Postoperative Flexion Analysis of 3 Rotating-platform Knee Designs

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abstract

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Rotating-platform knee implants have successively undergone modifications to improve postoperative flexion. The cruciate-sacrificing Low Contact Stress (LCS) implant (DePuy Orthopaedics, Inc, Warsaw, Indiana) was modified into the cruciate-substituting PFC Sigma RP (ΣRP) implant and further into the PFC Sigma RPF (ΣRPF) implant (DePuy Orthopaedics, Inc). The goal of this study was to determine whether these modifications improved postoperative flexion. Postoperative flexion at 2 years was compared against preoperative flexion with regard to the general demographics of each group.

Statistical analysis showed that the pre- to postoperative flexion changes achieved by the ΣRP (14.6°) and the ΣRPF (2.9°) were better ($P<.001$) than that achieved by the LCS (−10.3°); however, between the ΣRP (14.6°) and the ΣRPF (2.9°), the change was statistically insignificant ($P = .045$). In subgroups with preoperative flexion less than 125°, postoperative flexion achieved was 100.1° with the LCS, 119.8° with the ΣRP, and 121.3° with the ΣRPF. The difference between the ΣRP and ΣRPF and the LCS was statistically significant ($P < .001$), but between the ΣRP and the ΣRPF was statistically insignificant ($P = .621$). In subgroups with preoperative flexion 125° or more, postoperative flexion was 125° with the LCS, 132° with the ΣRP, and 130° with the ΣRPF, with no significant difference between groups ($P = .416$). Both cruciate-substituting designs produced better postoperative flexion than the cruciate-sacrificing design. The ΣRP, despite less preoperative flexion ($P = .004$), achieved statistically better postoperative flexion than the LCS ($P < .001$). In subgroups with comparable preoperative flexion, no statistical difference in postoperative flexion was achieved by the ΣRP and the ΣRPF.

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The goal of total knee arthroplasty (TKA) is to achieve better postoperative flexion. Toward this end, investigators have tried to mimic normal knee kinematics in artificial implants. The rotating-platform, mobile-bearing implant design is one such endeavor.

The first rotating-platform, posterior cruciate-sacrificing design (Low Contact Stress [LCS]; DePuy Orthopaedics, Inc, Warsaw, Indiana) was introduced in 1977. Excellent survivorship of 88% to 100% up to 20 years has been reported.\(^1,9\) Its average postoperative range of motion (ROM) is reported to be between 94° and 114°.\(^1,9\) Its counterpart, the fixed-bearing design substituting for the posterior cruciate ligament with the post and cam mechanism, showed more consistent posterior rollback of the femur and better flexion postoperatively.\(^10-13\) This prompted a modification of the LCS implant to incorporate a post and cam mechanism; thus, the posterior cruciate-sacrificing PFC Sigma RP design (ΣRP) (DePuy Orthopaedics, Inc) was introduced in 2000.

By 2005, the ΣRP was further modified to accommodate higher flexion and permit deep knee bending. The high-flex PFC Sigma RPF design (ΣRPF) (DePuy Orthopaedics, Inc) had a modified post and cam mechanism and an enhanced posterior femorotibial articulation to provide a larger contact area. The senior author (R.N.M.) has implanted all 3 designs. The authors studied 163 patients in whom these 3 designs were implanted and analyzed the ROM achieved to draw a comparison between them. The primary goal was to determine whether an improvement in postoperative flexion occurred with the design modifications. General demographics and pre- and postoperative ROM were taken into account in each design group.

**Materials and Methods**

The senior author used the LCS between 1997 and 2001. He implanted them in 55 knees of a total of 341 TKAs performed during this period. The LCS was selected for young, active patients in whom the fixed-bearing modular knee was not considered a good option because of the concern of polyethylene wear.

From 2001 onward, the senior author used the ΣRP. The first consecutive 55 cases performed between September 2001 and April 2002 were studied. During this period, a total of 108 TKAs were performed, 53 of which used PFC Sigma fixed-bearing implants (DePuy Orthopaedics, Inc) and 55 of which used ΣRP implants. The selection criterion to implant the ΣRP was that the patient had good ligamentous stability at surgery, particularly in flexion.

The senior author began using the ΣRPF after its introduction in 2005, but only for a highly selected group of patients. The major deterrent of this design was the need for more bone removal from the posterior femoral condyles. Patients were selected for this design if they had good preoperative flexion (125° or more) and/or if they intended to perform activities requiring deep knee flexion postoperatively. In addition, they had to have good flexion stability intraoperatively. The first 53 TKAs performed between January 2005 and September 2008 were prospectively selected for this study. The ΣRPF knees formed a small percentage (4.4%) of the overall 1212 TKAs performed during this period (625 PFC Sigma fixed-bearing, 534 ΣRP, and 53 ΣRPF).

General demographics, preoperative ROM, and 2-year postoperative ROM were collected from patient records. Range of motion was measured using a goniometer placed on the lateral side of the leg, with the proximal arm placed from the lateral trochanter to the lateral epicondyle and the distal arm placed from the lateral epicondyle to the lateral malleolus. Range of motion was presented as pre- and postoperative flexion in each design group, along with statistical analyses to compare the 3 designs and to compare each paired design group. Pre- to postoperative flexion change was compared in each design group. For better comparison, each design group was subdivided into patients with restricted preoperative flexion less than 125° and patients with good preoperative flexion of 125° or more, and the postoperative flexion achieved in these subgroups was analyzed.

Statistical analysis was performed using Epi Info version 3.5.1 (Centers for Disease Control, Atlanta, Georgia). Analysis of variance, a parametric test for inequality of population means, was used. To determine the statistical significance of ROM differences, each difference was subjected to Student’s t test and Bonferroni’s correction (formal P divided by the number of comparisons [P/K]). For comparison between 3 values, P<.05/3 (or .017) was considered significant.

Post hoc power analysis was performed on pre- to postoperative flexion change. This showed that a sample size of 55 patients in the LCS group and 55 patients in the ΣRP group would have a power of 100% to detect a difference between the 2 groups. Similarly, a sample size of 55 patients in the LCS group and 53 patients in the ΣRPF group would have a power of 100%, and a sample size of 55 patients in the ΣRP group and 53 patients in the ΣRPF group would have a power of 99.9% to detect differences between the 2 respective groups.

**Results**

Each design group had a comparable number of knees, and general demographics are presented in Table 1. Average age was 59.6 years (range, 40-77 years) in the LCS group, 64 years (range, 44-81 years) in the ΣRP group, and 65.9 years (range, 51-79 years) in the ΣRPF group. Other demographic features, such as sex, diagnosis, and body mass index, were similar in the 3 groups (Table 1).

Average preoperative flexion was 113° in the LCS group, 106° in the ΣRP group, and 124° in the ΣRPF group (Table 2). Differences in preoperative flexion be-
between the 3 groups (P<.001) and between each paired group (LCS/ΣRP [P=.004]; LCS/ΣRPF [P<.001]; ΣRP/ΣRPF [P<.001]) were statistically significant. Average postoperative flexion was 102.8° in the LCS group, 121° in the ΣRP group, and 126.9° in the ΣRPF group (Table 3; Figures 1-3). Differences in postoperative flexion between the 3 groups (P<.001) and between each paired group (LCS/ΣRP, P<.001; LCS/ΣRPF, P<.001; ΣRP/ΣRPF, P=.007) were statistically significant (Table 3).

Table 4 shows the pre- to postoperative flexion change with adjustments made for preoperative flexion. The flexion increase achieved by the ΣRP (14.6°) and the ΣRPF (2.9°) was statistically better (P<.001) than that achieved by the LCS (−10.3°). The difference in flexion change between the ΣRP (14.6°) and the ΣRPF (2.9°) was statistically insignificant (P=.045). Regression analysis showed no association between flexion change (difference between pre- and postoperative flexion) and demographic parameters of age (P=.124) and body mass index (P=.691).

Table 5 shows the average postoperative flexion in the 3 subgroups of patients with restricted preoperative flexion (less than 125°). The LCS, ΣRP, and ΣRPF subgroups comprised 49, 50, and 19 such patients, respectively, and their postoperative flexion was 101.1°, 119.8°, and 121.3°, respectively. Analysis revealed a statistically significant difference (P<.001) between these 3 results. Comparison of paired groups revealed a statistically significant difference between the LCS/ΣRP (P<.001) and LCS/ΣRPF subgroups (P<.001). No significant statistical difference (P=.622) existed between the ΣRP and ΣRPF subgroups when preoperative flexion was comparable.

Table 6 shows the average postoperative flexion achieved in the 3 design subgroups of patients with good preoperative flexion (125° or more). The LCS, ΣRP, and ΣRPF subgroups comprised 6, 5, and 34 such patients, respectively, and their postoperative flexion was 125°, 132°, and 130°, respectively. Analysis showed no significant statistical difference (P=.416) between these 3 results. Five of 6 patients in the LCS subgroup had less flexion postoperatively than preoperatively. All 5 patients in the ΣRP subgroup and 22 of 34 patients in the ΣRPF subgroup achieved more flexion postoperatively than they had preoperatively.

**Discussion**

The principal finding of this study was that postoperative flexion achieved with the 3 implant designs differed significantly. Mean postoperative flexion in the LCS group was 102.8°; the literature reports 94° to 114° flexion for the LCS. Mean postoperative flexion was 120.9° in the ΣRP group and 126.9° in the ΣRPF group, both of which are comparable with the reports available in the literature.

Preoperative flexion was different in each group. This could have played a determining role in the postoperative flexion achieved. Hence, a comparison of pre- to postoperative flexion change was done...
with adjustments made for the differences in preoperative flexion values to eliminate bias. Each design group was further divided into patients with restricted preoperative flexion of less than 125° and those with good preoperative flexion of 125° or more, and the postoperative flexion achieved in these subgroups was compared.

The results suggest that the change in pre- to postoperative flexion was significantly more with the use of the cruciate-substituting designs (ΣRPF and ΣRP) compared with the cruciate-sacrificing design (LCS) (P < .001 and P < .001, respectively) (Table 5). However, the ΣRPF showed no improvement over the standard ΣRP design in flexion change achieved (P = .045). Similarly, when considering the subgroups with restricted preoperative flexion (less than 125°), the same results were found. This suggests that the cruciate-substituting designs improved postoperative flexion compared with the cruciate-sacrificing design, but the high-flex variety of the cruciate-substituting design did not improve postoperative flexion compared with the standard cruciate-substituting design.

In the subgroup of patients with good preoperative flexion (125° or more), average postoperative flexion achieved with the LCS design was less (125°) than the average preoperative flexion (130.8°). All patients in the LCS group had equal or less flexion postoperatively compared with their preoperative flexion. Average postoperative flexion achieved with the ΣRP was better (132°) than the average preoperative flexion (130°). Thus, all patients in the ΣRP group retained or gained flexion postoperatively. Average postoperative flexion achieved with the ΣRPF was the same (130°) as the preoperative average flexion. Forty of 53 patients in the ΣRPF group retained or gained flexion postoperatively. Previous studies have shown that patients with good preoperative ROM tend to lose flexion postoperatively,24-25 but in the current study, the cruciate-substituting designs resulted in the same or better flexion postoperatively.

Average preoperative flexion in the ΣRP group was statistically less than in the LCS and ΣRPF groups (P = .004 and P < .001, respectively), yet its average postoperative flexion was better than that with the LCS (P < .001).

The ΣRP and ΣRPF designs substitute the posterior cruciate ligament using a post and cam mechanism. This leads to more consistent posterior femoral rollback, as reported in various studies.10-12,24-25 This explains the better flexion achieved postoperatively. Fluoroscopic and clinical studies on the post and cam design of fixed-bearing knees report a mean postoperative flexion of 110° to 129°.13-15,26-29 One study on fixed-bearing designs with a configuration similar to the current study found that the ultracongruent design (without post and cam) had less postoperative flexion compared with designs with a post and cam mechanism.30 The addition of the post and cam mechanism to the LCS rotating-platform implant may have improved the stability and flexion of the design, but it has also

### Table 3

<table>
<thead>
<tr>
<th>Prosthesis</th>
<th>No.</th>
<th>Mean Postoperative Flexion, deg</th>
<th>P</th>
<th>Inference</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCS</td>
<td>55</td>
<td>102.8±12.8</td>
<td>&lt;.001&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Significant difference between groups</td>
</tr>
<tr>
<td>ΣRP</td>
<td>55</td>
<td>121±12.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ΣRPF</td>
<td>53</td>
<td>126.9±9.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LCS/ΣRP</td>
<td>55/55</td>
<td>102.8±12.8/121±12.4</td>
<td>&lt;.001&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Significant difference: ΣRP &gt; LCS</td>
</tr>
<tr>
<td>LCS/ΣRPF</td>
<td>55/53</td>
<td>102.8±12.8/126.9±9.8</td>
<td>&lt;.001&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Significant difference: ΣRPF &gt; LCS</td>
</tr>
<tr>
<td>ΣRPF/ΣRP</td>
<td>55/53</td>
<td>121±12.4/126.9±9.8</td>
<td>.007&lt;sup&gt;c&lt;/sup&gt;</td>
<td>Significant difference: ΣRP &gt; ΣRP</td>
</tr>
</tbody>
</table>

Abbreviations: deg, degrees; LCS, Low Contact Stress (DePuy Orthopaedics, Inc, Warsaw, Indiana); ΣRP, PFC Sigma RP (DePuy Orthopaedics, Inc); ΣRPF, PFC Sigma RPF (DePuy Orthopaedics, Inc).

<sup>a</sup>Analysis of variance. Difference among the 3 means significant at P < .001.
<sup>b</sup>Student’s t test and Bonferroni correction. Difference significant at P < .01.
<sup>c</sup>Student’s t test and Bonferroni correction. Difference significant at P < .05.
added 2 concerns. One concern is the risk of an additional source of polyethylene wear due to post impingement. The second concern is the decrease in the articular surface contact area compared with that of the LCS. Two studies on the performance of the SRP design at an average follow-up of more than 5 and 10 years, respectively, reported no osteolysis.\textsuperscript{15,18} Two studies on the performance of the SRPF up to 6 years reported 100% survivorship and no osteolysis.\textsuperscript{13,14} Whether the reduced contact area will affect survival in cruciate-substituting post and cam designs of rotating-platform implants compared with the LCS design requires further study.

The current study presents the first consecutive cases of a single surgeon using each implant design with comparable preoperative demographics. The demographics reflect the selection criteria used for a particular design at the time. The LCS, which was used by the senior author between 1996 and 2001, was selected for young, active patients provided the preoperative flexion stability was adequate. Thus, the demographics reflect a younger average age (\(P<.001\)) for the LCS than for the SRP and SRPF and relatively better preoperative flexion in the LCS group (\(P=.004\)) than in the SRP group. The LCS was used in 16.1% of the total number of TKAs performed in the study period.

The SRP, introduced in 2001, promised better stability and could be used by the senior author for a larger section of patient population (50.9% of the total number who underwent TKA in the study period). The average age of 64 years in this
group was representative of the average age of the population undergoing TKA at that time. The ΣRPF, introduced in 2005, promised deep knee flexion, but the senior author used it with strict selection criteria due to possible extra bone resection from the posterior femoral condyles; thus, it was used in only 4.4% of the total TKAs performed in the study period. One criterion for selection was that the patient should have good preoperative flexion; hence, the demographics show a higher average of preoperative flexion (123.9°) in this group. The ΣRPF group comprised 34 patients with preoperative flexion of 125° or more compared with 6 in the LCS group and 5 in the ΣRP group.

This study was retrospective in nature. A limitation of the study is that the assignment of implant design to patients was not randomized; specific selection criteria were followed for each design. The LCS was used in younger patients. A regression analysis showed no effect of age on postoperative flexion; thus, comparisons were justified. The ΣRPF was used for patients with preoperative flexion of 125° or more and/or who intended to perform activities requiring deep knee flexion postoperatively. To eliminate bias of different preoperative flexion values, flexion change was studied, with adjustments for preoperative values. Also, subgroups with preoperative flexion less than 125° and 125° or more were studied separately. Also, the study could not compare the 3 designs in 1 time frame because they have been progressively developed and introduced for use. Thus, the senior author selected the first consecutive cases of each design group operated on by him.

**CONCLUSION**

The cruciate-substituting designs of rotating-platform implants (ΣRP and ΣRPF) produced better postoperative flexion than did the cruciate-sacrificing design of rotating-platform implant (LCS). The ΣRP, despite less preoperative flexion ($P = .004$), achieved postoperative flexion statistically better than that with the LCS ($P < .001$). Considering subgroups with comparable preoperative flexion, no statistical difference was found in the postoperative flexion achieved between the ΣRP and the ΣRPF.

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| Table 6 Postoperative Flexion of Patients With Preoperative Flexion 125° or More |
|---------------------------------|---------|--------|------|
| Prosthesis                  | n   | Mean Postoperative Flexion, deg | P     | Inference                  |
| LCS                          | 6   | 125±6.3                        |       |                             |
| ΣRP                         | 5   | 132±13.0                       | .4162 | Insignificant difference   |
| ΣRPF                        | 34  | 130±9.4                        |       |                             |

Abbreviations: deg, degrees; LCS, Low Contact Stress (DePuy Orthopaedics, Inc, Warsaw, Indiana); ΣRP, PFC Sigma RP (DePuy Orthopaedics, Inc); ΣRPF, PFC Sigma RPF (DePuy Orthopaedics, Inc).


