HSSJ (2014) 10:107–115
DOI 10.1007/s11420-014-9389-5

HSS Journal®
The Musculoskeletal Journal of Hospital for Special Surgery

ORIGINAL ARTICLE

The Surgeon's Role in Relative Success of PCL-Retaining and PCL-Substituting Total Knee Arthroplasty

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Received: 10 October 2013/Accepted: 26 March 2014 / Published online: 24 May 2014

Abstract *Background:* The orthopedic literature has not shown a universal and replicated difference, outside of flexion, in clinical results between posterior cruciate ligament retention and posterior cruciate ligament substitution in total knee arthroplasty. *Questions/Purposes:* This study was performed to compare the restoration of flexion and knee function in a large series of cruciate-retaining and cruciate-substituting total knee arthroplasties (TKRs). In addition, we aimed to study how other variables, such as those unique to each surgeon, may have affected the results. *Patients and Methods:* The current study evaluated 8,607 total knee arthroplasties in 5,594 patients performed by six surgeons, each using one of four prosthesis designs (two posterior cruciate ligament retaining, two posterior cruciate ligament substituting). Knees were compared at the level of cruciate-retaining and cruciate-substituting knees, at the level of the four prostheses, and at the level of surgeon-implant combinations. Least squared means scores were obtained through multiple linear regression, analysis of variance, and the maximum likelihood method. *Results:* At the level of posterior cruciate ligament treatment, posterior cruciate ligament substitution as a whole showed 3.2° greater flexion than posterior cruciate ligament retention. At the prosthesis level, cruciate-substituting models provided greater flexion and cruciate-retaining models provided higher function scores. In the surgeon-implant combinations, surgeons provided mixed results that often did not reflect findings from other levels; one surgeon's use of a posterior cruciate ligament retaining prosthesis achieved 14.7° greater flexion than the surgeon's use of a corresponding posterior cruciate ligament substituting design. *Conclusions:* Posterior cruciate ligament treatment is confounded by other variables, including the operating surgeon. The arthroplasty surgeon should choose a prosthesis based, not only on outside results, but also on personal experience and comfort.

Keywords posterior cruciate ligament retention · posterior cruciate ligament substitution · total knee arthroplasty · surgeon effect

A commentary by Thomas P. Sculco, MD is available for this article

Level of Evidence Therapeutic Study Level III. See Levels of Evidence tables for a complete description.

Electronic supplementary material The online version of this article (doi:10.1007/s11420-014-9389-5) contains supplementary material, which is available to authorized users.

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Introduction

One of the most persistent issues discussed in total knee arthroplasty is the role of retention of the posterior cruciate ligament. There are two current options for contemporary TKR, retention (CR) and substitution (PS), which are based on divergent philosophies for each replacement method which cite the importance of preservation of joint structures and potential kinematic benefits in PCL retention, and relative ease of surgery and increased range of motion in PCL substitution [4, 19]. Both methods have produced excellent long-term survivorship, function, and flexion results [2, 5, 7, 8, 12–14, 21], and the published literature has not found a significant, replicable and universal difference in their clinical outcomes other than increased flexion for PCL substitution [10].

For this study, the authors formed two hypotheses: (1) A prosthesis-level comparison of individual PCL-substituting and PCL-retaining implants would produce clinically significant differences in Knee Society evaluation measurements, with PCL-substituting implants producing consistently greater flexion and PCL-retaining implants producing greater function scores; (2) Observed clinical differences between PCL-substituting and PCL-retaining implants may not be due solely to the difference in treatment of the PCL, and more complex variables such as surgeon and patient selection should be examined.

At The Center for Hip and Knee Surgery, St. Francis Hospital, Mooresville, Mooresville, IN, total knee replacement using four predominant designs (2 are CR and 2 are PS) has been performed for 20 years. The authors aimed to use this large experience in an effort to provide an answer as to the difference in flexion and Knee Society Scores that can be expected between CR and PS designs. The authors also aimed to assess using statistical analysis what factors such as the operating surgeon and patient selection might contribute to differences in outcome.

Patients and Methods

From January 1, 1983, through April 1, 2011, 15,953 total knee arthroplasties were performed at the authors' center; 14,153 of these TKAs were primary operations by one of six surgeons and using one of four prosthesis most frequently used at the center (Biomet, Warsaw, IN.; Zimmer, Warsaw, IN.). Because this was a clinical outcomes study, exclusion criteria that eliminated patients with less than 2 years of follow-up was applied, after which 8,830 total knee arthroplasties in 5,594 patients remained. Sixty-one percent of the patients were female, their mean age at time of surgery was 68.3 years (standard deviation, 8.9), their mean body mass index was 31.2 kg/m^2 (SD, 5.9), and the diagnosis was osteoarthritis in 8,335 knees (96.8%), rheumatoid arthritis in 196 knees (2.3%), osteonecrosis in 61 knees (0.7%), and any other reason in 15 knees (0.2%).

In this series of 8,830 TKAs there were 6,515 AGC PCL-retaining knees (Biomet, Warsaw, IN) (73.8%), 376 Legacy PCL-substituting knees (Zimmer, Warsaw, IN) (4.3%), 853 Vanguard PCL-retaining knees (Biomet) (9.7%), and 1,086 Vanguard PCL-substituting knees (Biomet) (12.3%) performed by six surgeons at our center with more than 100 TKAs per year. None of these implants have undergone any significant changes in design throughout the study period; other prosthesis models have been used at the authors' center during this period, and improvements in polyethylene formation have been introduced, but the prostheses used in this study have remained unchanged in their relevant characteristics (articulation conformity, patellar tracking, position of the cam-post mechanism, etc.).

Patient follow-up was performed in person at the authors' clinic at 2 months, 6 months, and 1, 3, 5, 7, 10, 12, 15, 17, and 20 years after surgery (when available). Follow-up appointments included Knee Society score evaluations [9], flexion measurements using a standard goniometer, and a standardized radiograph; measurements were performed by either one of the six surgeons or an experienced physician's assistant. After the appointment, data were entered using a standardized form into a patient database maintained at the authors' center.

Demographic data for the patient groups for cruciate-retaining and posterior-stabilized implants are included in Table 1. The AGC prosthesis has a flat tibial surface in the anteroposterior and coronal planes, while the Legacy prosthesis and the Vanguard prostheses have a highly conforming tibial surface throughout. There were no differences in tibiofemoral articulation between the Vanguard PCL-retaining and PCL-substituting designs outside of the cam-and-post mechanism in the PCL-substituting implant.

The authors performed a retrospective analysis of the clinical measurements found at follow-up (performed at 2 months, 6 months, and 1, 3, 5, 7, 10, 12, 15, 17, and 20 years, when available) as measured by the Knee Society clinical rating system [9]. ANOVA/multiple linear regression with the maximum likelihood method was used to find the least squares means (LSM) of each variable (Knee Society score, function score, flexion, pain score, stairs score, medial lateral stability and anterior posterior stability). Each model included for covariates preoperative alignment $<-8°$, preoperative valgus $>11°$, bmi>41, height, age≥71, gender, follow-up interval, and cruciate-retaining prosthesis compared to posterior-stabilized prosthesis or surgeon with nested prosthesis, or individual prosthesis. The nested model had 24 groups (6 surgeons, 4 implant models: Surgeon 1× AGC, Surgeon 1×Vanguard PS, Surgeon 2 x AGC, etc.). Four of the surgeons implanted a greater variety of TKA designs than the other two, and they were the focus of most of the present analysis. In all models, the level of significance for post hoc LSM-tested p values was set at $p=0.05$.

Source of Funding

No outside source of funding was used in support of this study.

Results

Significant differences were found in flexion, function, and the stairs subscore in most comparisons with every significant difference in flexion favoring a PCL-substituting design, while significant differences in function and stairs more often favored retention over substitution (Table 2). No significant differences were found in the Knee Society knee score and the pain and walk subscores between any implant types ($p>0.0528$).

Table 1 Demographics of patients between posterior-stabilized and cruciate-retaining prosthesis

Statistical measurement	Posterior stabilized	Cruciate retaining
n	1,093	7,514
Avg. age (SD)	66.8 (9.0)	68.4 (8.8)
% female	61.1	60.6
% diagnosis OA	98.9	96.5
Avg. BMI (SD)	33.0 (6.1)	31.0 (5.8)
Avg. pre-op flexion (SD)	102.5 (12.8)	111.6 (12.8)
% Pre-op varus $<-8°$	1.2%	7.4%
% pre valgus $>11°$	16.7%	7.7%

SD standard deviation

Table 2 Comparison of clinical outcomes between TKA designs

Implant	Number	LSM	Effect size (SD)[a]	*p* value
Knee score				
Legacy	376	88.2	2.2 (1.1)	0.0528
Vanguard CR	853	86.1	0.0 (1.1)	0.9839
Vanguard PS	1,086	87.2	1.2 (1.0)	0.2299
AGC	6,515	86.1	Base	Base
Pain subscore				
Legacy	376	47.8	0.3 (0.4)	0.4821
Vanguard CR	853	47.4	−0.1 (0.4)	0.7595
Vanguard PS	1,086	47.5	−0.0 (0.3)	0.9318
AGC	6,515	47.5	Base	Base
Flexion				
Legacy	376	117.3	3.2 (0.5)	<0.0001
Vanguard CR	853	113.7	−0.4 (0.6)	0.4857
Vanguard PS	1,086	117.5	3.4 (0.5)	<0.0001
AGC	6,515	114.1	Base	Base
Function score				
Legacy	376	85.1	1.4 (0.8)	0.0853
Vanguard CR	853	85.9	2.3 (0.9)	0.0095
Vanguard PS	1,086	83.2	−0.4 (0.7)	0.5577
AGC	6,515	83.6	Base	Base
Stairs subscore				
Legacy	376	41.2	1.0 (0.5)	0.0273
Vanguard CR	853	42.7	2.5 (0.5)	<0.0001
Vanguard PS	1,086	40.0	−0.2 (0.4)	0.5588
AGC	6,515	40.2	Base	Base
Walk subscore				
Legacy	376	45.0	0.4 (0.5)	0.5057
Vanguard CR	853	44.6	−0.0 (0.6)	0.9468
Vanguard PS	1,086	44.1	−0.6 (0.5)	0.2002
AGC	6,515	44.7	Base	Base
AP stability				
Legacy	376	10.01	0.04 (0.02)	0.0087
Vanguard CR	853	10.05	0.08 (0.01)	<0.0001
Vanguard PS	1,086	10.01	0.05 (0.01)	0.0010
AGC	6,515	9.97	Base	Base
ML stability				
Legacy	376	14.98	−0.01 (0.02)	0.6040
Vanguard CR	853	15.00	0.01 (0.02)	0.4168
Vanguard PS	1,086	15.00	0.01 (0.01)	0.5664
AGC	6,515	14.99	Base	Base

[a] Effect size compared to AGC with standard deviation in parenthesis

Table 3 Overall comparison of clinical results after TKA using either PCL-retaining (CR) or PCL-substituting (PS) prostheses

Treatment	Number	LSM	Effect size (SD)[a]	*p* value
Knee score				
CR	7,368	86.3	−1.1 (0.7)	0.1565
PS	1,462	87.3	Base	Base
Pain subscore				
CR	7,368	47.5	−0.1 (0.3)	0.6952
PS	1,462	47.6	Base	Base
Flexion				
CR	7,368	114.3	−3.2 (0.4)	<0.0001
PS	1,462	117.5	Base	Base
Function score				
CR	7,368	84.1	0.6 (0.6)	0.3112
PS	1,462	83.5	Base	Base
Stairs subscore				
CR	7,368	40.6	0.5 (0.3)	0.1442
PS	1,462	40.1	Base	Base
Walk subscore				
CR	7,368	44.7	0.3 (0.4)	0.4583
PS	1,462	44.4	Base	Base
AP stability				
CR	7,368	9.98	−0.02 (0.01)	0.1520
PS	1,462	10.00	Base	Base
ML stability				
CR	7,368	14.99	0.00 (0.01)	0.6525
PS	1,462	14.99	Base	Base

[a] Effect size compared with PCL substitution, with standard deviation in parenthesis

The authors were unable to find differences in the knee score ($p=0.1565$), function score ($p=0.3112$), pain subscore ($p=0.6952$), stairs subscore ($p=0.1442$), and walk subscore ($p=0.4583$) between PCL retention and PCL substitution with the four implants included in this study. A significant difference was found in flexion, with PCL substitution providing 3.2° greater flexion than PCL retention (117.5 vs. 114.3, $p<0.0001$) (Table 3).

Four-by-six matrices of all possible combinations of surgeon, implant, and clinical measure are shown in Tables 4, 5 and 6; further analysis is limited to surgeons 1 through 4, who implanted a greater variety of prostheses. Using a combination of LSM score differences and intra-surgeon ranking, the data indicate that surgeons displayed varying levels of success with each of the four implants examined in the study, after controlling for demographic and preoperative factors. Overall, surgeon 1 showed relatively less success with AGC, surgeon 2 showed relatively less success with Vanguard CR, surgeon 3 showed relatively less success with Vanguard PS, and surgeon 4 showed relatively less success with Vanguard PS. For example, in knee score, surgeon 1 obtained a score 2.3 points lower with his worst prosthesis (AGC) than with his best prosthesis (Vanguard PS); surgeon 2 obtained a score 8.3 points lower with his worst prosthesis (Vanguard CR) than with his best prosthesis (AGC); surgeon 3 obtained a score 14.8 points lower with his worst prosthesis (Vanguard PS) than with his best prosthesis (Legacy); and surgeon 4 obtained a score 5.9 points lower with his worst prosthesis (Vanguard PS) than with his best prosthesis (Legacy).

In terms of clinical goals, for Pain relief, significant differences were found between the best and worst Knee Society pain subscore in surgeon 4 (Legacy 47.4 vs. Vanguard CR 42.7, $p=0.0009$). Best/worst differences in surgeons 1 ($p=0.4334$), 2 ($p=0.2168$), and 3 ($p=0.1317$) were not significant. For Flexion, significant differences were found between the greatest and least flexion in surgeons 1 (Legacy 120.9 vs. AGC 114.7, $p=0.0495$), 2 (Legacy 110.4 vs. Vanguard CR 105.0, $p<0.0001$), 3 (Vanguard CR 121.1 vs. Vanguard PS 106.4, $p<0.0001$), and 4 (Vanguard PS 120.3 vs. AGC 116.3, $p<0.0001$). These differences favored PCL substitution in surgeons 1, 2, and 4 and favored PCL retention in surgeon 3. For Function, significant differences were found between the best and worst Knee Society function score in surgeons 1 (Vanguard CR 89.9 vs. AGC 84.0, $p<0.0001$) and 4 (AGC 81.9 vs. Vanguard PS 77.0, $p<0.0001$). The best/worst difference in surgeon 3 (Legacy 83.0 vs. AGC 74.7, $p=0.0674$) was marginally significant ($p<0.10$), and the best/worst difference in surgeon 2 ($p=0.3960$) was not significant.

Table 4 Knee Society knee scores and subscores for surgeon-implant combinations

Implant	Statistical measurement	Surgeon 1	2	3	4	5	6
Knee score							
Legacy	*n*	2	306	3	63	2[b]	0
	Least squared mean	91.2	84.6	91.0	87.5		
	LSM rank w/in surgeon	2	3	1	1		
	Effect size (SD)[a]	5.3 (3.3)	−1.4 (1.1)	5.1 (2.8)	1.6 (2.6)		
	p value	0.1066	0.2174	0.0672	0.5445		
VCR	*n*	369	216	37	146[b]	85[b]	0
	Least squared mean	90.8	79.7	86.94			
	Rank w/in surgeon	3	4	2			
	Effect size (SD)	4.9 (1.4)	−6.2 (2.1)	1.0 (3.0)			
	p value	0.0005	0.0039	0.7325			
VPS	*n*	319	328	28	294	117	0
	Least squared mean	91.9	84.8	76.2	81.6	90.3	
	Rank w/in surgeon	1	2	4	3		
	Effect size (SD)	6.0 (1.3)	−1.1 (2.3)	−9.7 (2.9)	−4.3 (2.2)	4.4 (3.1)	
	p value	<0.0001	0.6316	0.0008	0.0573	0.1646	
AGC	*n*	354	851	2,887	459	0	1,964
	Least squared mean	89.6	88.0	83.8	85.9		85
	Rank w/in surgeon	4	1	3	2		
	Effect size (SD)	3.6 (1.0)	2.1 (2.4)	−2.1 (0.9)	Base		−0.9 (1.0)
	p value	0.0004	0.3893	0.0225	Base		0.3607
Best vs. worst	LSM difference	2.3	8.3	14.8	5.9		
	p value	0.0336	0.0056	0.0001	0.0680		
Pain subscore							
Legacy	*n*	2	306	3	63	2	0
	Least squared mean	50.0	47.1	49.2	47.4	50.6	
	LSM rank w/in surgeon	1	3	3	1	1	
	Effect size (SD)[a]	4.0 (2.4)	1.1 (0.4)	3.2 (2.0)	1.3 (0.7)	4.6 (3.2)	
	p value	0.0907	0.0056	0.1099	0.0524	0.1465	
VCR	*n*	369	216	37	146	85[b]	0
	Least squared mean	48.9	46.88	50.49	42.69		
	Rank w/in surgeon	3	4	1	4		
	Effect size (SD)	2.9 (0.6)	0.8 (0.6)	4.5 (2.1)	−3.3 (1.3)		
	p value	<0.0001	0.1555	0.0375	0.0093		
VPS	*n*	319	328	28	294	117	0
	Least squared mean	49.6	47.6	45.87	44.39	48.39	
	Rank w/in surgeon	2	2	2	3	2	
	Effect size (SD)	3.6 (0.6)	1.6 (0.5)	−0.2 (1.7)	−1.6 (0.5)	2.4 (1.4)	
	p value	<0.0001	0.0007	0.9252	0.0010	0.0958	
AGC	*n*	354	851	2,887	459	0	1,964
	Least squared mean	48.2	48.2	47.3	46.0		47.6
	Rank w/in surgeon	4	1	4	2		
	Effect size (SD)	2.2 (0.4)	2.1 (1.0)	1.3 (0.3)	Base		1.6 (0.4)
	p value	<0.0001	0.0247	<0.0001	Base		<0.0001
Best vs. worst	LSM difference	1.8	1.3	3.2	4.7	2.2	
	p value	0.4334	0.2168	0.1317	0.0009	0.5170	
Flexion							
Legacy	*n*	2	306	3	63	2	0
	Least squared mean	120.9	110.4	111.0	117.6	126.73	
	LSM rank w/in surgeon	1	1	3	2	1	
	Effect size (SD)[a]	4.6 (3.2)	−5.9 (0.5)	−5.2 (2.6)	1.3 (0.9)	10.5 (5.5)	
	p value	0.1443	<0.0001	0.0474	0.1654	0.0554	
VCR	*n*	369	216	37	146	85[b]	0
	Least squared mean	115.8	105.0	121.1	116.6		
	Rank w/in surgeon	3	4	1	3		
	Effect size (SD)	−0.5 (0.8)	−11.3 (0.8)	4.8 (2.9)	0.3 (1.7)		
	p value	0.5354	<0.0001	0.0942	0.8397		
VPS	*n*	319	328	28	294	117	0
	Least squared mean	120.1	109.6	106.4	120.3	123.0	
	Rank w/in surgeon	2	2	4	1	2	
	Effect size (SD)	3.8 (0.9)	−6.6 (0.6)	−9.9 (2.3)	4.1 (0.7)	6.8	
	p value	<0.0001	<0.0001	<0.0001	<0.0001	0.0010	
AGC	*n*	354	851	2,887	459	0	1,964
	Least squared mean	114.7	107.2	117.2	116.3		109.2
	Rank w/in surgeon	4	3	2	4		

Table 4 (continued)

Implant	Statistical measurement	Surgeon					
		1	2	3	4	5	6
Best vs. worst	Effect size (SD)	−1.6 (0.6)	−9.1 (1.3)	0.9 (0.4)	Base		−7.1 (0.5)
	p value	0.0050	<0.0001	0.0342	Base		<0.0001
	LSM difference	6.2	5.4	14.7	4.0	3.7	
	p value	0.0495	<0.0001	<0.0001	<0.0001	0.5257	

[a] Effect size compared to surgeon 4×AGC, with standard deviation in parenthesis
[b] These observations were not full rank in the model because of missing values such as preoperative alignments or intermediate follow-up

In the Vanguard family of prostheses (Vanguard CR vs. Vanguard PS), in which the only difference between the two prosthesis designs are in the treatment of the PCL, the authors were unable to show a statistically significant difference between most comparisons (Table 7). Those that did show significant differences were the knee score for surgeon 3 (CR 86.9 vs. PS 76.2, $p=0.0069$), flexion for all four surgeons (surgeons 1, 2, and 4 favoring PS, surgeon 3 favoring CR; surgeon 4 $p=0.0348$, all others $p<0.0001$), and the stairs subscore for surgeon 1 (CR 44.33 vs. PS 41.86, $p=0.0024$). The differences in knee score for surgeon 2 ($p=0.0770$), the pain subscore for surgeon 3 ($p=0.0873$), and the function score for surgeon 1 ($p=0.0925$) were marginally significant.

Discussion

PCL-retaining and PCL-substituting total knee arthroplasties have provided excellent results in long-term follow-up, both in survivorship and in clinical measurements like range of motion and function [2, 5, 7, 8, 12–14, 21]. Because the debate between PCL retention and PCL substitution has lasted since at least the 1970s [11, 18, 20], and because the literature has not provided a consistent conclusion on the matter [10], it is difficult to determine which design provides consistently better outcomes. PCL substitution is often preferred in the absence of definitive differences between the two options due to the experience and attention required in PCL-retaining designs to correctly balance the PCL [4, 19]. One recent study [1, 6], however, reported significantly greater survivorship for PCL-retaining knees at 15 years.

The current investigation found results within one prosthesis generation (Vanguard) that are largely, but not completely, consistent with those published previously. Three of the four surgeons obtained greater flexion with the Vanguard PS implant than with the CR version, in agreement with the results of a Cochrane analysis [11]; surgeon 1 also obtained higher stairs subscores with Vanguard CR than with Vanguard PS. Other comparisons, however, did not conform to what has been expected of PCL-retaining and PCL-substituting systems. The Vanguard stairs scores for surgeons 2, 3 and 4 were not found to be significantly different, and surgeon 3, in even greater contrast, achieved more flexion with Vanguard CR than with Vanguard PS (121.1° vs. 106.4°).

These results suggest that a deeper examination of the influence of operating surgeon is required before a significant and independent difference in PCL results can be declared. The current study began with one hypothesis (hypothesis 1 as described in the Introduction) as an examination of each implant model's independent influence on clinical outcome; the original goal was to conclude whether PCL substitution or PCL retention provided more favorable universal results. Because of the inconsistent conclusions from other investigators studying PCL treatment in TKA, however, the authors felt that a second hypothesis was required, thus the projection that examinations at other levels would elucidate further influences on TKA success.

A nested model of prosthesis within surgeon was necessary as the surgeon variable seemed to confound the authors' preliminary results across both PCL treatment and implant generation, preventing a conclusion on the efficacy of the two PCL treatments independent of the operating surgeon. This nested model through successive layers has shown results that, in the uppermost layer of PCL retention versus PCL substitution, only showed a difference in flexion; many differences did not surface until the surgeon variable was considered.

This study follows a line of evidence gathered in previous published studies from the authors' center. A study published in 2004 [3] cited abnormal anatomic knee alignment along with preoperative factors like morbid obesity and ligamentous imbalance as the main mechanisms of failure in AGC cruciate-retaining total knee replacement. Further studies expounded on the influence of postoperative [17] and preoperative [15] anatomic alignment on failure rates, while another [16] concluded that, even if the PCL is completely excised during TKA, the surgeon need not convert to a posterior-stabilized prosthesis if anteroposterior and coronal stability are maintained. These studies collectively argue that prosthesis selection with regard to the PCL may not affect the results of TKA as much as do other variables like anatomic alignment or patient comorbidities. More studies are needed to substantiate this argument, but the present series of published manuscripts may currently provide enough rationale to merit its application in a clinical setting.

A recent study by Abdel et al. [1] of 8,117 primary TKAs (Press-Fit Condylar, DePuy, Warsaw, IN; and Genesis I, Smith & Nephew, Memphis, TN) performed between 1988 and 1998 reported significantly greater survivorship rates for cruciate-retaining implants, with 15-year survivorship for PCL retention at 89.8% versus 76.5% for PCL substitution

Table 5 Knee Society function scores and subscores for surgeon-implant combinations

		Surgeon					
Implant	Statistical measurement	1	2	3	4	5	6
Function score							
Legacy	*n*	2	306	3	63	2	0
	Least squared mean	89.3	88.5	83.0	81.6	91.8	
	LSM rank w/in surgeon	2	1	1	2	1	
	Effect size (SD)[a]	7.3 (5.2)	6.5 (0.8)	1.0 (4.3)	−0.4 (1.5)	9.9 (6.9)	
	p value	0.1547	<0.0001	0.8108	0.8055	0.1513	
VCR	*n*	369	216	37	146	85[b]	0
	Least squared mean	89.9	87.4	78.8	78.7		
	Rank w/in surgeon	1	4	2	3		
	Effect size (SD)	8.0 (1.2)	5.5 (1.3)	−3.1 (4.7)	−3.3 (2.8)		
	p value	<0.0001	<0.0001	0.5086	0.2422		
VPS	*n*	319	328	28	294	117	0
	Least squared mean	87.5	87.8	74.7	77.0	83.9	
	Rank w/in surgeon	3	3	3	4	2	
	Effect size (SD)	5.5 (1.2)	5.9 (1.0)	−7.3 (3.7)	−4.9 (1.1)	2.0 (3.1)	
	p value	<0.0001	<0.0001	0.0489	<0.0001	0.5150	
AGC	*n*	354	851	2,887	459	0	1,964
	Least squared mean	84.0	88.3	75.2	81.9		88.0
	Rank w/in surgeon	4	2	4	1		
	Effect size (SD)	2.0 (0.9)	6.4 (2.1)	−6.8 (0.7)	Base		6.1 (0.8)
	p value	0.0251	0.0021	<0.0001	Base		<0.0001
Best vs. worst	LSM difference	5.9	1.1	7.8	4.9	7.9	
	p value	<0.0001	0.3960	0.0674	<0.0001	0.2931	
Stairs subscore							
Legacy	*n*	2	306	3	63	2	0
	Least squared mean	39.2	43.6	34.6	40.2	46.8	
	LSM rank w/in surgeon	3	3	2	1	1	
	Effect size (SD)[a]	−0.5 (2.8)	3.9 (0.5)	−5.2 (2.4)	0.5 (0.8)	7.0 (3.8)	
	p value	0.8610	<0.0001	0.0290	0.5616	0.0630	
VCR	*n*	369	216	37	146	85[b]	0
	Least squared mean	44.3	43.6	35.2	37.2		
	Rank w/in surgeon	1	1	1	3		
	Effect size (SD)	4.6 (0.7)	3.9 (0.7)	−4.5 (2.6)	−2.5 (1.5)		
	p value	<0.0001	<0.0001	0.0806	0.0992		
VPS	*n*	319	328	28	294	117	0
	Least squared mean	41.9	43.3	34.5	36.5	41.9	
	Rank w/in surgeon	2	4	3	4	2	
	Effect size (SD)	2.1 (0.7)	3.6 (0.5)	−5.3 (2.0)	−3.2 (0.6)	2.2 (1.7)	
	p value	0.0017	<0.0001	0.0095	<0.0001	0.1969	
AGC	*n*	354	851	2,887	459	0	1,964
	Least squared mean	39.0	43.6	33.2	39.7		44.0
	Rank w/in surgeon	4	2	4	2		
	Effect size (SD)	−0.8 (0.5)	3.8 (1.1)	−6.6 (0.4)	Base		4.3 (0.5)
	p value	0.1170	0.0007	<0.0001	Base		<0.0001
Best vs. worst	LSM difference	5.3	0.3	2.0	3.7	4.9	
	p value	<0.0001	0.7404	0.4129	<0.0001	0.2386	
Walk subscore							
Legacy	*n*	2	306	3	63	2	0
	Least squared mean	49.4	45.7	48.9	42.5	47.6	
	LSM rank w/in surgeon	1	2	1	2	1	
	Effect size (SD)[a]	6.4 (3.3)	2.7 (0.5)	5.9 (2.7)	−0.5 (1.0)	4.6 (4.4)	
	p value	0.0510	<0.0001	0.0326	0.6199	0.2942	
VCR	*n*	369	216	37	146	85[b]	0
	Least squared mean	46.4	44.7	44.1	42.5		
	Rank w/in surgeon	2	4	2	3		
	Effect size (SD)	3.4 (0.8)	1.7 (0.8)	1.1 (3.0)	−0.5 (1.8)		
	p value	<0.0001	0.0416	0.7189	0.7905		
VPS	*n*	319	328	28	294	117	0
	Least squared mean	45.9	45.2	39.8	41.3	45.3	
	Rank w/in surgeon	3	3	4	4	2	
	Effect size (SD)	2.9 (0.8)	2.2 (0.6)	−3.2 (2.4)	−1.7 (0.7)	2.3 (2.0)	
	p value	0.0003	0.0006	0.1699	0.0141	0.2506	
AGC	*n*	354	851	2,887	459	0	1,964
	Least squared mean	45.5	46.0	42.9	43.0		45.0
	Rank w/in surgeon	4	1	3	1		

Table 5 (continued)

		Surgeon					
Implant	Statistical measurement	1	2	3	4	5	6
	Effect size (SD)	2.5 (0.6)	3.0 (1.3)	−0.1 (0.4)	Base		2.1 (0.5)
	p value	<0.0001	0.0233	0.7773	Base		0.0001
Best vs. worst	LSM difference	3.9	1.3	9.1	1.7	2.3	
	p value	0.3605	0.3554	0.0109	0.0141	0.6221	

[a] Effect size compared to surgeon 4 x AGC, with standard deviation in parenthesis
[b] These observations were not full rank in the model because of missing values such as preoperative alignments or intermediate follow-up

Table 6 Stability measurements for surgeon-implant combinations

		Surgeon					
Implant	Statistical measurement	1	2	3	4	5	6
Anteroposterior stability							
Legacy	*n*	2	306	3	63	2	0
	Least squared mean	10.01	10.00	10.00	10.00	9.99	
	LSM rank w/in surgeon	2	4	2	3	2	
	Effect size (SD)[a]	0.01 (0.10)	0.00 (0.02)	0.00 (0.08)	0.00 (0.03)	−0.00 (0.13)	
	p value	0.9079	0.7611	0.9652	0.9843	0.9713	
VCR	*n*	369	216	37	146	85[b]	0
	Least squared mean	10.01	10.01	9.99	10.01		
	Rank w/in surgeon	1	2	3	1		
	Effect size (SD)	0.01 (0.02)	0.01 (0.02)	−0.01 (0.09)	0.01 (0.05)		
	p value	0.5981	0.7340	0.9523	0.8844		
VPS	*n*	319	328	28	294	117	0
	Least squared mean	9.98	10.00	9.98	10.00	10.00	
	Rank w/in surgeon	3	3	4	2	1	
	Effect size (SD)	−0.02 (0.02)					
	p value	0.5227					
AGC	*n*	354	851	2,887	459	0	1,964
	Least squared mean	9.87	10.01	10.00	10.00		9.99
	Rank w/in surgeon	4	1	1	4		
	Effect size (SD)	−0.13	0.01 (0.04)	0.01 (0.01)	Base		−0.01 (0.01)
	p value	<0.0001	0.8232	0.6984	Base		0.5274
Best vs. worst	LSM difference	0.14	0.01	0.02	0.01	0.01	
	p value	<0.0001	0.9190	0.7552	0.8844	0.9242	
Mediolateral stability							
Legacy	*n*	2	306	3	63	2	0
	Least squared mean	14.99	14.98	15.00	15.00	15.00	
	LSM rank w/in surgeon	1	4	3	2	2	
	Effect size (SD)[a]	−0.01 (0.10)	−0.02 (0.01)	−0.01 (0.08)	0.00 (0.03)	−0.00 (0.12)	
	p value	0.9254	0.2022	0.9394	0.9206	0.9846	
VCR	*n*	369	216	37	146	85[b]	0
	Least squared mean	14.98	15.01	15.00	15.00		
	Rank w/in surgeon	2	1	1	4		
	Effect size (SD)	−0.02 (0.02)	0.00 (0.02)	−0.00 (0.08)	−0.00 (0.05)		
	p value	0.4388	0.8665	0.9569	0.9807		
VPS	*n*	319	328	28	294	117	0
	Least squared mean	14.98	15.00	15.00	15.00	15.00	
	Rank w/in surgeon	3	2	2	1	1	
	Effect size (SD)	−0.02 (0.02)	0.00 (0.02)	−0.00 (0.07)	0.00 (0.02)	0.00 (0.05)	
	p value	0.3319	0.9035	0.9389	0.8792	0.9895	
AGC	*n*	354	851	2,887	459	0	1,964
	Least squared mean	14.97	15.00	14.99	15.00		14.99
	Rank w/in surgeon	4	3	4	3		
	Effect size (SD)	−0.03 (0.02)	−0.00 (0.04)	−0.01 (0.01)	Base		−0.01 (0.01)
	p value	0.0471	0.9485	0.5572	Base		0.3472
Best vs. worst	LSM difference	0.02	0.03	0.01	0.00	0.00	
	p value	0.7943	0.3048	0.9751	0.9352	0.9815	

[a] Effect size compared to surgeon 4 x AGC, with standard deviation in parenthesis
[b] These observations were not full rank in the model because of missing values such as preoperative alignments or intermediate follow-up

Table 7 Clinical results of TKA in 12 implant-surgeon combinations within the Vanguard prosthesis family

	Surgeon							
	1		2		3		4	
	CR	PS	CR	PS	CR	PS	CR	PS
Knee score	90.8	91.9	79.7	84.8	86.9	76.2	n/a	81.6
Difference	1.0	1.0	5.1	5.1	10.7	10.7		
p-value	0.4793	0.4793	0.0770	0.0770	0.0069	0.0069		
Pain subscore	48.9	49.6	46.9	47.6	50.5	45.9	42.7	44.4
Difference	0.7	0.7	0.7	0.7	4.6	4.6	1.7	1.7
p-value	0.2787	0.2787	0.2440	0.2440	0.0873	0.0873	0.1969	0.1969
Flexion	115.8	120.1	105.0	109.6	121.1	106.4	116.6	120.3
Difference	4.3	4.3	4.7	4.7	14.7	14.7	3.7	3.7
p-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0348	0.0348
Function score	89.9	87.5	87.4	87.8	78.8	74.7	78.7	77.0
Difference	2.5	2.5	0.4	0.4	4.2	4.2	1.6	1.6
p-value	0.0925	0.0925	0.7745	0.7745	0.4765	0.4765	0.5684	0.5684
Stairs subscore	44.3	41.9	43.6	43.3	35.2	34.5	37.2	36.5
Difference	2.5	2.5	0.3	0.3	0.8	0.8	0.7	0.7
p-value	0.0024	0.0024	0.7404	0.7404	0.8103	0.8103	0.6669	0.6669
Walk subscore	46.4	45.9	44.7	45.2	44.1	39.8	42.5	41.3
Difference	0.5	0.5	0.5	0.5	4.3	4.3	1.2	1.2
p-value	0.6049	0.6049	0.5456	0.5456	0.2512	0.2512	0.4997	0.4997
AP stability	10.01	9.98	10.01	10.00	9.99	9.98	10.01	10.00
Difference	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.01
p-value	0.3344	0.3344	0.8748	0.8748	0.9194	0.9194	0.9163	0.9163
ML stability	14.98	14.98	15.01	15.00	15.00	15.00	15.00	15.00
Difference	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00
p-value	0.8507	0.8507	0.9444	0.9444	0.9959	0.9959	0.9352	0.9352

($p<0.001$). The difference extended to those knees with preoperative flexion contracture and angular deformity (89.8% vs. 70.5%, $p=0.04$); however, only 52 PCL-substituting knees in this group were followed for 15 years. A concurrent comment [6] noted this limitation, as well as the possibility of differences in sterilization and polyethylene oxidation between the two groups caused by PCL substitution's limited use in the early phase of the study period.

A cited strength of the above study is the use of data exclusively from surgeons performing at least 50 total knee arthroplasties per year. This technique controls for the influence of surgeons who are relatively inexperienced with TKA; it does not, however, address any preferences or familiarities that experienced orthopedic surgeons may hold toward a specific implant.

This study is a retrospective review of prospectively gathered data, so any findings must be considered in this light; however, the sample size and statistical methods counteract the weakness from which a retrospective cohort study typically suffers. Comparisons between the various designs in this study were only made after the use of generalized linear regression and the maximum likelihood method to minimize the influence of confounding variables. This statistical test was used on a large set of nearly 9,000 knees, which produced sufficient power to determine differences between most individual surgeon-prosthesis combinations. A second possible limitation arises from the prevalence of each TKA design at the center. The surgeon-authors and their colleagues implanted more PCL-retaining than PCL-substituting TKAs, and they may have used the PCL-substituting design only in patients with the worst deformities, such as extreme preoperative varus or valgus. These cases, however, did not unduly influence the results described here because the surgeons only used PCL-substituting implants in these cases to compensate for the deformity, not to specifically increase flexion in a preoperatively low-flexion patient. There was no systematic bias in the surgeons involved in this study that would result in a disproportionate amount of any preoperative patient population receiving one of the four implant designs.

Future studies, especially from large-volume centers with high statistical power, should use a nested model to examine the possible interacting variables of surgeon and implant design. Such evaluations may show that it is more important, not for the surgeon to choose which total knee design provides universally improved results, but instead for the surgeon to determine which total knee design provides consistently favorable results for the surgical technique he or she feels comfortable with in practice. In this case, the surgeon may find that different prostheses may provide different advantages in function, flexion, and pain relief, and that these advantages (and any possible disadvantages) may not extend to other surgeons at his/her practice or in the orthopedic field. The same conditions in situ (preoperative angular deformity, anteroposterior stability, etc.) may spur different surgeons to implant different arthroplasty models based on their familiarity and technique, while still obtaining good or excellent long-term clinical results.

Previous studies have asserted that PCL-substituting total knee arthroplasty provides more consistent results than

PCL-retaining TKA, particularly in flexion. In light of the data from the present study and from documented success with PCL retention, however, the operating surgeon may prove to be a substantially influential variable of overall TKA success than previously thought. If this is the case, then it is the surgeon's responsibility to establish which TKA design is most suited to his or her operative technique.

Disclosures

Conflict of Interest Merrill A. Ritter, MD reports grants from Biomet, Inc. during the conduct of the study and grants from Exactech, Pacira and DePuy, outside the work. Philip M. Faris, MD reports grants and personal fees from Biomet, Inc. during the conduct of the study and grants from Exactech, Pacira and DePuy, outside the work. E. Michael Keating, MD reports grants from Biomet, Inc. during the conduct of the study and grants from Exactech, Pacira and DePuy, outside the work. Kenneth E. Davis, MS and Alex Farris, BA have declared that they have no conflict of interest.

Human/Animal Rights All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008 (5).

Informed Consent Informed consent was obtained from all patients for being included in the study.

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