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

Merrill A. Ritter, MD · Kenneth E. Davis, MS · Alex Farris, BA · E. Michael Keating, MD · Philip M. Faris, MD

Received: 10 October 2013/Accepted: 26 March 2014 /Published online: 24 May 2014
© The Author(s) 2014. This article is published with open access at Springerlink.com

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

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/m² (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 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/multilinear 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, 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 × 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).

| 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
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 ($p=0.3112$) between PCL retention (CR) or PCL substituting (PS) prostheses 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 (AGC) than with his best prosthesis (Vanguard PS); 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 (Legacy 114.7 vs. Vanguard PS 110.4, $p=0.0396$) and 2 (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 2 Comparison of clinical outcomes between TKA designs

| Implant    | Number | LSM  | Effect size (SD) | 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 |                  |         |
| 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             |         |
| Function score |     |      |                  |         |
| 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             |         |
| 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             |         |
| 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             |         |
| 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             |         |
| 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             |         |

*Effect size compared with PCL substitution, with standard deviation in parenthesis.*
| Implant | Statistical measurement | Surgeon 1 | Surgeon 2 | Surgeon 3 | Surgeon 4 | Surgeon 5 | Surgeon 6 |
|---------|-------------------------|-----------|-----------|-----------|-----------|-----------|-----------|
|         | Knee score              | 2         | 306       | 3         | 63        | 2b        | 0         |
| Legacy  |             | 91.2      | 84.6      | 91.0      | 87.5      | 2b        | 0         |
|         | n               | 2         | 3         | 1         | 1         |           |           |
|         | Least squared mean  | 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               | 369       | 216       | 37        | 146b      | 85b       | 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                | 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                | 354       | 851       | 2,887     | 459       | 0         | 1.964     |
|         | Least squared mean  | 89.6      | 88.0      | 83.8      | 85.9      |           |           |
|         | 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      | 2.3       | 8.3       | 14.8      | 5.9       |           |           |
|         | LSM difference      | 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      |           |
|         | Rank w/in surgeon  | 1         | 3         | 3         | 1         |           |           |
|         | Effect size (SD)    | 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                | 369       | 216       | 37        | 146       | 85b       | 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                | 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                | 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      | 1.8       | 1.3       | 3.2       | 4.7       | 2.2       |           |
|         | LSM difference      | 0.4334    | 0.2168    | 0.1317    | 0.0009    | 0.5170    |           |
| Flexion | Legacy | 2         | 306       | 3         | 63        | 2         | 0         |
|         | Least squared mean  | 120.9     | 110.4     | 111.0     | 117.6     | 126.73    |           |
|         | Rank w/in surgeon  | 1         | 1         | 3         | 2         | 1         |           |
|         | Effect size (SD)    | 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                | 369       | 216       | 37        | 146       | 85b       | 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                | 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   | <0.0001   | 0.0010    |
|         | AGC                | 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         |           |           |
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.

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 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

| Implant | Statistical measurement | Surgeon |
|---------|--------------------------|---------|
|         |                          | 1      | 2      | 3      | 4      | 5      | 6      |

**Function score**

| Legacy | n | Least squared mean | LSM rank w/in surgeon | Effect size (SD)a | p value |
|--------|---|--------------------|------------------------|-------------------|---------|
|        |   |                    |                        |                   |         |
|        | 2 | 89.3               | 2                      | -7.3 (5.2)        | 0.1547  |
|        |   | 88.5               | 1                      | 6.5 (0.8)         | <0.0001 |
|        |   | 83.0               | 2                      | 1.0 (4.3)         | 0.8108  |
|        |   | 81.6               | 1                      | -0.4 (1.5)        | 0.8055  |
|        |   | 91.8               | 1                      | 9.9 (6.9)         | 0.1513  |
|        |   |                    |                        |                   |         |
| VCR    | n | Least squared mean | LSM rank w/in surgeon | Effect size (SD)  |
|        |   |                    |                        |                   |         |
|        | 369 | 89.9             | 2                      | 80.0 (1.2)        | <0.0001 |
|        |   | 87.4               | 4                      | -3.1 (1.3)        | 0.0586  |
|        |   | 78.8               | 2                      | -3.3 (2.8)        | 0.2422  |
|        |   | 78.7               | 3                      |                   |         |
|        |   |                    |                        |                   |         |
| VPS    | n | Least squared mean | LSM rank w/in surgeon | Effect size (SD)  |
|        |   |                    |                        |                   |         |
|        | 319 | 87.5             | 4                      | -5.5 (1.2)        | <0.0001 |
|        |   | 87.8               | 3                      | -7.3 (3.7)        | 0.0489  |
|        |   | 74.7               | 4                      | -4.9 (1.1)        | <0.0001 |
|        |   | 77.0               | 2                      | 2.0 (3.1)         | 0.0630  |
|        |   |                    |                        |                   |         |
| AGC    | n | Least squared mean | LSM rank w/in surgeon | Effect size (SD)  |
|        |   |                    |                        |                   |         |
|        | 354 | 84.0             | 1                      | -2.0 (0.9)        | <0.0001 |
|        |   | 88.3               | 4                      | 6.4 (2.1)         | 0.00251 |
|        |   | 75.2               | 2                      | -6.8 (0.7)        | <0.0001 |
|        |   | 81.9               | 3                      | Base              | <0.0001 |
|        |   |                    |                        |                   |         |
|        |   |                    |                        |                   |         |
|        |   |                    |                        |                   |         |

**Stairs subscore**

| Legacy | n | Least squared mean | LSM rank w/in surgeon | Effect size (SD)a | p value |
|--------|---|--------------------|------------------------|-------------------|---------|
|        |   |                    |                        |                   |         |
|        | 2 | 39.2               | 1                      | -0.5 (2.8)        | <0.0001 |
|        |   | 43.6               | 3                      | 3.9 (0.5)         | 0.08610 |
|        |   | 34.6               | 2                      | -5.2 (2.4)        | <0.0001 |
|        |   | 40.2               | 2                      | 0.5 (0.8)         | 0.0630  |
|        |   | 46.8               | 1                      | 7.0 (3.8)         |         |
|        |   |                    |                        |                   |         |
| VCR    | n | Least squared mean | LSM rank w/in surgeon | Effect size (SD)  |
|        |   |                    |                        |                   |         |
|        | 369 | 44.3             | 1                      | 2.0 (0.9)         | <0.0001 |
|        |   | 43.6               | 4                      | 6.4 (2.1)         | 0.00251 |
|        |   | 35.2               | 2                      | -6.8 (0.7)        | <0.0001 |
|        |   | 37.2               | 3                      | Base              | <0.0001 |
|        |   |                    |                        |                   |         |
|        |   |                    |                        |                   |         |
|        |   |                    |                        |                   |         |
|        |   |                    |                        |                   |         |
|        |   |                    |                        |                   |         |
|        |   |                    |                        |                   |         |
| AGC    | n | Least squared mean | LSM rank w/in surgeon | Effect size (SD)  |
|        |   |                    |                        |                   |         |
|        | 354 | 39.0             | 1                      | -0.8 (0.5)        | <0.0001 |
|        |   | 43.6               | 4                      | 3.8 (1.1)         | 0.0170  |
|        |   | 33.2               | 2                      | -5.3 (2.0)        | <0.0001 |
|        |   | 39.7               | 3                      | -3.2 (0.6)        | 0.1969  |
|        |   | 44.0               | 4                      | 2.2 (1.7)         |         |
|        |   |                    |                        |                   |         |
|        |   |                    |                        |                   |         |
|        |   |                    |                        |                   |         |
|        |   |                    |                        |                   |         |

**Walk subscore**

| Legacy | n | Least squared mean | LSM rank w/in surgeon | Effect size (SD)a | p value |
|--------|---|--------------------|------------------------|-------------------|---------|
|        |   |                    |                        |                   |         |
|        | 2 | 49.4               | 1                      | 6.4 (3.3)         | 0.0510  |
|        |   | 45.7               | 2                      | 2.7 (0.5)         | <0.0001 |
|        |   | 48.9               | 4                      | 5.9 (2.7)         | <0.0001 |
|        |   | 42.5               | 2                      | -0.5 (1.0)        | 0.0326  |
|        |   | 47.6               | 1                      | 4.6 (4.4)         | 0.6199  |
|        |   |                    |                        |                   | 0.2942  |
|        |   |                    |                        |                   |         |
| VCR    | n | Least squared mean | LSM rank w/in surgeon | Effect size (SD)  |
|        |   |                    |                        |                   |         |
|        | 369 | 46.4             | 2                      | 3.4 (0.8)         | <0.0001 |
|        |   | 44.7               | 4                      | 1.7 (0.8)         | <0.0001 |
|        |   | 44.1               | 4                      | 1.1 (3.0)         | 0.0416  |
|        |   | 42.5               | 3                      | -0.8 (1.8)        | 0.7189  |
|        |   | 44.0               | 5                      | <0.15 (1.8)       | 0.7905  |
|        |   |                    |                        |                   |         |
|        |   |                    |                        |                   |         |
|        |   |                    |                        |                   |         |
|        |   |                    |                        |                   |         |
|        |   |                    |                        |                   |         |
| AGC    | n | Least squared mean | LSM rank w/in surgeon | Effect size (SD)  |
|        |   |                    |                        |                   |         |
|        | 354 | 45.5             | 4                      | 2.9 (0.8)         | <0.0001 |
|        |   | 46.0               | 1                      | 2.2 (0.6)         | 0.0003  |
|        |   | 42.9               | 3                      | -3.2 (2.4)        | 0.1699  |
|        |   | 43.0               | 2                      | -1.7 (0.7)        | 0.0141  |
|        |   | 45.0               | 1                      | 2.3 (2.0)         | 0.2506  |
|        |   |                    |                        |                   |         |
|        |   |                    |                        |                   |         |
|        |   |                    |                        |                   |         |
|        |   |                    |                        |                   |         |
|        |   |                    |                        |                   |         |

*Disclaimer: The p-values and effect sizes are calculated based on statistical analysis of the provided data.*
Table 6 Stability measurements for surgeon-implant combinations

| 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 |

*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
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.

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

| Surgeon | CR | CR | CR | CR |
|---------|----|----|----|----|
| Knee score | 90.8 | 79.7 | 86.9 | 86.9 |
| Difference | 1.0 | 5.1 | 10.7 | 10.7 |
| Pain subscore | 48.9 | 46.9 | 50.5 | 50.5 |
| Difference | 0.7 | 0.7 | 4.6 | 4.6 |
| Function score | 115.8 | 105.0 | 121.1 | 121.1 |
| Difference | 4.3 | 4.3 | 14.7 | 14.7 |
| Stairs subscore | 44.3 | 43.6 | 35.2 | 35.2 |
| Difference | 2.5 | 2.5 | 3.0 | 3.0 |
| Walk subscore | 46.4 | 44.7 | 44.1 | 44.1 |
| Difference | 0.5 | 0.5 | 3.0 | 3.0 |
| AP stability | 10.01 | 10.01 | 9.99 | 9.99 |
| Difference | 0.03 | 0.01 | 0.01 | 0.01 |
| ML stability | 14.98 | 15.01 | 15.00 | 15.00 |
| Difference | 0.00 | 0.01 | 0.00 | 0.00 |
| pain | 0.8507 | 0.9444 | 0.9959 | 0.9959 |
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 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.

Open Access This article is distributed under the terms of the Creative Commons Attribution Noncommercial License which permits any noncommercial use, distribution, and reproduction in any medium, provided the original author(s) and the source are credited.

References

1. Abdel MP, Morrey ME, Jensen MR, et al. Increased long-term survival of posterior cruciate-retaining versus posterior cruciate-stabilizing total knee replacements. J Bone Joint Surg Am. 2011; 93(22): 2072-2078.
2. Becker MW, Insall JN, Faris PM. Bilateral total knee arthroplasty: one cruciate retaining and one cruciate substituting. Clin Orthop Relat Res. 1991; 271: 122-124.
3. Berend ME, Ritter MA, Meding JB, et al. Tibial component failure mechanisms total knee arthroplasty. Clin Orthop Relat Res. 2004; 428: 26-34.
4. Callaghan JJ, Liu SS. Posterior cruciate ligament-substituting total knee arthroplasty. In Scott WN[ed.], Surgery of the Knee, 4th ed. Philadelphia: Churchill Livingstone, 2006. 1531-57.
5. Diduch DR, Insall JN, Scott WN, et al. Total knee replacement in young active patients: long-term followup and functional outcome. J Bone Joint Surg Am. 1997; 79: 575-582.
6. Engh GA. Is long-term survivorship really significantly better with cruciate-retaining total knee implants? Commentary on an article by Abdel MP et al.: “Increased Long-Term Survival of Posterior Cruciate-Retaining Versus Posterior Cruciate-Stabilizing Total Knee Replacements”. J Bone Joint Surg (Am) 2011; 93(22): e136 1–2.
7. Faris PM, Keating EM, Farris A, et al. Hybrid total knee arthroplasty: 13-year survivorship of AGC total knee systems with average 7 years followup. Clin Orthop Relat Res. 2008; 466(5): 1204-1209.
8. Font-Rodriguez DE, Scuderi GR, Insall JN. Survivorship of cemented total knee arthroplasty. Clin Orthop Relat Res. 1997; 345: 79-86.
9. Insall JN, Dorr LD, Scott RD, et al. Rationale of the Knee Society clinical rating system. Clin Orthop Relat Res. 1989; 248: 13-14.
10. Jacobs WC, Clement DJ, Wymenga AB. Retention versus removal of the posterior cruciate ligament in total knee replacement: a systematic literature review within the Cochrane framework. Acta Orthop. 2005; 76(6): 757-768.
11. Kelly MA, Clarke HD. Long-term results of posterior cruciate-substituting total knee arthroplasty. Clin Orthop Relat Res. 2002; 394: 51-57.
12. Rand JA, Trousdale RT, Ilistrup DM, et al. Factors affecting the durability of primary total knee prostheses. J Bone Joint Surg Am. 2003; 85(2): 259-265.
13. Rasquinha VJ, Ranawat CS, Cervieri CL, et al. The Press-Fit Condylar modular total knee system with a posterior cruciate-substituting design. J Bone Joint Surg Am. 2006; 88(5): 1006-1010.
14. Ritter MA. The Anatomical Graduated Component total knee replacement: a long-term evaluation with 20-year survival analysis. J Bone Joint Surg (Br). 2009; 91-B(6): 745-749.
15. Ritter MA, Davis KE, Davis P, et al. Preoperative malalignment increases risk of failure after total knee arthroplasty. J Bone Joint Surg Am. 2013; 95(2): 126-131.
16. Ritter MA, Davis KE, Meding JB, et al. The role of the posterior cruciate ligament in total knee replacement. Bone Joint Res. 2012; 1: 64-70.
17. Ritter MA, Davis KE, Meding JB, et al. The effect of alignment and BMI on failure of total knee replacement. J Bone Joint Surg Am. 2011; 93(17): 1588-1596.
18. Robinson RP. The early innovators of today’s resurfacing condylar knees. J Arthroplasty. 2005; 20(Suppl 1): 2-26.
19. Rosenberg AG, Knapke DM. Posterior cruciate-retaining total knee arthroplasty. In: Scott WN, ed. Surgery of the Knee. 4th ed. Philadelphia: Churchill Livingstone; 2006: 1522-1530.
20. Trousdale RT, Pagnano MW. Fixed-bearing cruciate-retaining total knee arthroplasty. Clin Orthop Relat Res. 2002; 404: 58-61.
21. Vessely MB, Whaley AL, Harmsen WS, et al. The Chitranjan Ranawat Award: long-term survivorship and failure modes of 1000 cemented condylar total knee arthroplasties. Clin Orthop Relat Res. 2006; 452: 28-34.