

Evaluation of Postoperative Range of Motion and Functional Outcomes after Cruciate-Retaining and Posterior-Stabilized High-Flexion Total Knee Arthroplasty

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Purpose: The purpose of this study was to compare postoperative range of motion and functional outcomes among patients who received high-flexion total knee arthroplasty using cruciate-retaining (CR-Flex) and posterior-stabilized (PS-Flex) type prostheses. **Materials and Methods:** Among 127 patients (186 knees) who underwent high-flexion total knee arthroplasty between 2005 and 2007, 92 knees were placed in the CR-Flex group, and 94 knees were placed in the PS-Flex group. After two years of postoperative follow-up, clinical and radiographic data were reviewed. Postoperative non-weight-bearing range of knee motion, angle of flexion contracture and functional outcomes based on the Western Ontario and McMaster Universities Osteoarthritis (WOMAC) functional sub-scale were assessed and compared between the two groups. **Results:** After the 2-year postoperative period, the mean range of motion was 131° in the CR-Flex group and 133° in the PS-Flex group. There were no significant differences in postoperative range of motion between the two groups. Only age at operation and preoperative range of motion were significantly associated with postoperative range of motion after high-flexion total knee arthroplasty. Postoperative functional outcomes based on the WOMAC functional sub-scale were slightly better in the CR-Flex group (9.2±9.1 points) than in the PS-Flex group (11.9±9.6 points); however, this difference was not statistically significant (p =non-significant). **Conclusion:** The retention or substitution of the posterior cruciate ligament does not affect postoperative range of motion (ROM) or functional outcomes, according to 2 years of postoperative follow-up of high-flexion total knee arthroplasty.

Key Words: Total knee arthroplasty, range of motion, functional outcomes, cruciate-retaining, posterior-stabilized, high-flexion

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INTRODUCTION

Postoperative range of motion (ROM) is one of the most important factors influencing patient satisfaction after total knee arthroplasty (TKA). Patients planning to undergo TKA, especially in non-western cultures, usually expect that he or she will be able to sit cross-legged or kneel with ease after the operation; however,

these activities require deep knee flexion.¹ Predicting postoperative ROM is complicated, as the results can be affected by multiple factors such as the patient's age, gender, diagnosis, preoperative ROM, the surgeon's skill, the design of the prosthesis, postoperative rehabilitation, etc.²⁻⁴ While most of these factors are not easily modifiable, the selection of the prosthesis is mostly dependent upon the surgeon's discretion. Accordingly, there have been many attempts to improve postoperative ROM by modifying the prosthetic design. The high-flexion total knee system is one among the more recently introduced prostheses. Therein, thickened and round posterior femoral condyles of the prosthesis are able to increase the articular contact area and prevent posterior impingement of the femur at a high flexion angle. Consequently, increased ROM and diminished contact stress were expected. Both cruciate-retaining (CR) and posterior-stabilized (PS) type TKAs are available with the high-flexion type total knee system. A few comparison studies on the CR-Flex and PS-Flex type TKAs regarding postoperative outcomes or *in vivo* kinematics have been reported. Sharma, et al.⁵ and Seon, et al.⁶ reported in their *in vivo* kinematic studies, that the PS-Flex type TKAs showed weight-bearing knee flexion and posterior femoral roll-back, while Cates, et al.⁷ reported no difference in weight-bearing knee flexion, but rather more consistent axial rotation in the CR-Flex type TKAs. Kim, et al.,⁸ on the other hand, reported, in a study of bilateral simultaneous TKAs of CR-Flex type TKA on one side and PS-Flex type TKA on the other side, that no difference in knee flexion and functional outcomes between the two groups after 2-year postoperative follow-up. However, there is no general consensus regarding the postoperative range of motion or the functional outcomes between the CR- and PS-type high-flexion TKAs as of now. Therefore, the purpose of this study was to compare the postoperative ROMs and functional outcomes in patients who underwent TKA utilizing either the CR- or PS-type high-flexion total knee system. We hypothesized that the postoperative ROM would be slightly better in the PS-Flex type TKAs and that the postoperative functional outcomes would be similar between the two groups.

MATERIALS AND METHODS

Patient demographics

Between November 2005 and October 2007, 242 consecutive cemented TKAs in 134 patients were performed by a

single surgeon using Nexgen high-flexion prostheses (Zimmer, Warsaw, IL, USA). Regardless of the patient's age, gender, diagnosis or severity of the preoperative deformity, CR-type TKAs using a Nexgen CR-Flex prosthesis were performed in every patient during the first half of the study period, and PS-type TKAs using a Nexgen LPS-Flex prosthesis were performed during the second half of the study period. There were no patients who received bilateral TKAs using different types of prosthesis on each side of knee. All patients were diagnosed with advanced arthritis of the knee and previously failed to respond to conservative management. Although all clinical and radiographic data were collected prospectively, analysis of the data was performed in a retrospective manner. An informed consent form was offered and signed by each patient. Also, Institutional Review Board approval was obtained before starting this study.

To minimize the influence of preoperative characteristics upon postoperative results, only female patients with a diagnosis of osteoarthritis, a minimum preoperative ROM $\geq 90^\circ$, and a preoperative flexion contracture $\leq 20^\circ$ were included in the analysis, and patients with a history of previous knee infection, trauma requiring surgery, or revision arthroplasty were excluded. One hundred thirty-four patients (196 knees) who fulfilled all of the criteria were identified, and their clinical and radiographic data were reviewed. Six patients (8 knees) were lost to follow-up, and 1 patient (2 knees) died of causes unrelated to the index operation before the end of the 2-year postoperative period. None of these patients required revision of the prosthesis. The remaining 186 knees (127 patients) had a minimum of 2 years postoperative clinical and radiographic records available for analysis. Ninety-two knees (67 patients) received TKA using the Nexgen CR-Flex prosthesis (CR-Flex group), and 94 knees (60 patients) received TKA using the Nexgen LPS-Flex prosthesis (PS-Flex group). The mean age at the time of the index operation was 67.5 ± 5.7 years in the CR-Flex group, and 68.0 ± 5.8 years in the PS-Flex group. The mean body mass index (BMI) was 27.5 ± 3.4 kg/cm² in the CR-Flex group, and 27.4 ± 4.0 kg/cm² in the PS-Flex group. Mean age and BMI did not differ between the two groups [p =non-significant (n.s.)]. Preoperative femoral-tibial alignment also did not differ significantly between the two groups: $4.0 \pm 4.6^\circ$ varus in the CR-Flex group versus $4.4 \pm 5.7^\circ$ varus in the PS-Flex group (p =n.s.).

Prosthesis and procedures

Both the CR-Flex and the LPS-Flex Nexgen high-flexion

prostheses have more extended and more rounded posterior condyles of the femoral component than the Nexgen CR and LPS prostheses. In addition, the Nexgen CR-Flex prosthesis, like its predecessor, comprises asymmetrical radii of the femoral condyles, i.e., the lateral condyle is larger than the medial condyle; whereas, the Nexgen LPS-Flex prosthesis comprises symmetrical femoral condyles.

All operations were performed by the senior author (C. D.H.). All knees were approached via a midline skin incision with a midvastus capsular incision into the joint after tourniquet application. The anterior cruciate ligament was sacrificed and patella resurfacing was not performed in either of the groups. The surgical procedures were identical for the two groups except for intercondylar box cutting of the femur in the PS-Flex group. Thorough ligament balancing was performed by means of equal flexion and extension gap. All components were fixed with cement using a standard modern technique. Lateral retinacular release was performed for proper patellofemoral tracking if necessary. In the CR-Flex group, proper tension of the PCL (anterior tibial translation less than 5 mm) was confirmed before closure. Hemovac drains were inserted in all cases and remained for 24 hours. Full weight-bearing ambulation with crutches or a walker and range of motion exercises were started on the first postoperative day after removal of the drain. The rehabilitation programs were identical in both groups.

Outcome assessment

Patients were evaluated clinically and radiographically at 6 weeks, 6 months, 1 year after the operation, and then yearly thereafter. The data assessed during the 2-year postoperative period was used for evaluation in both groups. Values for knee scores were obtained according to the Knee Society clinical scoring system⁹ and the Hospital for Special Surgery (HSS) knee-rating system.¹⁰ To assess the patients' functional status, the functional sub-scale of the Western Ontario and McMaster Universities Osteoarthritis (WOMAC) score¹¹ was checked separately. The functional sub-scale of the WOMAC score consisted of 17 questions regarding functional activities of daily living, with a lower score indicating better functional status (0 to 68 points).

Preoperative and postoperative ROMs were recorded in an active non-weight-bearing mode using a goniometer on the skin surface, measuring the sagittal angle between the hip, knee, and ankle centers. Flexion contracture of the knee joint was checked separately. The preoperative and postoperative alignments of the limb were also checked and compared.

Anteroposterior and lateral fluoroscopically assisted radiographs, as well as a skyline patellar radiograph, were obtained preoperatively and postoperatively with the patient standing and in a supine position. The radiographs were assessed for radiolucency at the bone-cement interface around the components, the position of the components, the alignment of the limb (femoral-tibial angle), patellar tilt or subluxation, and osteolysis according to the method of the Knee Society.¹² Changes in joint line position were measured using preoperative and 2-year postoperative standing lateral radiographs as described by Figgie, et al.¹³ At the 2-year postoperative follow-up, patients were assessed for signs or symptoms suggesting instability. All clinical and radiographic data were recorded by a clinical fellow (C.W.H.) who did not participate in the operation.

Statistical analysis

Statistical analysis was performed using SPSS software version 18.0 for Windows (SPSS Inc., Chicago, IL, USA). Student's t-tests for continuous variables with normal distribution, the Mann-Whitney U test for continuous variables with non-normal distribution, and chi-square tests or Fisher's exact tests for dichotomous variables were used to determine whether there were significantly different values between the two groups. To determine the factors affecting postoperative range of motion, a stepwise multiple linear regression analysis was performed with backwards elimination (p -values >0.10 were used for removal). The following independent variables were entered for analysis: age at operation, body mass index, preoperative ROM, postoperative joint line elevation, type of prosthesis (CR or PS type) and preoperative varus/valgus deformity. The variance inflation factor was used to check for colinearity between the independent variables. Differences were considered significant if p -values were less than 0.05.

RESULTS

Range of motion

The mean ROM increased from $124.5 \pm 15.3^\circ$ preoperatively to $131.0 \pm 10.5^\circ$ at the 2-year postoperative follow-up in the CR-Flex group, and from $128.4 \pm 13.4^\circ$ preoperatively to $132.7 \pm 7.0^\circ$ at the 2-year postoperative follow-up in the PS-Flex group. The average ROM of knees in both groups was significantly improved after the operation ($p=0.000$). There was no significant difference in ROM between the two

groups in either the preoperative or the 2-year postoperative period ($p=n.s.$).

The mean flexion contracture decreased from $3.2\pm 5.4^\circ$ preoperatively to $0.2\pm 1.5^\circ$ at the 2-year postoperative follow-up in the CR-Flex group, and from $3.6\pm 4.9^\circ$ preoperatively to $0.2\pm 1.1^\circ$ at the 2-year postoperative follow-up in the PS-Flex group. The average angle of flexion contracture was also significantly decreased after the operation in both groups ($p=0.000$). There was no significant difference in flexion contracture between the two groups in either the preoperative or the 2-year postoperative period ($p=n.s.$) (Table 1).

In the multiple regression model, used to investigate independent factors affecting postoperative ROM, type of prosthesis (CR-Flex or PS-Flex type) also had no significant influence upon postoperative ROM ($p=n.s.$). Only the patient's age at operation ($p=0.018$) and preoperative ROM ($p=0.000$) showed statistical significance. Better postopera-

tive ROM was expected for patients with older age as well as for those with better preoperative ROM (Table 2).

Knee scores

The Knee Society score and Hospital for Special Surgery score improved significantly after the operation in both groups ($p=0.000$). There was no significant difference in either preoperative or postoperative Knee Society or HSS scores between the two groups ($p=n.s.$) (Table 3).

Functional outcomes (WOMAC functional sub-scale)

Preoperative functional status based on the WOMAC functional sub-scale did not differ between the two groups ($p=n.s.$). After the 2-year postoperative period, the average WOMAC functional sub-scale was improved by 9.2 ± 9.1 points in the CR-Flex group and by 11.9 ± 9.6 points in the PS-Flex group. Although the postoperative functional status based on the WOMAC functional sub-scale was slightly better in the

Table 1. Comparison of Preoperative and Postoperative Range of Knee Motion

Parameters	CR-Flex group*	PS-Flex group*	p value
ROM (degree)			
Preoperative	124.5±15.3	128.4±13.4	N.S. [†]
2-yr postoperative	131.0±10.5	132.7±7.0	N.S.
Flexion contracture (degree)			
Preoperative	3.2±5.4	3.6±4.9	N.S.
2-yr postoperative	0.2±1.5	0.2±1.1	N.S.

ROM, range of motion; N.S., non-significant.

*The values are given as the mean and the standard deviation.

[†]Non-significant.

Table 2. Final Step in Multiple Regression Analysis with Backward Elimination

Independent variables	Unstandardized coefficients		p value	95% CI for B		Colinearity statistic (VIF)
	B	SE		Lower bound	Upper bound	
Age at operation (yrs)	0.257	0.107	0.018	0.045	0.468	1.017
Preoperative ROM (degree)	0.226	0.042	0.000	0.143	0.310	1.017

SE, standard error; CI, confidence interval; VIF, variance inflation factor.

Table 3. Comparison of Preoperative and Postoperative Knee Scores

Parameters	CR-Flex group*	PS-Flex group*	p value
KS knee score (points)			
Preoperative	51.7±8.5	53.7±10.0	N.S.
2-yr postoperative	97.9±3.1	97.6±3.2	N.S.
HSS score (points)			
Preoperative	69.1±6.3	70.7±6.9	N.S.
2-yr postoperative	94.8±4.8	93.5±4.2	N.S.
WOMAC functional sub-scale (points)			
Preoperative	51.5±6.2	52.3±7.7	N.S.
2-yr postoperative	9.2±9.1	11.9±9.6	N.S.

KS, Knee Society; N.S., non-significant; HSS, Hospital for Special Surgery; WOMAC, Western Ontario and McMaster Universities Osteoarthritis.

*The values are given as the mean and the standard deviation.

CR-Flex group (9.2 points versus 11.9 points), the difference was not statistically significant ($p=n.s.$) (Table 3).

Radiographic results

The mean femoral-tibial angle was corrected to valgus $6.8\pm 1.0^\circ$ postoperatively in the CR-Flex group, and to valgus $6.9\pm 1.2^\circ$ postoperatively in the PS-Flex group. No significant difference was found between the two groups ($p=n.s.$). Only 1 knee in the PS-Flex group was found to be an outlier in terms of postoperative femoral-tibial alignment, but the incidence of the outlier was not statistically different between the two groups ($p=n.s.$).

The mean length of postoperative joint line elevation was 1.1 ± 3.7 mm in the CR-Flex group, and 2.1 ± 2.7 mm in the PS-Flex group. Although the mean level of elevation was higher in the PS-Flex group ($p=0.029$), the incidence of knees with a postoperative joint line elevation greater than 8 mm was not different between the two groups [2 knees (2%) in the CR-Flex group, 1 knee (1%) in the PS-Flex group, $p=n.s.$].

A radiolucent line was observed in 3 knees at 2-year postoperative follow-up (1 knee in the CR-Flex group, and 2 knees in the PS-Flex group, $p=n.s.$). However, the radiolucent lines were less than 2 mm in width and did not progress, as observed upon serial radiographic follow-up. Loosening of the prosthesis or osteolysis around the components was not seen in either group during the 2-year postoperative follow-up.

Complications

After the 2-year postoperative period, anterior-posterior instability was checked in 2 knees in the CR-Flex group. The degree of anteroposterior translation was less than 10 mm and the patients did not complain of any discomfort in daily activity. One knee in the PS-Flex group showed mild (less than 10°) mediolateral laxity, but this symptom was also subclinical. There was no subluxation or dislocation of the patellofemoral or tibiofemoral joint in both groups. No knee had superficial or deep infection. No revision operations were performed in either group during the 2-year postoperative follow-up.

DISCUSSION

The most important function of prostheses in arthroplasty is to reproduce the kinematic mechanism of a normal joint

during joint motion while preserving the longevity of the prosthesis. The main purpose of retaining or substituting the PCL in TKA is also to realize normal knee kinematics and improve postoperative knee motion and functional outcomes. Several studies have compared outcomes between CR- and PS-type implants.¹⁴⁻²¹ Theoretically, retaining the PCL has many advantages; it is possible to minimize bone resection, to prevent the flexion gap from widening, to keep proprioception, and to expect better knee flexion through natural posterior femoral roll back (PFR).²²⁻²⁵ Despite such advantages, many kinematic studies have observed paradoxical femoral movement or reverse axial rotation in existing CR-type prostheses,^{16,17,19-21} and inferior results also have been reported in comparison studies of PS-type prostheses.^{24,26,27} However, most of those studies investigated traditional CR-type prostheses, in which the two femoral condyles had the same radii.²⁸ In contrast, in the Nexgen CR-type prosthesis, the lateral femoral condyle has a larger radius than the medial femoral condyle, similar to a normal knee. In an *in vivo* kinematics study, Bertin, et al.²⁸ reported that due to such condyle asymmetry, the PFR and axial rotation in Nexgen CR TKAs had a similar pattern to that of a normal knee. In a prospective randomized controlled trial examining 40 knees using Nexgen CR- and PS-type prostheses, Tanzer, et al.²⁹ reported that there was no difference in ROM or knee scores between the two TKAs, performed using the same surgical technique and accurate balancing of the flexion-extension gap.

In the Nexgen High-Flex prosthesis, both the CR-Flex- and PS-Flex-type femoral components have an extended and rounder posterior condyle than conventional prostheses, the design of which was incorporated to reduce articular contact stress and prevent impingement during deep flexion.

Several studies have compared the *in vivo* kinematics of the CR- and PS-Flex Nexgen high-flex TKA prostheses. In a study of 10 cases each of the Nexgen CR-Flex and LPS-Flex TKAs, Sharma, et al.⁵ found that although both TKAs showed normal PFR and axial rotation patterns and lower contact stresses compared to conventional TKAs, the LPS-Flex group had greater weight-bearing knee flexion and posterior femoral movement, as well as lower medial contact stress than the CR-Flex group. Similarly, a study by Seon, et al.,⁶ involving 48 Nexgen CR-Flex and 47 LPS-Flex TKA cases, found that both TKA types showed normal PFR and axial rotation; however, the level of PFR was higher in the LPS-flex group. In contrast, a study by Cates,

et al.,⁷ comparing 15 cases each of Nexgen CR-Flex and LPS-Flex TKA, showed that the former demonstrated more consistent axial rotation than the latter, although both groups showed a normal kinematic pattern and there was no difference in weight-bearing knee flexion.

The above results suggest that after the Nexgen High-Flex TKA, the LPS-Flex TKA showed little or no superiority in terms of range of knee motion and PFR; however, in terms of axial rotation during knee motion, there was no difference or slightly more consistent results when using the CR-Flex. However, the above kinematic studies involved only a small number of patients, and therefore the results may have been influenced by factors including individual patient characteristics, the rotational alignment of the components, and the rotational posture of the foot during measurement.

Kim, et al.⁸ conducted bilateral simultaneous TKA using the Nexgen CR-Flex TKA for one knee and the LPS-Flex TKA for the other. The 2-year postoperative results indicated that there was no difference in weight-bearing ROM, knee scores and functional outcomes between the two knee groups. However, as the authors stated, when inserting two different prostheses into one patient, it is possible to generate errors when measuring functional outcomes separately for each implant.

In the present study, the Nexgen CR-Flex and LPS-Flex TKAs were implanted into different patients. After the 2-year postoperative period, we found no difference in ROM, knee scores or functional outcomes based on the WOMAC functional sub-scale. In addition, only preoperative ROM and patient age at the time of surgery showed a significant influence upon postoperative ROM. This indicates that, as in the study by Tanzer, et al.,²⁹ if all surgeries are performed with exact flexion-extension gap balancing, retention or substitution of the PCL would not have a significant influence on postoperative clinical results, even in high-flexion TKAs.

In the current study, although the functional outcomes measured using the WOMAC functional sub-scale were similar for the two groups, the difference between them almost reached statistical significance, with the *p*-value being 0.054. Perhaps, the use of a larger number of patients may have shown that superior functional outcomes were obtained when using the CR-Flex implant. This would suggest more consistent axial rotation throughout flexion in the CR-type prostheses with condyle asymmetry⁷ and preserved proprioception through retention of the PCL^{30,31} might be helpful in performing daily living activities. Similarly, Con-

ditt, et al.,²⁵ using a new scoring system based on functional performance during specific high-flexion activities, reported that patients with CR knees showed better functional outcomes than patients with PS knees during specific high-flexion activities such as squatting, kneeling and gardening. However, further research with larger sample sizes is necessary to confirm any superiority of the CR-Flex TKAs in functional outcomes.

The present study had some limitations. First, because *in vivo* kinematic analysis was not performed, the differences of further kinematic factors, such as the posterior femoral roll back and internal tibial rotation, could not be compared. Second, postoperative ROM was measured under non-weight-bearing conditions. A previous report suggested that flexion was diminished under weight-bearing conditions,³² so our results may have been more valuable if ROM had been measured under such conditions. Third, although the data were collected prospectively, they were analyzed in a retrospective manner. However, any selection bias may have been eliminated by our allocation of patients to each group based on surgery sequence. As a strength of the study, all TKAs were performed by the senior author, who has over 10 years of experience with arthroplasty, thereby the effect of improving surgical skill over the study period is likely to have been minimized. Despite the study limitations, we believe the present clinical comparison between CR- and PS-type high-flexion TKAs involving a relatively large number of patients who each received only one of the two implant types was able to produce reliable results regarding postoperative clinical and functional outcomes for both of those groups.

In conclusion, after a minimum of 2 years of postoperative period follow-up, high-flexion TKAs utilizing both CR-Flex and PS-Flex type prostheses showed satisfactory clinical and radiographic results, and demonstrated that retention or substitution of the PCL does not affect postoperative ROM. With regard to functional outcomes, although the CR-Flex TKAs showed slightly better results than the PS-Flex TKAs, the difference was not significant. Further investigation is necessary to determine the long-term stability of the joint and the longevity of the polyethylene insert in each of these high-flexion TKAs.

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