A Comparison of Standard and High-Flexion Knees: Are We Getting What We Expected?

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Abstract

Some patients have been less than satisfied with flexion after total knee arthroplasty (TKA). As early designs provided limited flexion, companies have developed high-flexion designs.

We conducted a study to compare flexion between 2 standard and 3 high-flexion designs and to compare clinical and radiographic postoperative flexion. Clinical and radiographic measurements were obtained by 3 independent orthopedists. Clinical flexion, with the patient maximally bending his or her knee as far as possible, was measured with a goniometer, recorded, and compared with measurements from lateral radiographs of the knee in the same position.

A total of 144 knees (108 patients) were included in the study. Mean preoperative flexion was 110° for both groups, and mean postoperative flexion was 111° clinically and 109° radiographically for the standard designs, and 114° clinically and 117° radiographically for the high-flexion designs ($P<.05$). The groups had similar preoperative and postoperative Knee Society knee and function scores. Measurements obtained by the 3 independent examiners were highly correlated. Compared with the standard designs, the high-flexion designs demonstrated statistically significantly more flexion, though the clinical increase in flexion was relatively small (3°).

Total knee arthroplasty (TKA) successfully restores function, corrects deformity, and reduces the pain of end-stage arthritis.[1-5] One important factor in determining patients' post-TKA satisfaction is postoperative flexion.[6] Postoperative flexion depends on preoperative flexion, surgical technique, implant design, and rehabilitation.[7-14] Studies have found that postoperative flexion tends to stabilize by 12 months after surgery; there is little change after that point.[15-19] Although activities of daily living require a minimum of 105° to 110° of flexion, patients from non-Western cultures often engage in activities that require much more flexion (eg, kneeling and squatting).[20,21]

As clinicians offer TKAs to younger and more active patients, the need for improved postoperative flexion and more demanding function may increase. The desire for more flexion is driving the development of prosthetic modifications, including high-flexion designs. However, high-flexion designs come with increased implant costs, and the ability of these devices to improve postoperative flexion has not been definitively proved. Another clinical study found that postoperative flexion is determined largely by preoperative flexion.[14] Other studies, comparing flexion between standard and high-flexion designs, had conflicting conclusions about whether the design changes were beneficial.[10,22-28] In addition, the techniques used to measure flexion, and the position of the knee during measurement, are often not described. Comparing the flexion of different prostheses is difficult when measurement methods are inconsistent; this inconsistency may partly explain the wide range in postoperative flexion values reported (103°-139°).[25,29-31]

We conducted a study to compare flexion between 2 standard and 3 high-flexion designs. Using 3 different examiners, each blinded to one another's findings, we also aimed to compare clinical flexion (measured with a goniometer) and radiographic flexion (measured on a true lateral radiograph) after successful TKA.

Materials and Methods

We evaluated 5 knee prostheses with the posterior cruciate ligament–retaining design used at our institution. There were 2 standard designs, the Natural Knee (Zimmer Inc, Warsaw, Indiana) and the PFC Sigma (DePuy Orthopaedics Inc, Warsaw, Indiana); and 3 high-flexion designs, the Genesis II (Smith & Nephew, Memphis, Tennessee), the Scorpio NRG (Stryker Orthopaedics, Mahwah, New Jersey), and the Triathlon (Stryker Orthopaedics, Mahwah, New Jersey). Patients were recruited into this nonrandomized, unblinded study before surgery and remained in the study if they met the inclusion criteria of no knee injury or surgery before TKA, minimal or no postoperative pain, no malalignment or instability, and no postoperative complications (eg, stiffness, infection, fracture, manipulation, revision). Minimum clinical and radiologic follow-up for

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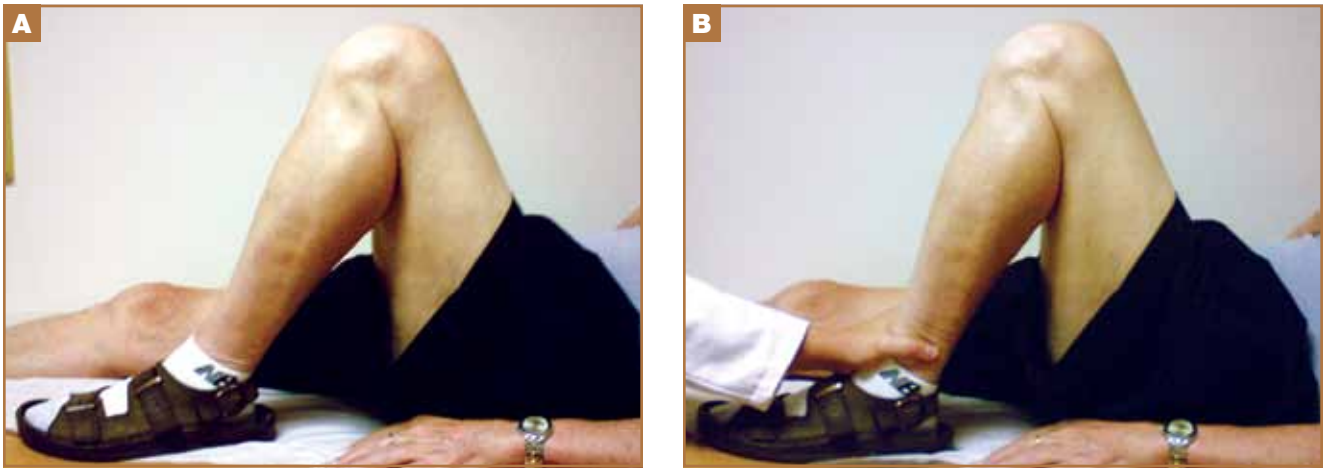

Figure. (A) Gravity-assisted flexion was measured using a long goniometer with the patient supine and maximally bending his or her own knee. (B) Active-assisted flexion was measured using a long goniometer with the patient's operative knee bent maximally by the examiner until stopped by the patient's anterior discomfort or impingement of posterior soft tissue.

all patients was 1 year (mean, 2.7 years). One hundred eight patients (144 TKAs) participated in the study, which was approved by our institutional review board.

Three senior surgeons (CWC, KAE, SNC) experienced with the 5 knee prostheses performed the TKAs using similar surgical techniques. Ninety-two percent of the patients presented for TKA because of advanced end-stage osteoarthritis. The standard surgical technique used in this study included a midvastus or a medial parapatellar arthrotomy and an intramedullary guide for both the distal femoral and the proximal tibial osteotomies. Distal femoral and proximal tibial osteotomies were routinely performed with 6° of valgus and 5° of posterior inclination, respectively. All prostheses were cemented, and all patellae were resurfaced with a dome-shaped patellar button. The postoperative protocol included deep vein thrombosis prophylaxis with enoxaparin, weight-bearing as tolerated, and passive and active range of motion exercises beginning the day after surgery. We did not employ continuous passive motion machines. Hospital stay averaged 3 days. The rehabilitation protocol was the same for all patients.

Only non–weight-bearing flexion was measured because of the relative ease in obtaining radiographs with the patients in position and both the reproducibility of measurements among examiners. Preoperative flexion was measured with each patient supine and maximally bending his or her own knee (**Figure A**) and with the knee maximally bent with the examiner's assistance (**Figure B**). Clinical measurement of flexion with a long-arm goniometer and true lateral digital radiographic measurement were performed before surgery. Radiographic flexion was measured using the software included in the digital radiology system (Stentor picture archiving and communications systems [PACS]; Philips Medical Systems, Brisbane, California) in place at our institution. Radiographic flexion was based on the angle subtended by the lines midway between the anterior and posterior cortices of the femur and the tibia. Radiographic flexion was then compared with clinical flexion. To improve reliability, we had 3 independent observers perform the postoperative clinical and radiographic measurements, and values were compared and reported as mean flexion. We also evaluated each patient by determining Knee Society knee and function scores before surgery and at final postoperative visit.

Statistical analysis was performed with SPSS 13.0 (SPSS Inc, Chicago, Illinois). Independent-sample t-tests were used to assess differences in preoperative flexion and demographics (age, height, weight, body mass index) between the standard and high-flexion groups. Chi-square tests were used to assess sex differences between groups. Independent-sample t-tests were used to compare postoperative clinical and radiographic flexion between the groups as measured clinically with a goniometer and radiographically with a true lateral radiograph. The average of all 3 examiners' measurements was used for the t-test. Pearson correlation coefficients were used to compare flexion measurements among the 3 examiners. Preoperative and postoperative differences in knee and function scores between the groups were also assessed with a t-test. Subgroup analyses were performed to compare flexion between surgical technique groups (midvastus vs medial parapatellar). All tests were 2-tailed, and an α of 0.05 was used to determine statistical significance.

Results

At mean follow-up of 2.7 years (range, 1-5.6 years), all 108 patients (144 TKAs) completed the study. Implant design characteristics and surgical approach are detailed in **Table I**. There were no statistically significant differences in height, weight, body mass index, preoperative flexion, knee scores, or function scores among the standard and high-flexion groups (**Table II**).

The groups' preoperative flexion (non–weight-bearing) was similar and improved after surgery. Mean preoperative flexion was 110° for both groups, and mean postoperative flexion was 111° clinically and 109° radiographically for the standard design and 114° clinically and 117° radiographically for the high-flexion design (**Table III**). Clinical flexion increased by

0.35° (from 110.41° to 110.76°) in the standard group and by 4.52° (from 109.67° to 114.19°) in the high-flexion group (P=.043). Knee and function scores improved in both groups (**Tables II, III**). There was no statistically significant difference in postoperative flexion between the midvastus approach and the medial patellar approach. Postoperative clinical flexion and radiographic flexion for each implant are listed in **Table III**. Among the 3 observers, clinical correlations (r) ranged from 0.78 to 0.90; the radiographic correlations were stronger, ranging from 0.90 to 0.97.

As there were statistically significantly more women in the high-flexion cohort (72%) than in the standard cohort (51%), we explored the association between sex and postoperative flexion measurements to assess if this could be confounding the relationship between implant type and flexion. Overall, there were no differences in postoperative flexion between men and women. When stratified into implant-type groups, however, men had statistically significantly more flexion than women in the standard group but not in the high-flexion group. Age at time of surgery was borderline statistically significant between groups, and there was no correlation between age and postoperative flexion. The proportion of males and females differed among implant-type groups, but this did not affect the flexion results. Although patients in the Genesis II group were significantly younger than the rest of the cohort, age did not correlate with flexion in this study. Patients with bilateral TKA were evenly distributed between the 2 groups.

Discussion

Recent prosthetic modifications include high-flexion designs, which were developed to promote improved postoperative flexion. In our comparison of 2 standard flexion designs with 3 high-flexion designs, we found a statistically significant difference in flexion between the implants in clinical examination and in radiographic examination. However, the difference was 3° clinically and 8° radiographically, which may not be clinically significant.

The early outcomes of high-flexion knee prostheses on postoperative flexion have been mixed.[25-28] Schurman and Rojer[18] reported postoperative flexion of 5 older designs used between 1985 and 2002, with average passive non–weight-bearing flexion of 113°. More than 2 decades later, despite numerous prosthetic modifications, our study found marginal improvement in postoperative flexion. With patients maximally bending their own knees, our study found postoperative non–weight-bearing clinical flexion to be 111° for the standard cohort and 114° for the high-

Table I. Description of Implant Characteristics and Surgical Approach

	Surgical Approach, n		
Implant Design[a]	Midvastus	Medial Parapatellar	Insert
Standard			
Natural Knee	24	5	Highly crosslinked polyethylene, congruent
PFC Sigma	33	7	Unconstrained, posterior lip
High Flexion			
Scorpio NRG	20	1	Unconstrained, flat posterior
Triathlon	0	25	Unconstrained, flat posterior
Genesis II	5	24	Deep flexion
Total	**82**	**62**	

[a]Natural Knee (Zimmer Inc, Warsaw, Indiana), PFC Sigma (Depuy Orthopaedics Inc, Warsaw, Indiana), Genesis II (Smith & Nephew, Memphis, Tennessee), Scorpio NRG and Triathlon (Stryker Orthopaedics, Mahwah, NJ).

Table II. Preoperative Patient Characteristics, Including Flexion and Knee Society Scores by Implant Type

	Implant Type							
	Standard			High Flexion				
Characteristic	Natural Knee	PFC Sigma	Combined Standard Cohort, mean (SD)	Genesis II	Scorpio NRG	Triathlon	Combined High Flexion Cohort, mean (SD)	P
n	29	40	69	29	21	25	75	—
Female	66%	40%	51%	76%	62%	76%	72%	.009
Mean age, y	72	72	72 (7.1)	66	70	71	69 (9.6)	.057
Mean height, in	68	67	67 (3.7)	66	66	66	66 (4.1)	.116
Mean weight, lb	188	186	187 (41.6)	187	177	187	184 (39.7)	.726
Body mass index	29	29	29 (6.1)	30	28	30	30 (5.1)	.489
Preoperative flexion[a]	108°	111°	110° (12.5°)	111°	110°	109°	110° (12.1°)	.951
Knee Society knee score	57	51	53 (14.2)	57	55	55	56 (13.3)	.174
Knee Society function score	52	59	55 (16.6)	55	53	42	50 (18.6)	.403[b]

[a]Non–weight-bearing, gravity-assisted, determined by goniometer.
[b]Based on comparison of standard group and high-flexion group means.

Table III. **Mean Postoperative Active Flexion and Knee Society Scores by Implant Type**

Characteristic	Implant Type							
	Standard			High Flexion				
	Natural Knee	PFC Sigma	Combined, mean (SD)	Genesis II	Scorpio NRG	Triathlon	Combined, mean (SD)	P[b]
Postoperative Flexion[a]								
Clinical	107°	114°	111° (9.7°)	115°	113°	115°	114° (8.2°)	.023
Radiographic	105°	112°	109° (12.0°)	118°	111°	117°	117° (8.9°)	<.001
Knee Society Score								
Knee	87	90	89 (12.3)	88	92	93	90 (11.2)	.478
Function	81	78	79 (17.4)	76	82	72	76 (21.2)	.439

[a]Mean of measurements of all 3 examiners; clinical flexion measured by goniometer, radiographic flexion determined by digital lateral radiographs.
[b]Based on *t*-test of flexion of combined mean of standard implants compared with flexion of combined mean of high-flexion implant.

flexion cohort, similar to values reported in other studies.[2,4,31,32] When Mehin and colleagues[23] conducted a meta-analysis of randomized clinical trials, they found no relevant clinical or statistical improvement in flexion with high-flexion prostheses.

Of the 5 implants used in our study, 3 (Genesis II, Scorpio NRG, Triathlon) are designed with features to improve flexion. Although the average collective postoperative clinical non–weight-bearing flexion for these 3 prostheses (114°) was statistically different from that of the standard design without specific high-flexion features (111°), we consider the 3° difference not clinically significant. Mehin and colleagues[23] thought the same about the 3° difference they found.

By standardizing the measurement method and using patients with similar preoperative characteristics, similar surgical techniques, and the same rehabilitation protocol, we were able to examine the effect of implant design on flexion. Preoperative diagnosis has been suggested as a factor influencing flexion,[33] but Bourne and colleagues[34] found no difference in flexion between osteoarthritis and other diagnoses. Similarly, our study did not find a difference in flexion between osteoarthritis and other diagnoses, though our conclusion was based on a small number of patients without osteoarthritis (7.6%). Furthermore, our study did not find a significant difference in postoperative flexion when TKA was performed with either a midvastus or a medial parapatellar arthrotomy approach, which is consistent with previous reports.[24,30,32,33,35]

Limitations of this study include lack of randomization and blinding of patients and surgeons, and a small sample size for each prosthetic group. A larger cohort may reveal further differences between these types of implants. Our study examined only postoperative flexion associated with these specific prostheses. The study used more than 1 type of implant and more than 1 surgeon, which could detract from the findings, but the surgical and rehabilitation protocols were the same. Although the standard and high-flexion implants differed, all were posterior cruciate ligament–retaining designs. We did not examine any prostheses that are no longer in widespread clinical use. A type II statistical error is possible in this study, but our findings are similar to those in a meta-analysis of other studies.[23,36,37]

Although implant costs vary by contract and facility, prices quoted by manufacturers reflect an estimated $1000 higher cost for the high-flexion implant.[38] Our results do not justify the increased implant cost associated with high-flexion designs based on flexion alone. However, newer designs may have additional benefits not evaluated in our study—eg, improved patellar tracking, diminished anterior knee pain, improved polyethylene wear, and improved tibial insert locking mechanisms. Longer term follow-up studies are needed to determine if implant modifications contribute to improvements in longevity and function of TKA, which may justify the higher implant cost.

Although this study neither proved nor disproved that high-flexion implants provide more flexion, it did provide an evaluation of flexion in the standard and high-flexion implants currently used in clinical practice.

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