LITERATURE REVIEW

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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 of a combination of high condylar congruency and compensatory bearing rotation to promote loadsharing. However, other MB designs have become available and critical points have been raised about the benefit of MBs 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 form others.

INTRODUCTION

In 2002 the 25th anniversary of mobile-bearing (MB) total knee arthroplasty (TKA) was celebrated with a book¹ and a supplement edition of this journal.² Excellent clinical outcome and prosthesis survivorship of Low Contact Stress (LCS) knee cohorts were published.³⁴ The results may have encouraged MB users, but the question is what really determines a surgeons’ preference for using a MB 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 nowadays
prosthetic replacement. Is it because surgeons hope to benefit from the natural accommodation of femorotibial alignment through a rotating bearing? These surgeons would also have to overstep a fear of possible bearing dislocation, although with the current instrumentation and technical knowledge this complication appears not to be an issue anymore. 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 our younger and more demanding patients. Polyethylene (PE) wear might be lesser of a problem with further improvement of material properties, however, the problem of aseptic loosening is still a concern in nowadays TKA. New results regarding kinematics, kinetics, tribologics and clinical outcome of TKA have become available since the year 2002. These results either support or criticize the use of MB. The question rises, whether MB, originally being part of the low-contact-stress concept, should have a place in future TKA development.

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

First 25 years
In order to reduce failures and complications, many modifications in TKA design were introduced during the seventies. Researchers realized the need to provide rotation to the prosthetic knee. Natural knee characteristics served as prototype to design bearing properties consistent with an extended service life. The use of MB elements allowed development of devices
that served two competing requirements: adequate mobility and wear resistance.\textsuperscript{6} 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 is generally acknowledged as the first MB knee, but it actually was a merging of femoral component properties of the Total Condylar Prosthesis and tibial components resembling those of the Oxford knee.\textsuperscript{7} Two important design features were new: firstly, the decreasing posterior femoral condylar radius to provide flexion mobility; secondly, in case of the absence of cruciates, the rotating-platform (RP) placed in a posterior tilt to provide anterioposterior stability (Figure 6.1).\textsuperscript{8} The results of the LCS in the eighties with mostly meniscal bearings were good, but with the passage of time it appeared that the cruciate substituting RP device (LCS Classic, 1977-2006) was not only easier to implant, but also yielded better survivorship with fewer complications.\textsuperscript{5} Further enhancements, since Food and Drug Administration approval in 1985, were mainly to facilitate instrumentation (LCS Universal, 1985-2006). The latest version of the LCS RP knee has a higher and slimmer flange (LCS Complete, since 2001), but the articular geometry of the femoral component had not been altered to ensure a 0.99 congruency ratio with the PE bearing surface.\textsuperscript{9}

**Development since 2002**

Although recognizing the need to decrease fatigue wear in younger more active patients, Callaghan et al. questioned the enthusiasm for MB designs based on just a few intermediate follow-up reports then available.\textsuperscript{10} They suggested better control
of bearing mobility patterns to reduce fluoroscopically observed paradoxical motion. Greenwald and Heim also acknowledged an increased global interest in the use of MB.\textsuperscript{11} They posted that its future success would be dependent on the adequacy of congruency manufacturing, bearing material properties and soft tissue balancing technique. Let us step-wise focus on each of these critical points:

1. Longer follow-up. New results of the LCS series mentioned in Callaghan’s review have become available. Buechel and Pappas’ original series of RP knees\textsuperscript{12} still had 98 percent survival at 20 years (cemented) and 18 years (cementless), respectively.\textsuperscript{3} Sorrells et al. republished the results of a series of cementless fixated LCS RP knees, which were implanted between 1984 and 1995.\textsuperscript{13} However, instead of presenting longer follow-up, they upscaled the 12-years survival to 90 percent.\textsuperscript{14} Callaghan’s own series of cemented LCS RP knees went from zero revisions at 9-12 years\textsuperscript{15} to 97 percent survival at 20 years.\textsuperscript{16}

2. Patterns of mobility. Callaghan’s review showed a high variability and a so-called reversed rotation pattern in RP knees like in 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 versus freedom of mobility seems similar to the ‘kinematic conflict’,\textsuperscript{18} which once ended the debate on the issue of posterior cruciate substitution: do we want a prosthesis imitating natural kinematics or do we want a clinically successful design without full preservation of natural kinematics. Finally, even natural knee rotation seemed to have a high variability.\textsuperscript{17}
3. 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 a FB concept in which higher peak stresses are realized (Figure 1.1). Heim et al. expressed this nicely in constraint-displacement graphs (Figure 6.2). Their results revealed that in nine MB designs the amount of anterior-posterior and medial-lateral condylar displacement was highly variable. Actually, only two designs were categorized as truly unconstrained in the transverse plane and constrained in the coronal and sagittal plane.19

4. Bearing material. The reduction of articular wear is one potential advantage of the principle of loadsharing in MB knees.19 Reduction of loosening stresses on the implant-bone interface, by transferring torques and shear forces to the soft tissues, is another. The further improvement of PE quality would therefore only make a certain need for loadsharing superfluous, if it were in combination with improved component fixation.

5. Soft tissue balancing. A conventional bone-referenced determination of sawcuts depends on eventually necessary ligament releases as the final step of the surgical procedure. On the opposite, 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
FIGURE 6.2. Force-displacement plots of two MB total knees. Reproduction from Heim et al.
only result in difference of femoral component rotational alignment.\textsuperscript{20} This in turn appeared not to be associated with abnormal patellar tracking.\textsuperscript{21} 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 Rotating Platform TKA Perform More Like a Natural Knee or Like Fixed Bearing TKA?**

**Natural knee**

Although the knee is often 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 four-bar-link mechanism of the cruciate ligaments have already been known for more than a century.\textsuperscript{22} Freeman and Pinskerova explained the involved anatomy of knee mechanics based on *in vivo* MRI studies.\textsuperscript{23} Arguable, however, is the authors’ suggestion of axial knee rotation being a vestigial movement in humans. While bipedestal stance in primates started only three to four million years ago, our common anatomic and functional joint characteristics with tetrapods had persisted with only little modification for more than 300 million years.\textsuperscript{24} Humans may not have the functional demands of their arboreal predecessors, but walking from office to office and through a cafeteria still takes 45-50 percent of turning steps (*Figure 6.3*).\textsuperscript{25}

Healthy women have 77 degrees and men have 62 degrees of passive knee rotation at 30 degrees of flexion under
maximal torque in vivo.\textsuperscript{26} Fluoroscopic analysis showed that only 11 degrees are used in the middle third of the stance phase of gait. Higher demanding tasks, such as a deep knee bending and chair sitting/rising, need around 15 degrees of rotation between 0-45 degrees of flexion.\textsuperscript{27} Further task complexity, for instance adding a turn while moving form sit-to-walk, increases the range of rotation from 14 to 21 degrees.\textsuperscript{28}

**Rotating platform versus fixed bearing TKA**

Stiehl et al. published one of the earlier fluoroscopic studies on LCS RP knee kinematics.\textsuperscript{29} Individual maxima between 9.6 degrees tibial internal rotation and 6.2 degrees external rotation were measured during walking. It also appeared that a ‘normal screw-home’ was present – tibia rotated back from internal rotation, when the knee extended. However, with a central axis of bearing rotation, normal medial pivoting was only present in two out of 20 patients. Haas et al.\textsuperscript{30} compared the LCS RP posterior cruciate (PC) sacrificing knee with a FB
knee, finding less anterioposterior 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 degrees at the under-surface and 3.6 degrees at the upper-surface during a knee bend.\textsuperscript{31} Dennis et al. determined axial rotation magnitudes and patterns during deep knee manoeuvres in healthy subjects and patients with many variances of implant design.\textsuperscript{32} Ten healthy knees showed an average amount of 17.8 degrees of axial femorotibial rotation, 10 anterior cruciate retaining FB knees 15.1 degrees, 163 PC retaining FB knees 9.2 degrees, 157 PC retaining MB knees 11.4 degrees, 212 PC substituted FB knees 7.6 degrees, and 157 PC substituted MB knees 9.0 degrees. A total of 76 LCS knees, being a PC sacrificing MB knee had an average of 7.6 degrees of axial rotation. Beside these similar magnitudes between implant groups, they found a substantial variability within each group. The authors 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 could also determine axial rotation. The authors suggested as limitation of the study, that not higher demanding manoeuvres than knee bends were tested. More comparative in vivo fluoroscopic studies on RP and FB axial rotation have been published (Table 6.1). Their group sizes were smaller, but implant design and surgeon factors were more similar.\textsuperscript{33-38}

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 rotating platform designs may depend on the extent of congruency between the bearing upper-surface and femoral component. Condylar congruency in the Sigma knee was described in one of the above mentioned studies in terms of ‘tibiofemoral contact area’ – 400 mm² in the MB versus 200 mm² in the FB design;33 ‘more concavity in both the sagittal and coronal plane’ was mentioned in the study with Performance knees;34 in the study with NexGen knees it was noted that the ‘articulating radii’ were different – 1:1.05 in MB and 1:1.07 in FB.35 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

**TABLE 6.1.** Summary of studies comparing in vivo axial knee rotation.

<table>
<thead>
<tr>
<th>Reference</th>
<th>N</th>
<th>Task</th>
<th>FB</th>
<th>MB</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dennis et al. 2004</td>
<td>212/76*</td>
<td>Knee band</td>
<td>7.6°</td>
<td>7.6°</td>
<td>NS</td>
</tr>
<tr>
<td>Ranawat et al. 2004</td>
<td>20/20</td>
<td>Knee band</td>
<td>3.8°</td>
<td>7.4°</td>
<td>0.01</td>
</tr>
<tr>
<td>Delport et al. 2006</td>
<td>10/10</td>
<td>Knee band</td>
<td>2.4°</td>
<td>7.5°</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>Shi et al. 2008</td>
<td>26/30</td>
<td>Passive knee bend</td>
<td>5.2°</td>
<td>7.9°</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Lui et al. 2009</td>
<td>11/7</td>
<td>Squat-to-stand</td>
<td>5°</td>
<td>5°</td>
<td>NS</td>
</tr>
<tr>
<td>Wolterbeek et al. 2011</td>
<td>8/7§</td>
<td>Step-up</td>
<td>8.3°</td>
<td>10.4°</td>
<td>NS</td>
</tr>
<tr>
<td>Zürcher et al. 2014</td>
<td>10/11</td>
<td>Sit-to-walk</td>
<td>11.7</td>
<td>21.0</td>
<td>0.002</td>
</tr>
</tbody>
</table>

N Number of fixed-versus mobile-bearing knees;
NS Not significant;
* Refers to posterior cruciate (PC) substituted variant versus PC sacrificing variant;
§ Refers to multiradius PC substituted variant versus multiradius PC sacrificing variant.
rotational axis may be of influence: the anteriorly placed axis in the NexGen may be the cause of lesser bearing mobility.

Some of the above mentioned studies showed more overall axial femorotibial rotation in MB versus FB TKA. Because full restoration of rotation is strictly nonrelevant 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 concern, rotational provocation in the lower flexion ranges may be more relevant than we realize. Most of our walking with or without slopes and sitting up and down actually takes place within the first 20 degrees of knee flexion. It also appeared from a finite element study, that in the lower flexion ranges the primary contributor in knee replacement mechanics was torsional load. Instead of knee bends, which focus on flexion, we may need to study turning provocative and other daily-living-related taskloads?

**KINETICS. DOES LOAD SHARING LEAD TO A REDUCTION OF LOOSENING STRESS?**

In 1978 Werner et al. wrote 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 currently 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 (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 6.4).44

To predict how knee implants will perform considering muscle, ligament and contact forces altogether, either telemetry or mathematical modelling is available. The best possible solution for determining *in vivo* loads in the human knee should

**FIGURE 6.4.** Example of a finite element stress diagram of the proximal tibia with a prosthetic component in situ. Compressive stresses were labelled red when indicating lack of stress, orange and yellow for low, green for moderate, and blue and gray for high stress. Reproduction from Witzel.
utilize 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 healthy subjects walking. Beyond 15 degrees 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 condyl. Sharma et al. used fluoroscopy derived kinematic data and force-plate-derived kinetic data from two groups of patients: five with a FB and five with a RP TKA. Other than bearing mobility and coronal plane congruency both designs were identical. They integrated the results 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. Bottlang et al. performed an in vitro experiment to record local strain magnitude and regional strain distribution on the proximal tibia after TKA. Under compressive loading only, there was no difference in cortical strain between the FB and RP variant of otherwise identical Scorpio knees. However, superimposing a torsional load induced less compressive local strain and less transmitted torque in the proximal tibia in the RP variant. This leads to the suggestion that RP TKA tolerates axial rotation better by transferring less shear strain to the bone-implant interface. Malinzak et al. came to the same conclusion in their in vitro study with RP and FB primary and revision PFC knees. In the RP variants transmitted torque under compressive loading conditions was lessened significantly, which resulted in significantly reduced cortical strains around the entire periphery of the proximal tibial cortex. The PFC knee derives from the same
company as the LCS knee and complies with the qualifications of the low-contact-stress concept.\textsuperscript{50} The LCS and PFC even may share the same tibial component, however, it is unclear whether both knees have a quantitative difference in articular congruency.

The role of torsional loading in the knee may have been underestimated. Being less than 10 Nm, internal-external rotation moments would not play a substantial role in loading the knee during walking.\textsuperscript{51} More recent studies have illustrated how turning steps significantly increase these moments.\textsuperscript{28,52} Many factors contribute to the ultimate result of long-lasting component fixation in TKA. After successful surgical implantation, the mechanical concept of the prosthesis and activity of the patient are probably the most important factors.\textsuperscript{44} The mechanical comparison between new prosthetic designs or concepts should be carried out under three-dimensional loading conditions, through \textit{in vivo} derived kinematic and kinetic parameters that are ideally integrated in a mathematical model.

**TRIBOLOGICS. DOES THE LOW CONTACT STRESS CONCEPT REDUCE POLYETHYLENE WEAR?**

Where constraint forces are a risk factor for loosening, articular contact stresses lead to PE wear. The concept of utilizing a mobile bearing is to reduce contact stress due to higher articular congruency without increasing bone-implant constraint forces.\textsuperscript{6,10} PE quality may further improve in the future, nevertheless, design factors with a potential for enhanced PE longevity should require continued analysis.\textsuperscript{53-54} This is not only because the incidence of
implantation of TKA in younger patients is increasing, but also because our life expectancy increases as well as our activity demands. Retrieval studies are able to determine the mechanisms of wear and can retrospectively indicate the wear performance of a particular design. Ho et al. found more low-grade wear (burnishing, abrasion, cold flow) and less high-grade wear (scratching, pitting, metal embedding, delamination) in LCS RP versus Miller-Galante revision cases. They found no asymmetric wear in the LCS knees. Berry et al. found less wear rate in RP versus 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. 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. McEwen et al. were the first to systematically study motion, design and material variables, using physiological *in vitro* simulator testing. They found a fourfold reduction in wear rate in LCS and Sigma RP variants, as compared to the Sigma FB variant. Delport et al. also found a fourfold lower wear rate in the RP variant of the Performance knee, compared to the FB variant with identical PE quality. Grupp et al. demonstrated no significant differences in overall wear rate between RP and FB Columbus knees, 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, is clearly illustrated by Utzschneider et al. All cross-linked PE bearings in their study showed reduced wear rates as opposed to conventional ultra-high mo-
molecular weight PE bearings. One cross-linked PE FB knee showed a significant lower wear rate than three other cross-linked PE knees, including one RP variant, but all of them differed in PE manufacturing process (Table 6.2). Material superiority was also shown in an in vivo study on PE wear particles. The prosthesis variant representing the highly cross-linked PE group showed by far the lowest number in wear particles.63 Although an improvement in

**TABLE 6.2.** Example of material specifications of total knee implants tested in a wear simulation study. Reproduction from Utschneider et al.

<table>
<thead>
<tr>
<th>Material</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knee design</td>
<td>Scorpio®</td>
<td>Natural Knee®</td>
<td>NexGen®</td>
<td>LCS® complete</td>
<td>LCS® complete</td>
<td>Natural Knee®</td>
</tr>
<tr>
<td>Femoral material</td>
<td>CoCr alloy (ASTM F-75)</td>
<td>CoCr alloy (ASTM F-75)</td>
<td>Zimaloy™ (CoCr alloy)</td>
<td>CoCr alloy (ASTM F-75)</td>
<td>CoCr alloy (ASTM F-75)</td>
<td>CoCr alloy (ASTM F-75)</td>
</tr>
<tr>
<td>Composition</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Femoral size</td>
<td>Large</td>
<td>4</td>
<td>D</td>
<td>Medium</td>
<td>Medium</td>
<td>4</td>
</tr>
<tr>
<td>Composition</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bearing type</td>
<td>Fixed</td>
<td>Fixed</td>
<td>Fixed</td>
<td>Mobile</td>
<td>Mobile</td>
<td>Fixed</td>
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<tr>
<td>Insert design</td>
<td>Cruciate retaining</td>
<td>Ultra-congruent</td>
<td>Cruciate retaining</td>
<td>Rotating platform</td>
<td>Rotating platform</td>
<td>Congruent</td>
</tr>
<tr>
<td>Tibial size</td>
<td>11</td>
<td>4</td>
<td>Yellow/C-H</td>
<td>Medium</td>
<td>Medium</td>
<td>4</td>
</tr>
<tr>
<td>Height of insert (mm)</td>
<td>24</td>
<td>19</td>
<td>14</td>
<td>15</td>
<td>15</td>
<td>13</td>
</tr>
<tr>
<td>Type of polyethylene</td>
<td>GUR® 1020 XLPE</td>
<td>GUR® 1020 XLPE</td>
<td>GUR® 1020 XLPE</td>
<td>GUR® 1020 XLPE</td>
<td>GUR® 1020 XLPE</td>
<td>GUR® 1050 conventional UHMWPE</td>
</tr>
<tr>
<td>Manufacturing process</td>
<td>Annealed sequential irradiated (X3™) 95 kGy E-beam Eto</td>
<td>Remelted (Durasul™) 65 kGy E-beam Gasplasma</td>
<td>Remelted (Prolong™) 50 kGy Gamma Gasplasma</td>
<td>20-40 kGy Gamma under vacuum in foil (GVF)</td>
<td>40 kGy Gamma</td>
<td></td>
</tr>
</tbody>
</table>

**XLPE** Crosslinked polyethylene;
**UHMWPE** Ultra-high molecular weight polyethylene.
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
Systematic reviews from recent years have shown that there is no difference between MB and FB TKA at short- and mid-term follow-up. Van der Bracht et al. criticized the methodological quality of orthopedic studies in general. They pointed out that no conclusion could be made as far as prosthesis survival was concerned, because of utilizing relatively small sample sizes. Smith et al. also stated that the theoretical advantage of implant longevity in MB TKA could not be excluded without longer follow-up. Wen et al. argued whether the evidence was sufficient to make firm conclusions about the efficacy of MB TKA at all. Firstly, because of a high variability of prosthetic design other than just bearing mobility. Secondly, because of inadequate duration of follow-up. Thirdly, because of a possible age selection bias — most of the included patients were elder patients who are relatively inactive and require lower quality of life. The authors presented a nice table to describe all studies included in their meta-analysis. Carothers et al. performed a meta-analysis of RP TKA with versus without anterioposterior gliding option (APG). They found no clinically significant differences, similar high prosthesis survival rates, and similar low bearing complications. Van der Voort et al. performed a study of MB versus FB TKA, indicating
no clinically relevant differences in terms of revision rates, range of movement, clinical scores and radiological parameters.\(^6^8\) Li et al. only found a significant lower pain score in favor of the MB group in a meta-analysis on 24 studies comparing clinical and radiographic results between MB and FB TKA.\(^6^9\)

Bilateral studies have the advantage of minimizing patient, surgeon, and observer-related bias. Bhan et al. compared the LCS RP versus the Insall Burnstein-II knee in 32 patients, operated on at a mean age of 63 years, and followed-up for a mean duration of 6 years.\(^7^0\) Clinical and radiographic outcome showed no difference. No revisions took place for loosening or wear. Kim et al. compared the LCS RP with the Anatomic Modular Knee in 108 patients, operated on at a mean age of 45 years, and followed-up for a mean of 16.8 years.\(^7^1\) There was no difference in clinical outcome and survivorship (endpoint ‘revision for any reason’). The authors mention that differences in wear and loosening remains to be proven with even longer follow-up. Close reading of the results revealed that four FB knees needed to be revised for loosening or wear, while there was no revision case for loosening or wear in the RP group. The same Korean group performed a bilateral study in a series of 444 patients with RP and FB variants of the PFC knee.\(^7^2\) They found no difference in clinical outcome and revision rate for aseptic loosening at 12 years follow-up (six RP versus eight FB revision cases).

**Loosening, osteolysis and survival**

Dalury et al. showed that 24 percent of late revisions were the result of loosening, but the ‘burden’ of PE wear, aseptic loosening and osteolysis altogether was 66 percent.\(^7^3\) The Knee Society created a standardized list of TKA complications.\(^7^4\) Osteolysis
was defined as an ‘expansive lytic lesion adjacent to one of the implants of one centimeter or more in any dimension or increasing in size on serial radiographs/CT’. 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 versus FB knees, using radiographs and CT. One cohort in the FB group consisted of 350 NexGen knees in patients operated on at a mean age of 58 years and followed-up for a mean duration of 11 years. One RP cohort consisted of 336 LCS knees in patients operated on at 57 years of age with 13 years follow-up. Both groups had a prosthesis survivorship of 98 percent and 0 percent 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). Pijls et al. performed a randomized clinical trial, comparing the RP versus the FB variant of the Interax knee. Using RSA they found that both knees had a comparable migration during ten to 12 years follow-up. A quantified description of a ‘higher (condylar) congruency’ in the MB Interax variant was not given, but we learned from Figure 6.3 that this design does not fully meet the low-contact-stress criteria. One other RSA micromotion study has been performed on a 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.

<table>
<thead>
<tr>
<th>Femoral Component</th>
<th>Tibial Component</th>
<th>Number</th>
<th>5 Years CPR</th>
<th>10 Years CPR</th>
<th>12 Years CPR</th>
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<tbody>
<tr>
<td>AGC</td>
<td>AGC</td>
<td>3470</td>
<td>3.4 (2.9, 4.2)</td>
<td>5.4 (4.5, 6.5)</td>
<td>6.6 (5.3, 8.2)</td>
</tr>
<tr>
<td>Duracon</td>
<td>Duracon</td>
<td>9283</td>
<td>3.3 (3.0, 3.7)</td>
<td>5.0 (4.5, 5.6)</td>
<td>5.7 (5.0, 6.6)</td>
</tr>
<tr>
<td>Genesis II</td>
<td>Genesis II</td>
<td>21919</td>
<td>3.7 (3.4, 4.0)</td>
<td>4.8 (4.4, 5.3)</td>
<td>5.0 (4.6, 5.6)</td>
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Only combinations with over 2500 procedures and a follow-up time of five or more years have been listed.
In a systematic review, containing 21,000 TKAs, a clinically relevant association between early migration and late revision for loosening was found. The authors propose a migration threshold in phased, evidence-based introduction of new types of knee prostheses to early detect high-risk designs. Another way to detect bad performing ‘outliers’ in terms of prosthesis survivorship is the use of national implant registries. The Australian Orthopaedic Association National Joint Replacement Registry contains 12446 cemented, 22428 cementless and 10123 hybrid fixated LCS knees amongst a total of 396472 primary total knee replacements. With a 5.4 years cumulative percent revision (CPR) at 10 years postoperatively, the LCS appeared not to live up to its theoretic potential of having the highest survival — 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 (Table 6.3).

**SUMMARY**

Low-contact-stress RP TKA comprises of a combination of high condylar congruency and compensatory subsurface bearing rotation to promote the concept of loadsharing. In over 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 in longer than 20-years-follow-up study. Mid-term results did
not show a clinical benefit of RP over FB TKA. Future comparison studies between different RP or other MB variants should utilize 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 polyethylene quality. Mechanical comparison between different TKA concepts should ideally be based on in vivo derived kinematic and kinetic parameters, which are acquired under three-dimensional loading conditions, which are to be integrated in a mathematical model.
REFERENCES


49. Malinzak RA, Small SR, Rogge RD, Archer DB, Oja JW, Berend ME, Ritter MA. The effect of rotating platform TKA on strain distribution and torque


