Low-Contact-Stress Knee Arthroplasty: Past History or Ahead of Time?

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abstract

Low-contact-stress mobile-bearing (MB) total knee arthroplasty (TKA) can rely on a long history. Its concept comprises a combination of high condylar congruency and compensatory bearing rotation to promote load sharing. However, other MB designs have become available, and critical points have been raised about the benefit of MB in general. Although there is kinematic and kinetic support for the low-contact-stress concept, there is no tribologic or clinical proof of its superiority over fixed-bearing concepts. Further study should be controlled for differences in polyethylene quality and need to provide a measure of condylar congruency to differentiate authentic low-contact-stress variants from others. [Orthopedics. 2016; 39(3):e402-e412.]

In 2002, the 25th anniversary of mobile-bearing (MB) total knee arthroplasty (TKA) was celebrated with a book and a supplement edition of this journal. Excellent clinical outcome and prosthesis survivorship of Low Contact Stress (LCS) knee cohorts were published. The results may have encouraged MB users, but the question is what really determines a surgeon’s preference for using an MB design instead of a more commonly used fixed-bearing (FB) design. Is it because these surgeons recognize an important role of axial mobility in the human knee? Certainly, our ancestors, millennia ago, required a certain knee mobility, but one could argue whether the preservation of axial rotation becomes a moot point in current prosthetic replacement. Is it because surgeons hope to benefit from the natural accommodation of femorotibial alignment through a rotating bearing? These surgeons also would have to overstep a fear of possible bearing dislocation, although with current instrumentation and technical knowledge, this complication no longer appears to be an issue. Finally, is it that current MB users still believe that the underlying concept maximizes long-term prosthesis survival? This potential benefit is especially appealing for younger and more demanding patients. Polyethylene (PE) wear might be less of a problem with further improvement of material properties; however, the problem of aseptic loosening is still a concern in current TKA. New results regarding kinematics, kinetics, tribologics, and clinical outcome of TKA have become available since 2002. These results either support or criticize the use of MB. The question arises whether MB, originally being part of the low-contact-stress concept, should have a place in future TKA development.

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CONCEPT: HAVE FUNDAMENTAL DESIGN PRINCIPLES OF THE ORIGINAL LCS BEEN CHANGED?

First 25 Years

To reduce failures and complications, many modifications in TKA design were introduced during the 1970s. Researchers realized the need to provide rotation to the prosthetic knee. Natural knee characteristics served as a prototype to design bearing properties consistent with an extended service life. The use of MB elements allowed development of devices that served 2 competing requirements: adequate mobility and wear resistance. The use of meniscal or rotating bearing elements would allow both mobility and congruency, producing low constraint forces and low contact stresses.

The New Jersey LCS knee (DePuy, Warsaw, Indiana) generally is acknowledged as the first MB knee, but it actually was a merge of femoral component properties of the total condylar prosthesis and tibial components resembling those of the Oxford knee. Two important design features were new: (1) the decreasing posterior femoral condylar radius provided flexion mobility, and (2) in case of the absence of cruciate ligaments, the rotating platform (RP) was placed in a posterior tilt to provide anteroposterior (AP) stability (Figure 1).

The results of the LCS in the 1980s with primarily meniscal bearings were good, but with the passage of time, it appeared that the cruciate-substituting RP device (LCS Classic; DePuy [1977-2006]) was not only easier to implant, but also yielded better survivorship with fewer complications. Further enhancements to the LCS since Food and Drug Administration approval of the prosthesis in 1985 were mainly to facilitate instrumentation (LCS Universal; DePuy [1985-2006]). The latest version of the LCS RP knee has a higher and slimmer flange (LCS Complete; DePuy Synthes [since 2001]), but the articular geometry of the femoral component has not been altered to ensure a 0.99 congruency ratio with the PE bearing surface.

Development Since 2002

Although recognizing the need to decrease fatigue wear in younger, more active patients, Callaghan et al10 questioned the enthusiasm for MB designs based on only a few intermediate follow-up reports then available. They suggested better control of bearing mobility patterns to reduce fluoroscopically observed paradoxical motion. Greenwald and Heim11 also acknowledged an increased global interest in the use of MB. They posited that its future success would be dependent on the adequacy of congruency manufacturing, bearing material properties, and soft tissue balancing technique. Critical points include the following: longer follow-up, patterns of mobility, condylar congruency, bearing material, and soft tissue balancing.

Longer Follow-Up. New results of the LCS series mentioned in the review by Callaghan et al10 have become available. The original series of RP knees by Buechel and Pappas12 still had 98% survival at 20 years (cemented) and 18 years (cementless). Sorrells et al13 republished the results of a series of cementless fixed LCS RP knees that were implanted between 1984 and 1995; however, instead of presenting longer follow-up, they up-
scaled the 12-year survival to 90%.

Cal laghan’s own series of cemented LCS RP knees went from zero revisions at 9 to 12 years to 97% survival at 20 years.

**Patterns of Mobility.** Callaghan’s review showed a high variability and a so-called reversed rotation pattern in RP knees similar to FB knees. Patterns of bearing rotation are influenced by placement of the rotation axis and availability of cruciate function. In a way, this discussion of patterns vs freedom of mobility seems similar to the “kinematic conflict,” which once ended the debate on the issue of posterior cruciate substitution regarding whether a prosthesis should imitate natural kinematics or whether the prosthesis should have a clinically successful design without full preservation of natural kinematics. Finally, even natural knee rotation seemed to have a high variability.

**Condylar Congruency.** The bearing upper-surface articular congruency and under-surface mobility are the paramount factors in the low-contact-stress concept. The result is a dual-surface mobility in which both surfaces of the bearing would wear less than the single surface in an FB concept in which higher peak stresses are realized (Figure 2). Heim et al expressed this nicely in constraint-displacement graphs (Figure 3). Their results revealed that in 9 MB designs, the amount of AP and mediolateral condylar displacement was highly variable. Actually, only 2 designs were categorized as truly unconstrained in the transverse plane and constrained in the coronal and sagittal planes.

**Bearing Material.** The reduction of articular wear is one potential advantage of the principle of load sharing in MB knees. Reduction of loosening stresses on the implant-bone interface, by transferring torques and shear forces to the soft tissues, is another. Further improvement of PE quality would therefore only make a certain need for load sharing superfluous, if it were in combination with improved component fixation.

**Soft Tissue Balancing.** A conventional bone-referenced determination of sawcuts depends on eventually necessary ligament releases as the final step of the surgical procedure. Conversely, the ligament-referenced determination of sawcuts starts with releases, if necessary. Both techniques, whether performed in MB or FB knees, share the same goals of identical flexion and extension gaps, balanced collateral stability, and full knee extension. If executed well, bone- and ligament-referenced sawcuts could only result in difference of femoral component rotational alignment. This in turn appeared not to be associated with abnormal patellar tracking. The success of TKA depends on adequate surgical technique, but essentially this has nothing
to do with the difference between MB and FB variants.

**Kinematics: Does RP TKA Perform More Like a Natural Knee or Like FB TKA?**

**Natural Knee**

Although the knee often is referred to as a biomechanical complex joint, principles such as medial compartment pivoting, a posterior decreasing femoral radius, coupled tibial internal rotation and flexion, and the 4-bar-link mechanism of the cruciate ligaments have been known for more than a century. Freeman and Pinskirova explained the involved anatomy of knee mechanics based on in vivo magnetic resonance imaging studies. Arguable, however, is the authors’ suggestion of axial knee rotation being a vestigial movement in humans. Although bipedal stance in primates started only 3 to 4 million years ago, common anatomic and functional joint characteristics with tetrapods had persisted with only little modification for more than 300 million years. Humans may not have the functional demands of their arboreal predecessors, but walking from office to office and through a cafeteria still takes 45% to 50% of turning steps (Figure 4).

Healthy women have 77° and men have 62° of passive knee rotation at 30° of flexion under maximal torque in vivo. Fluoroscopic analysis showed that only 11° are used in the middle-third of the stance phase of gait. Higher demanding tasks, such as deep knee bending and chair sitting or rising, need approximately 15° of rotation between 0° and 45° of flexion. Further task complexity, for instance, adding a turn while moving from sitting to walking, increases the range of rotation from 14° to 21°.

**RP Versus FB TKA**

Stiehl et al published one of the earlier fluoroscopic studies on LCS RP knee kinematics. Individual maxima between 9.6° tibial internal rotation and 6.2° external rotation were measured during walking. It also appeared that a “normal screw-home” was present: the tibia rotated back from internal rotation when the knee extended. However, with a central axis of bearing rotation, normal medial pivoting was present in only 2 of 20 patients. Haas et al compared the LCS RP posterior cruciate (PC)-sacrificing knee with an FB knee; they found less AP translation and less femoral condylar lift-off in the LCS. These findings support the high articular congruency design of the low-contact-stress concept, provided that most of the axial rotation happened at the bearing under-surface. Dennis et al showed that bearing rotation was 8.6° at the under-surface and 3.6° at the upper-surface during a knee bend.

Dennis et al determined axial rotation magnitudes and patterns during deep knee maneuvers in healthy adults and patients with many variences of implant design. The average degree of axial femorotibial rotation was 17.8° in 10 healthy knees, 15.1° in 10 anterior cruciate (AC)-retaining FB knees, 9.2° in 163 PC-retaining FB knees, 11.4° in 157 PC-retaining MB knees, 7.6° in 212 PC-substituted FB knees, and 9° in 157 PC-substituted MB knees. A total of 76 LCS knees, being a PC-sacrificing MB knee, had an average of 7.6° of axial rotation. Besides these similar magnitudes between implant groups, the authors found a substantial variability within each group. They originally hypothesized that different magnitudes and patterns would occur because of alterations of cruciate function and femoral congruency. They concluded, however, that individual patient and surgeon factors also could determine axial rotation. The authors suggested a limitation of the study was that higher demanding maneuvers other than knee bends were not tested. More comparative in vivo fluoroscopic studies on RP and FB axial rotation have been published (Table 1). Their group sizes were smaller, but implant design and surgeon factors were similar.

At this point, it is important to realize that the terms “mobile bearing” or “rotating platform” are not synonymous for “low contact stress.” Kinematic variances between RP designs may depend on the extent of congruency between the bearing upper-surface and femoral component. Condylar congruency in the Sigma knee (DePuy Synthes) was described in one study in terms of “tibiofemoral contact area” (400 mm² in the MB vs 200 mm² in the FB design). Another study with Performance knees (Zimmer Biomet, Warsaw, Indiana) mentioned “more concavity in both the sagittal and coronal plane,” and in a study with NexGen knees (Zimmer Biomet), it was noted that the “articulating radii” were different (1:1.05 in MB and 1:1.07 in FB). A uniform measure of condylar congruency would be practical to compare results and classify on authenticity in relation to the low-contact-stress concept. Also, the exact position of the bearing under-surface rota-
Some of these mentioned studies showed more overall axial femorotibial rotation in MB vs FB TKA. Because full restoration of rotation is strictly non-relevant for the functioning of the LCS concept, one might discuss whether it is even desirable to have a closer to natural amount of rotation. Knee bend studies showed higher rotation with higher flexion, but this could be because higher flexion also means loss of condylar congruency. As far as surface and interface stresses are concerned, rotational provocation in the lower flexion ranges may be more relevant than realized. Most walking with or without slopes and sitting up and down actually takes place within the first 20° of knee flexion. From a finite element study, it also appears that in the lower flexion ranges, the primary contributor in knee replacement mechanics is torsional load. Instead of studying knee bends, which focus on flexion, turning provocative and other daily living-related task loads may need to be studied.

**KINETICS: DOES LOAD SHARING LEAD TO REDUCED LOOSENING STRESS?**

In 1978, Werner et al noted that the possible effect of applied torque on prosthetic loosening had received little attention. Given the small number of kinetic studies on TKA, this is still the case. They showed with an in vitro model that the more unconstrained a prosthetic device was, the less transmitted torque was measured at a certain axial rotation under a certain compressive load. This transmitted torque was proportional to the amount of load through the capability of the soft tissues around the knee to absorb energy. The degree to which an implant substitutes for ligaments indicates the degree to which rotational stresses will be absorbed in the bone-cement interface. In other words, by removing the original articular surfaces and some of the extrinsic stabilizers (ie, cruciate ligaments), followed by implantation of a prosthesis, the direction of the forces and spread of load around the knee may be influenced considerably (Figure 5).

To predict how knee implants will perform considering muscle, ligament, and contact forces altogether, either telemetry or mathematical modeling is available. The best possible solution for determining in vivo loads in the human knee should use both approaches. Otto et al performed both an in vitro experiment and finite element analysis on RP LCS knees. Like Werner et al, they found a linear relationship between transmitted torque and torsional load, with peak values extending into the levels for walking in healthy adults. Beyond 15° of knee flexion, a bearing rotation lag and decrease of bearing upper-surface contact area happened as a result of the transition from a large to smaller radius in the femoral condyle.

Sharma et al used fluoroscopy-derived kinematic data and force-plate-derived kinetic data from 2 groups of patients: 5 with an FB and 5 with an RP TKA. Other than bearing mobility and coronal plane congruency, both designs were identical. The results were integrated in a model to compare the in vivo contact pressures during a knee bend; the RP group experienced higher contact areas and lower contact pressures.
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Review Article

Table 2

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TRIBOLOGIES: DOES THE LOW-CONTACT-STRESS CONCEPT REDUCE PE WEAR?

Where constraint forces are a risk factor for loosening, articular contact stresses lead to PE wear. The concept of using a mobile bearing is to reduce contact stress due to higher articular congruency without increasing bone-implant constraint forces.\(^{6,10}\) Polyethylene quality may improve in the future; nevertheless, design factors with a potential for enhanced PE longevity should require continued analysis.\(^{53,54}\) This is not only because the incidence of implantation of TKA in younger patients is increasing, but also because life expectancy is increasing as well as activity demand.

Retrieval studies are able to determine the mechanisms of wear and can retrospectively indicate the wear performance of a particular design.\(^{55}\) Ho et al\(^{56}\) found more low-grade wear (eg, burnishing, abrasion, and cold flow) and less high-grade wear (eg, scratching, pitting, metal embedding, and delamination) in LCS RP vs Miller-Galante (Zimmer, Warsaw, Indiana) revision cases. They found no asymmetric wear in the LCS knees. Berry et al\(^{57}\) found less wear rate in RP vs FB Sigma knees; surprisingly, they found even less wear rate in FB counterparts with a polished tibial tray, suggesting backside wear as being the main factor. Stoner et al\(^{58}\) found no advantage in RP over FB retrieved knees.

To determine the long-term durability of new designs and materials, a reliable and valid simulator is required.\(^{55}\) McEwen et al\(^{59}\) were the first to systematically study motion, design, and material variables using physiological in vitro simulator testing. They found a 4-fold reduction in wear rate in LCS and Sigma RP prostheses compared to the Sigma FB prosthesis. Delport et al\(^{60}\) also found a 4-fold lower wear rate in the Performance RP knee compared to the Performance FB knee with identical PE quality. Grupp et al\(^{61}\) demonstrated no significant differences in overall wear rate between RP and FB Columbus knees (Aesculap AG, Tuttingen, Germany), although a substantial reduction in the amount of wear per area gliding surface in favor of the mobile variant was observed.

The problem of comparison between TKA variants, with differences other than only bearing mobility, was clearly illustrated by Utzschneider et al.\(^{62}\) All cross-linked PE bearings in their study showed reduced wear rates as opposed to conventional ultra-high-molecular-weight PE bearings. One cross-linked PE FB knee showed a significantly lower wear rate than 3 other cross-linked PE knees, including one RP variant, but all of them differed in the PE manufacturing process (Table 2). Material superiority also was shown in an in vivo study on PE wear particles. The prosthesis representing the highly cross-linked PE group showed by far the lowest number in wear particles.\(^{63}\) Although an improvement in material quality may be the most relevant factor in decreasing wear, a clear comparison of prosthetic designs and concepts in future studies necessitates harmonization of material quality.

CLINICAL RESULTS: IS THERE ANY BENEFIT OF LOW-CONTACT-STRESS TKA?

Clinical Outcome

Recent systematic reviews have shown no difference between MB and FB TKA at short- and mid-term follow-up. Van der Bracht et al\(^{64}\) criticized the methodologic quality of orthopedic studies in general, though, and pointed out that no conclusion could be made as far as prosthesis survival was concerned because of using relatively small sample sizes. Smith et al\(^{65}\) also stated that the theoretical advantage of implant longevity in MB TKA could not be excluded without longer follow-up.

Wen et al\(^{66}\) questioned whether the evidence was sufficient to make firm conclusions about the efficacy of MB TKA
at all for several reasons. The first reason was because of a high variability of prosthetic design other than just bearing mobility, the second reason was because of inadequate duration of follow-up, and the third was because of a possible age selection bias as most of the included patients were older patients who were relatively inactive and required a lower quality of life. The authors presented a table to describe all of the studies included in their meta-analysis. Carothers et al performed a meta-analysis of RP TKA with vs without AP gliding option. They found no clinically significant differences, similar high prosthesis survival rates, and similar low bearing complications. In another study, Van der Voort et al found no clinically relevant differences in terms of revision rates, range of movement, clinical scores, and radiographic parameters. In a meta-analysis of 24 studies comparing clinical and radiographic results between MB and FB TKA, Li et al only found a significantly lower pain score in the MB group.

Bilateral studies have the advantage of minimizing patient, surgeon, and observer-related bias. Bhan et al compared the LCS RP vs the Insall Burnstein-II knee (Zimmer) in 32 patients; mean patient age was 63 years at the time of surgery, and mean follow-up was 6 years. Clinical and radiographic outcomes showed no difference; no revisions were performed for loosening or wear. Kim et al compared the LCS RP with the Anatomic Modular Knee (DePuy) in 108 patients; mean age was 45 years at the time of surgery, and mean follow-up was 16.8 years. There was no difference in clinical outcome and survivorship (endpoint, “revision for any reason”).

Table 2

Example of Material Specifications of Total Knee Implants Tested in a Wear Simulation Study

<table>
<thead>
<tr>
<th>Material Combination</th>
<th>Study Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knee design</td>
<td>A</td>
</tr>
<tr>
<td>Scorpio®</td>
<td>CoCr alloy (ASTM F-75)</td>
</tr>
<tr>
<td>Natural Knee® II</td>
<td>CoCr alloy (ASTM F-75)</td>
</tr>
<tr>
<td>Femoral material composition</td>
<td>GUR® 1020 XLPE</td>
</tr>
<tr>
<td>Tibial material composition</td>
<td>GUR® 1020 XLPE</td>
</tr>
<tr>
<td>Bearing type</td>
<td>Fixed</td>
</tr>
<tr>
<td>Insert design</td>
<td>Cruciate retaining</td>
</tr>
<tr>
<td>Height of insert, mm</td>
<td>24</td>
</tr>
<tr>
<td>Type of polyethylene</td>
<td>GUR® 1020 XLPE</td>
</tr>
<tr>
<td>Manufacturing process</td>
<td>Annealed sequential irradiated (X3™) 3×30 kGy Gamma Gasplasma</td>
</tr>
</tbody>
</table>

Abbreviations: Al, aluminum; ASTM, American Society for Testing and Materials; Co, cobalt; Cr, chromium; kGy, kilogram; Ti, titanium; UHMWPE, ultra-high-molecular-weight polyethylene; V, vanadium; XLPE, crosslinked polyethylene.

Loosening, Osteolysis, and Survival

Dalury et al reported that 24% of late revisions were the result of loosening but noted the “burden” of PE wear, aseptic loosening, and osteolysis altogether was 66%. The Knee Society created a standardized list of TKA complications. Os- teolysis was defined as an “expansive lytic lesion adjacent to one of the implants of I
<table>
<thead>
<tr>
<th>Femoral Component</th>
<th>Tibial Component</th>
<th>No. Revised</th>
<th>Total No.</th>
<th>5 Years CPR</th>
<th>10 Years CPR</th>
<th>13 Years CPR</th>
</tr>
</thead>
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<tr>
<td>AGC</td>
<td>AGC</td>
<td>146</td>
<td>3451</td>
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<td>5.4 (4.6-6.5)</td>
<td>6.5 (5.3-8.0)</td>
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<td>Active Knee</td>
<td>Active Knee</td>
<td>27</td>
<td>1077</td>
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<tr>
<td>Advance</td>
<td>Advance II</td>
<td>48</td>
<td>896</td>
<td>5.1 (3.7-7.0)</td>
<td>8.1 (6.0-11)</td>
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<tr>
<td>BalanSys</td>
<td>BalanSys</td>
<td>16</td>
<td>898</td>
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<td>4.8 (2.6-8.8)</td>
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<tr>
<td>Duracon</td>
<td>Duracon</td>
<td>377</td>
<td>8971</td>
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<td>4.8 (4.4-5.4)</td>
<td>6.4 (5.5-7.5)</td>
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<tr>
<td>Evolis</td>
<td>Evolis</td>
<td>6</td>
<td>599</td>
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<tr>
<td>Genesis II CR</td>
<td>Genesis II</td>
<td>338</td>
<td>11253</td>
<td>3.2 (2.9-3.6)</td>
<td>4.3 (3.8-4.8)</td>
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<tr>
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<td>Profix Mobile</td>
<td>24</td>
<td>490</td>
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<tr>
<td>Genesis II Oxinium CR</td>
<td>Genesis II</td>
<td>234</td>
<td>5924</td>
<td>3.6 (3.1-4.2)</td>
<td>6.1 (5.2-7.2)</td>
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<tr>
<td>Genesis II Oxinium PS</td>
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<td>493</td>
<td>11510</td>
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<td>7.8 (6.8-9.0)</td>
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<td>5.4 (4.7-6.1)</td>
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<td>Journey</td>
<td>Journey</td>
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<td>3132</td>
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<td>Kinemax Plus</td>
<td>Kinemax Plus</td>
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<td>7.1 (6.3-8.0)</td>
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<td>5.4 (4.6-6.4)</td>
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<td>2.3 (1.3-4.2)</td>
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<tr>
<td>Legion Oxinium PS</td>
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<td>4020</td>
<td>3.8 (2.9-5.1)</td>
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<td>Maxim</td>
<td>Maxim</td>
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<td>499</td>
<td>4.7 (3.2-7.1)</td>
<td>7.0 (4.8-10)</td>
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<tr>
<td>Natural Knee Flex</td>
<td>Natural Knee II</td>
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<td>787</td>
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<td>Natural Knee II</td>
<td>Natural Knee II</td>
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<td>1678</td>
<td>1.9 (1.3-2.8)</td>
<td>3.8 (2.7-5.3)</td>
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<tr>
<td>Nexgen CR</td>
<td>Nexgen</td>
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<td>3535</td>
<td>1.7 (1.3-2.2)</td>
<td>2.7 (2.2-3.4)</td>
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</tr>
<tr>
<td>Nexgen CR Flex</td>
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<td>11390</td>
<td>1.9 (1.6-2.3)</td>
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<tr>
<td>Nexgen LCCK</td>
<td>Nexgen</td>
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<td>449</td>
<td>5.4 (3.3-8.9)</td>
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<td>Nexgen LPS</td>
<td>Nexgen</td>
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<td>5118</td>
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<td>4.7 (4.1-6.4)</td>
<td>5.6 (4.7-6.7)</td>
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<td>Nexgen LPS Flex</td>
<td>Nexgen</td>
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<td>21737</td>
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<td>5.3 (4.8-5.8)</td>
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<td>Optetrak-PS</td>
<td>Optetrak</td>
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<td>2078</td>
<td>6.9 (5.8-8.3)</td>
<td>10.4 (8.3-13)</td>
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<td>Optetrak-PS</td>
<td>Optetrak-RBK</td>
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<td>567</td>
<td>6.6 (4.6-9.4)</td>
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<td>PFC Sigma CR</td>
<td>MBT</td>
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<td>1061</td>
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<td>3.0 (1.7-5.2)</td>
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<td>219</td>
<td>9584</td>
<td>2.4 (2.1-2.8)</td>
<td>4.0 (3.3-4.8)</td>
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<td>PFC Sigma PS</td>
<td>MBT</td>
<td>159</td>
<td>5219</td>
<td>3.5 (3.0-4.1)</td>
<td>4.7 (3.9-5.8)</td>
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<tr>
<td>PFC Sigma PS</td>
<td>PFC Sigma</td>
<td>171</td>
<td>6238</td>
<td>2.9 (2.5-3.4)</td>
<td>4.2 (3.5-5.2)</td>
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<tr>
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<td>Profix</td>
<td>133</td>
<td>3285</td>
<td>3.2 (2.7-3.9)</td>
<td>4.8 (4.0-5.7)</td>
<td>4.9 (4.1-5.9)</td>
</tr>
<tr>
<td>Profix Oxinium</td>
<td>Profix</td>
<td>76</td>
<td>999</td>
<td>6.9 (5.4-8.7)</td>
<td>8.5 (6.8-11)</td>
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<tr>
<td>RBK</td>
<td>RBK</td>
<td>53</td>
<td>1890</td>
<td>3.4 (2.5-4.5)</td>
<td>5.2 (3.4-8.1)</td>
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<tr>
<td>Scorpio CR</td>
<td>Series 7000</td>
<td>77</td>
<td>1757</td>
<td>3.0 (2.3-3.9)</td>
<td>5.1 (4.0-6.4)</td>
<td>6.4 (4.8-8.4)</td>
</tr>
<tr>
<td>Scorpio NRG CR</td>
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<td>16</td>
<td>964</td>
<td>1.8 (1.1-3.0)</td>
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<td></td>
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<tr>
<td>Scorpio NRG PS</td>
<td>Series 7000</td>
<td>43</td>
<td>2416</td>
<td>2.6 (1.9-3.6)</td>
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<td>Scorpio PS</td>
<td>Scorpio+</td>
<td>29</td>
<td>510</td>
<td>4.4 (2.9-6.7)</td>
<td>6.7 (4.6-9.7)</td>
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<tr>
<td>Scorpio PS</td>
<td>Series 7000</td>
<td>53</td>
<td>900</td>
<td>5.7 (4.3-7.4)</td>
<td>6.4 (4.9-8.4)</td>
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</tbody>
</table>
Table 3 (cont’d)

Cumulative Percent Revision of Primary TKA With Cement Fixation

<table>
<thead>
<tr>
<th>Femoral Component</th>
<th>Tibial Component</th>
<th>No. Revised</th>
<th>Total No.</th>
<th>5 Years CPR</th>
<th>10 Years CPR</th>
<th>13 Years CPR</th>
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<tr>
<td>Triathlon CR</td>
<td>Triathlon</td>
<td>304</td>
<td>16914</td>
<td>2.8 (2.4-3.1)</td>
<td>3.9 (3.2-4.8)</td>
<td>1.6 (0.7-3.4)</td>
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<tr>
<td>Triathlon PS</td>
<td>Triathlon</td>
<td>122</td>
<td>4118</td>
<td>2.9 (2.3-3.8)</td>
<td>6.0 (5.0-7.3)</td>
<td>8.5 (7.6-9.4)</td>
</tr>
<tr>
<td>Vanguard CR</td>
<td>Maxim</td>
<td>75</td>
<td>4447</td>
<td>1.6 (0.7-3.4)</td>
<td>1.6 (0.7-3.4)</td>
<td>1.6 (0.7-3.4)</td>
</tr>
<tr>
<td>Vanguard PS</td>
<td>Vanguard</td>
<td>118</td>
<td>2692</td>
<td>5.6 (5.0-6.2)</td>
<td>8.5 (7.6-9.4)</td>
<td>9.5 (8.5-11)</td>
</tr>
<tr>
<td>Other (168)</td>
<td>Maxim</td>
<td>414</td>
<td>8914</td>
<td>5.6 (5.0-6.2)</td>
<td>8.5 (7.6-9.4)</td>
<td>9.5 (8.5-11)</td>
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<tr>
<td>Total</td>
<td></td>
<td>6606</td>
<td>207,071</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Abbreviations: CPR, cumulative percent revision; TKA, total knee arthroplasty.

**Note:** Only combinations with over 400 procedures and a minimum of 5 years of follow-up have been listed.


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CM or more in any dimension or increasing in size on serial radiographs/CT [computed tomography].” There is a certain similarity with aseptic loosening, defined as “implant loosening confirmed intraoperatively or identified radiographically as a change in implant position or a progressive, radiolucent line at the bone-cement or bone-implant interface.” Osteolysis and aseptic loosening share a common multifactorial pathogenetic mechanism, existing of load, hydrostatic pressure, and particle disease. Kim et al. compared osteolysis in RP vs FB knees, using radiographs and CT. One cohort in the FB group consisted of 350 NexGen knees in patients who underwent surgery at a mean age of 58 years and had mean follow-up of 11 years. One RP cohort consisted of 336 LCS knees in patients who underwent surgery at a mean age of 57 years with 13 years of follow-up. Both groups had a prosthesis survivorship of 98% and 0% osteolysis.

In the same spectrum as osteolysis and loosening, but not yet acknowledged by The Knee Society’s list, is micromotion detected by radiostereometric analysis (RSA). Pijs et al. performed a randomized clinical trial comparing the RP vs the FB variant of the Interax knee (Stryker-Howmedica, Rutherford, New Jersey). Using RSA, the authors found both knees had comparable migration during 10 to 12 years of follow-up. A quantified description of a “higher (condylar) congruency” in the MB Interax prosthesis was not given, but as shown in **Figure 3**, this design does not fully meet the low-contact-stress criteria. One other RSA micromotion study has been performed on an RP knee. Tjørnild et al. randomized a series of patients with RP and FB variants of the PFC knee and found significant higher implant migration in the FB group.

In a systematic review containing 21,000 TKAs, a clinically relevant association between early migration and late revision for loosening was found. The authors proposed a migration threshold in phased, evidence-based introduction of new types of knee prostheses to detect high-risk designs early. Another way to detect poor performing “outliers” in terms of prosthesis survivorship is the use of national implant registries. The Australian Orthopaedic Association National Joint Replacement Registry contains 12,446 cemented, 22,428 cementless, and 10,123 hybrid LCS knees among a total of 396,472 primary TKAs. With a 5.4-year cumulative percent revision (CPR) at 10 years postoperatively, the LCS appeared not to live up to its theoretic potential of having the highest survival; there was no adjustment for age, PE quality, or reason for revision. The RP PFC Sigma, on the other hand, scored second best with 3.0 CPR at 10 years postoperatively (**Table 3**).

**Conclusion**

Low-contact-stress RPTKA comprises a combination of high condylar congruency and compensatory subsurface bearing rotation to promote the concept of load sharing. In more than 35 years of experience with the LCS knee, there is kinematic and kinetic support for the functioning of this concept, which potentially reduces PE wear and aseptic loosening. However, the issue of wear may be overtaken by improved PE quality, and a potentially higher prosthetic survival would have to be proven with follow-up study longer than 20 years. Midterm results did not show a clinical benefit of RP vs FB TKA. Future comparison studies between different RP or other MB variants should use a uniform quantifying measure of condylar congruency to discriminate original low-contact-stress from other concepts. Wear rate studies between MB and FB variants should be controlled for any difference in PE quality. Mechanical comparison between different TKA concepts ideally should be
based on in vivo derived kinematic and kinematic parameters that are acquired under 3-dimensional loading conditions and integrated in a mathematical model.

References


