induce a difference in ROM. In the present study, the group with osteophytes exhibited an increase in osteophyte size over time; however, the final follow-up result demonstrated no statistically significant difference between the groups. It appears that posterior impingement occurred due to insufficient femoral rollback and osteophytes were formed as a consequence, but it did not appear to cause a difference in the final ROM. However, ROM exhibited a decreasing pattern over time if an osteophyte was formed.

The clinical relevance of this study is that the mechanics of the UC design were verified even though it was an indirect assessment, and it was confirmed that the mechanics of the UC were not perfect compared to our expectations. In addition, the impact of osteophyte formation was addressed, and we verified how it was formed and how it altered the clinical outcome. However, there were also some limitations to be considered. First, rollback was indirectly assessed in only 2 dimensions, although it is well known that flexion of the knee is 3-dimensional. Nevertheless, we could predict whether the posterior movement of the femoral condyle was well maintained using indirect assessment. Second, we did not correlate the active deep flexion angle and rollback distance, which could have resulted in bias. The reason for this is that differences in the degree of active further flexion varied among the patients. The measured deep flexion angle was corrected as much as the value, but there may be still a bias from the actual angle. Finally, we could not evaluate the direct correlation between posterior impingement and posterior femoral osteophytes. However, previous studies have established that posterior impingement may cause the formation of posterior femoral osteophytes.[8,17,29)]

Posterior condylar osteophyte formation was related to posterior impingement. It was more frequently observed in the underhang of the femoral component and insufficient femoral rollback. In addition, it changed with time and caused negative effects, including a gradual decrease in flexion and more pain.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

ACKNOWLEDGEMENTS

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT; No. 2021R1A2C1092657).

ORCID

Ho Won Jeong https://orcid.org/0000-0001-6085-9157
Hyun Jin Yoo https://orcid.org/0000-0001-5979-1765
Seong Yun Park https://orcid.org/0000-0002-9639-3771
Yong Seok Lee https://orcid.org/0000-0002-4641-305X

REFERENCES

1. Rowe PJ, Myles CM, Walker C, Nutton R. Knee joint kinematics in gait and other functional activities measured using flexible electrogoniometry: how much knee motion is sufficient for normal daily life? Gait Posture. 2000 Oct;12(2):143-55.
2. Hefzy MS, Kelly BP, Cooke TD. Kinematics of the knee joint in deep flexion: a radiographic assessment. Med Eng Phys. 1998 Jun;20(4):302-7.
3. Weiss JM, Noble PC, Conditt MA, et al. What functional activities are important to patients with knee replacements? Clin Orthop Relat Res. 2002 Nov;(404):172-88.
4. Mizu-uchi H, Colwell CW Jr, Matsuda S, Flores-Hernandez C, Iwamoto Y, D'Lima DD. Effect of total knee arthroplasty implant position on flexion angle before implant-bone impingement. J Arthroplasty. 2011 Aug;26(5):721-7.
5. Devers BN, Conditt MA, Jamieson ML, Driscoll MD, Noble PC, Parsley BS. Does greater knee flexion increase patient function and satisfaction after total knee arthroplasty? J Arthroplasty. 2011 Feb;26(2):178-86.
6. Matsuda S, Kawahara S, Okazaki K, Tashiro Y, Iwamoto Y. Postoperative alignment and ROM affect patient satisfaction after TKA. Clin Orthop Relat Res. 2013 Jan;471(1):127-33.
7. Kurosaka M, Yoshiya S, Mizuno K, Yamamoto T. Maximizing flexion after total knee arthroplasty: the need and the pitfalls. J Arthroplasty. 2002 Jun;17(4 Suppl 1):59-62.
8. Yau WP, Chiu KY, Tang WM, Ng TP. Residual posterior femoral condyle osteophyte affects the flexion range after total knee replacement. Int Orthop. 2005 Dec;29(6):375-9.
9. Walker PS, Yildirim G, Sussman-Fort J, Roth J, White B, Klein GR. Factors affecting the impingement angle of fixed- and mobile-bearing total knee replacements: a laboratory study. J Arthroplasty. 2007 Aug;22(5):745-52.
10. Massin P, Gournay A. Optimization of the posterior condylar offset, tibial slope, and condylar roll-back in total knee arthroplasty. J Arthroplasty. 2006 Sep;21(6):889-96.
11. Keogh CJ, Mulcahy D, Reidy D, Beverland DE, Harty JA. Polyethylene spinout in the Attune Cruciate-Retaining

Rotating-Platform (CR RP) total knee arthroplasty performed with a cruciate-sacrificing and measured-resection technique. Knee Surg Relat Res. 2020 Jul;32(1):36.

12. Wong SH, Chiu KY, Yan CH. Review article: osteophytes. J Orthop Surg (Hong Kong). 2016 Dec;24(3):403-10.

13. Jang SW, Kim MS, Koh IJ, Sohn S, Kim C, In Y. Comparison of anterior-stabilized and posterior-stabilized total knee arthroplasty in the same patients: a prospective randomized study. J Arthroplasty. 2019 Aug;34(8):1682-9.

14. Kanekasu K, Banks SA, Honjo S, Nakata O, Kato H. Fluoroscopic analysis of knee arthroplasty kinematics during deep flexion kneeling. J Arthroplasty. 2004 Dec;19(8):998-1003.

15. Dai Y, Scuderi GR, Penninger C, Bischoff JE, Rosenberg A. Increased shape and size offerings of femoral components improve fit during total knee arthroplasty. Knee Surg Sports Traumatol Arthrosc. 2014 Dec;22(12):2931-40.

16. Mahoney OM, Kinsey T. Overhang of the femoral component in total knee arthroplasty: risk factors and clinical consequences. J Bone Joint Surg Am. 2010 May;92(5):1115-21.

17. Leie MA, Klasan A, Oshima T, et al. Large osteophyte removal from the posterior femoral condyle significantly improves extension at the time of surgery in a total knee arthroplasty. J Orthop. 2019 Nov;19:76-83.

18. Chang MJ, Kang SB, Chang CB, et al. Posterior condylar offset changes and its effect on clinical outcomes after posterior-substituting, fixed-bearing total knee arthroplasty: anterior versus posterior referencing. Knee Surg Relat Res. 2020 Jan;32(1):10.

19. Hanratty BM, Thompson NW, Wilson RK, Beverland DE. The influence of posterior condylar offset on knee flexion after total knee replacement using a cruciate-sacrificing mobile-bearing implant. J Bone Joint Surg Br. 2007 Jul;89(7):915-8.

20. Ishii Y, Noguchi H, Takeda M, Sato J, Toyabe S. Posterior condylar offset does not correlate with knee flexion after TKA. Clin Orthop Relat Res. 2013 Sep;471(9):2995-3001.

21. Lutzner J, Beyer F, Dexel J, Fritzsche H, Lutzner C, Kirschner S. No difference in range of motion between ultracongruent and posterior stabilized design in total knee arthroplasty: a randomized controlled trial. Knee Surg Sports Traumatol Arthrosc. 2017 Nov;25(11):3515-21.

22. Hofmann AA, Tkach TK, Evanich CJ, Camargo MP. Posterior stabilization in total knee arthroplasty with use of an ultracongruent polyethylene insert. J Arthroplasty. 2000 Aug;15(5):576-83.

23. Massin P, Boyer P, Sabourin M. Less femorotibial rotation and AP translation in deep-dished total knee arthroplasty: an intraoperative kinematic study using navigation. Knee Surg Sports Traumatol Arthrosc. 2012 Sep;20(9):1714-9.

24. Mizu-Uchi H, Colwell CW Jr, Fukagawa S, Matsuda S, Iwamoto Y, D'Lima DD. The importance of bony impingement in restricting flexion after total knee arthroplasty: computer simulation model with clinical correlation. J Arthroplasty. 2012 Oct;27(9):1710-6.

25. Mandalia V, Eyres K, Schranz P, Toms AD. Evaluation of patients with a painful total knee replacement. J Bone Joint Surg Br. 2008 Mar;90(3):265-71.

26. Hofmann S, Seitlinger G, Djahani O, Pietsch M. The painful knee after TKA: a diagnostic algorithm for failure analysis. Knee Surg Sports Traumatol Arthrosc. 2011 Sep;19(9):1442-52.

27. Flierl MA, Sobh AH, Culp BM, Baker EA, Sporer SM. Evaluation of the painful total knee arthroplasty. J Am Acad Orthop Surg. 2019 Oct;27(20):743-51.

28. Carvalho LH Jr, Temponi EF, Soares LF, Goncalves MJ. Relationship between range of motion and femoral rollback in total knee arthroplasty. Acta Orthop Traumatol Turc. 2014;48(1):1-5.

29. Pinskerova V, Johal P, Nakagawa S, et al. Does the femur roll-back with flexion? J Bone Joint Surg Br. 2004 Aug;86(6):925-31.