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Mobile-Bearing Knee Replacement: Concepts and Results

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Durable long-term fixation has been documented for many designs of fixed-bearing total knee replacement (TKR).[1-4] However, in the late 1970s and the early 1980s, implant fixation and poly-ethylene wear became recognized as long-term causes of late failure. Mobile-bearing knee replacements, with a poly-ethylene insert that articulates with a metallic femoral component and a metallic tibial tray, were designed to create a dual-surface articulation. This feature was intended to reduce the surface and subsurface stress states at the bearing surfaces and at the bone-implant surfaces by maximizing the conformity of the tibial and femoral components and allowing mobility of the bearing surface. We reserve the description "meniscal-bearing" is reserved for implants in which the femoral condyle is spherical and the bearing can function like its analogue in nature. These design features were developed to decrease the fatigue wear associated with failure of

the polyethylene in knee arthroplasty. Currently, there are few intermediate-term follow-up reports and no long-term follow-up reports, as far as we know, on the use of these devices, but almost every manufacturer of TKR components is developing a product that they hope to introduce to the market. In this chapter, the rationale for the use of mobile-bearing knee devices is explored and the clinical follow-up of these devices is updated. The clinical results of use of the Oxford unicompartmental replacement (Biomet, Warsaw, IN), the Low-Contact Stress knee replacement (LCS; DePuy, Warsaw, IN), and the Self-Aligning knee replacement (SAL; Sulzer, Austin, TX) are highlighted, because these devices have been followed for at least 5 years.

Why the Clinical Interest in Mobile-Bearing Knees?

Conventional fixed-bearing knee prostheses have proved to be clinically successful but with some reservations. In a study of 101 knees with such a prosthesis,[5] 96% had good-to-excellent clinical results, and the rate of survival of the prosthesis, with revision as the end point, was 96.4% after 10 to 15 years of follow-up.

However, there is an important caveat. Most of the patients involved in these follow-up studies have been elderly individuals with low activity levels, and thus low demands have been placed on the prosthesis. With a few exceptions,[1] there is little evidence that the same results could be duplicated in more active people. Also, even allowing for the preceding reservation, polyethylene wear and osteolysis remain important problems with current fixed-bearing knee prostheses.

Polyethylene Wear
There are two types of polyethylene wear. The first is articular wear, which was observed as a clinical problem in the 1980s and occurred in the so-called round-on-flat designs, which were popular then because they duplicated the normal motions of the knee. Round-on-flat designs, by definition, produce high contact stresses in the polyethylene.[6] When combined with sliding and skidding movements encouraged by an unconstrained articulation, these stresses lead to polyethylene damage and delamination, the particles from which can lead to osteolysis.[7,8]

The solution to this type of polyethylene wear is to design more conformity into the articulation (the so-called

round-on-round type of prosthesis). Because there is always a compromise between conformity and freedom of motion within the knee as articular contact stresses are reduced, a kinematic penalty is paid. The increased contact area reduces rotation. While lack of rotation may not be important for elderly patients, it is probably a drawback for younger, more active patients.[9-15]

The second type of polyethylene wear that has been recognized recently is undersurface wear,[16] which occurs between the polyethylene bearing and the tibial baseplate. Initially, tibial components had a monoblock construction; that is, the polyethylene was molded onto the tibial baseplate during manufacture. This type of design has yielded successful and durable long-term results. Unfortunately, increased sizing options have made modularity a virtual necessity so that at present, in most cases, the polyethylene is no longer attached to the tibial baseplate by the manufacturer but is fixed to the baseplate with some kind of locking mechanism by the surgeon during the surgery. No currently used locking mechanism is entirely reliable, and varying degrees of motion occur between the polyethylene and the baseplate. This motion can, of course, result in undersurface wear and the production of polyethylene particles. The problem is compounded because, for manufacturing reasons, the baseplate often is made of titanium and the surface is usually unpolished.

Mobile-Bearing Prostheses

On the basis of all of this information, it would appear that we are at a crossroad. There is little likelihood that additional refinement in the design of fixed-bearing knee prostheses can improve the current results and even less likelihood that it would resolve the aforementioned problems. It is impossible to envision a return to monoblock tibial components, given the desire to

closely match the implant size to the dimensions of the knee and to maintain the intraoperative flexibility provided by modularity. To date, implant manufacturers have failed to produce a completely reliable locking mechanism for attaching the polyethylene to the tibial baseplate. The kinematic conflict between low-stress articulations and free rotation cannot be solved by any fixed-bearing knee design.

Therefore, there are two possible options to pursue. One is the development of a new polyethylene or polyethylene alternative that is impervious to wear. The other is to further explore the possibilities of a mobile polyethylene bearing.

Biomechanical Concepts of Mobile Bearings

The success of total knee arthroplasty (TKA) is influenced by a complex interaction between the geometry of an implant design and the active and passive soft-tissue structures that surround the articulation.[17] This interaction, in turn, determines the stability, range of motion, and interface stresses that develop.

Dual-surface articulation between a polyethylene insert and the metallic femoral and tibial tray components is a consequence of mobile-bearing knee designs. These designs offer the advantage of conformal geometry with diminished surface and subsurface stress distributions, while the mobility of the bearings serves to minimize the development of interfacial bone stresses.

One of the principal features of mobile-bearing knee designs is the promotion of load sharing through the relative displacement between the tibial and femoral components. Simply stated, these designs allow the torques and shear forces of gait to be transferred by way of displacements to the soft tissues in a fashion similar to that of the normal knee. Load sharing has many potential advantages. It reduces the loosening stresses that are transferred to the

implant-bone interface, and it also promotes soft-tissue strengthening. These tissues, unlike the inert prosthesis, have the capacity to respond and remodel to the challenges of the expanding activities performed as the pain-free knee is rehabilitated. Finally, load sharing may contribute to the reduction of articular wear of these devices by decreasing the joint loads. Thus, in general, soft-tissue involvement should be encouraged in order to decrease the dependency on the intrinsic constraints afforded by condylar geometry. Contemporary mobile-bearing knee designs achieve this involvement, and they can be described in terms of the plateau mobility, which can be (1) pure rotation, (2) rotation with anterior-posterior translation, and (3) unconstrained.[18] With regard to the knee replacements described in the present investigation, the Oxford unicompartmental replacement allows only anterior-posterior translation; the LCS rotating-platform knee, pure rotation; and the LCS meniscal-bearing and SAL knee replacements, rotation and anterior-posterior translation.

Long-term evaluation of the LCS meniscal-bearing total knee system with use of a wear simulator that approximated 10 years of in vivo service life demonstrated low volumetric loss of ultra-high molecular weight polyethylene (UHMWPE) compared with that associated with fixed-plateau designs.[18] Specifically, a 160-mg weight loss over 10 million stance-phase cycles, from a bearing plateau that initially weighed 16,000 mg, has been verified by more than 15 years of clinical success associated with this particular design.[18,19] A reason for this result is the substantial reduction in the proximal and distal contact stress levels suggested by finite element computation analysis.[20,21] The low contact stresses on both articulating surfaces greatly attenuate any effect that increased sliding distances may have on abrasive wear-debris generation.[22,23]

An evolution is occurring in total knee design that will lead to increasing use of mobile-bearing knee systems. Although these systems are regulated by the Food and Drug Administration (FDA) in the United States, the growing use of these systems in other countries is continuing unabated. Mobile-bearing knee designs offer orthopaedic surgeons a unique option for restoring normal, pain-free activity. Because of the mobility that they provide, slight positional malalignment of the components should not substantially affect the expected in vivo service life of the device as long as that malalignment corresponds with the defined mobility of that design. The individual clinical performance of the devices is strongly influenced by the particular design kinematics of both the proximal and the distal surface as well as the distribution of contact stresses. In addition, the volume and size of UHMWPE particles produced by dual-surface articulation are affected by the quality of the polyethylene and the finish of the articulating metallic components. With regard to these parameters, not all mobile-bearing knee systems perform the same.

Design Features of Mobile-Bearing Knee Prostheses

Mobile-bearing knee prostheses are not new. The first to be used was the Oxford device[24] (Biomet, Bridgend, South Wales), which was designed almost 25 years ago, and the second was the LCS prosthesis,[22] which was based on similar concepts and appeared shortly thereafter. Other designs have followed, but, to date, all have enjoyed only limited popularity. The concept of a mobile-bearing knee prosthesis is intellectually attractive and can potentially solve the three problems that have been discussed.

First, if the need to allow rotation at the femorotibial articulation is eliminated and rotation of the tibial polyethylene-tibial tray interface is allowed instead, the contact area of the articular surface can be greatly increased, from approximately 200 square mm² in a good fixed bearing to 1,000 mm² or more, and there can be a consequent reduction in contact stresses, from approximately 25 MPa in a fixed bearing to 5 MPa or less. The former stresses theoretically result in polyethylene breakdown, whereas the latter should not damage the polyethylene even in active use. The difference is analogous to the indentations left by a high-heeled shoe compared with those caused by a boot.

Second, the problem of wear between the polyethylene bearing and the tibial baseplate also can be resolved. There are insurmountable difficulties with regard to the manufacture of a chromium-cobalt tibial baseplate with a suitable intraoperative locking mechanism for the polyethylene because the material must be cast and not machined. It is relatively easy to make a chromium-cobalt baseplate to accommodate a mobile bearing, and it is also feasible to provide a smooth, highly polished surface on which the mobile bearing can move. It is well known that, however well finished, titanium does not provide a good articulating surface for polyethylene.[25]

Third, a mobile bearing also solves the kinematic conflict of a fixed-bearing knee prosthesis because a highly conforming articular surface can now coexist with free rotation.

The mobile-bearing concept is therefore attractive, but many questions remain to be answered and details need to be dealt with in pursuit of the best mobile-bearing knee design.

Fully Conforming Articulation

A fully conforming articulation has a contact area that remains the same throughout the range of motion, which appears to be the most desirable configuration.

Full Flexion

It has been postulated that the knee flexes about an axis running through the femoral epicondyles,[19] and a femoral component with a constant sagittal radius would therefore be not only possible but desirable. Such a design should allow 120• of flexion but perhaps not more because of posterior impingement of the tibial component. Until now, this degree of flexion has been considered sufficient for a knee prosthesis, but should future knee designs allow full flexion?

A knee design that allows full flexion must have two essential features: it must be posterior stabilized to direct predictable femoral rollback, and the femoral component must have a decreasing sagittal radius. These requirements suggest the need for a hybrid type of mobile-bearing knee prosthesis. If rotation is not required, the conformity of a conventional fixed-bearing knee can be improved and the contact area can be approximately doubled even in flexed positions. Therefore, a hybrid knee would allow a large contact area for the first 20• of flexion (the motion that occurs during the gait cycle) and an improved contact area throughout the rest of knee flexion. Rotation of course would occur at the undersurface.

Axis of Rotation

The proper axis of rotation at the undersurface also remains debatable. For a fully conforming meniscal-bearing knee, both rotation and anterior-posterior translation seem desirable to mimic the motion of the natural knee. Hybrid posterior stabilized mobile-bearing knees do not demand anterior-posterior translation and therefore may be well suited to some type of rotating platform; however, a central axis of rotation is not physiologic because backward movement on one side is accompanied by forward movement on the other.

Prevention of Dislocation of the Bearing

A potential complication associated with mobile-bearing knee prostheses is dislocation of the bearing. To prevent dislocation, some type of restraint on

bearing movement seems desirable. This restraint could be provided by a "cylinder in a cylinder" or a "cone within a cone," with the cylinder or cone an extension of the polyethylene insert, which mates with a recess in the baseplate. Alternatively, a post or "mushroom" sprouting from the tibial baseplate could be used to anchor the polyethylene. An anterior or posterior metal stop that projects from the tibial tray may be used to limit unwanted movements.

Mobile-bearing knee designs should follow the tradition of fixed-bearing knee prostheses and have posterior cruciate-retaining (PCR) and posterior-stabilized variants. The former would be a rotating-gliding type, and the latter would most probably be a hybrid type. Although it is possible to envisage a fully conforming posterior-stabilized knee with motion driven by a tibial post fixed to the baseplate, the engineering complexities probably preclude the manufacture of such a design.

Fluoroscopic Evaluation of In Vivo Kinematics of Mobile-Bearing TKA

Previous in vivo kinematic studies with use of fluoroscopy have been conducted on patients with normal knee joints and on those who had implantation of a fixed-bearing PCR or posterior- stabilized TKR of multiple designs[26-30] to determine anteroposterior (AP) femorotibial contact patterns. Those studies have shown that, during a deep knee bend, patients with normal knees exhibited posterior femoral rollback with progressive flexion. In contrast, those who had a fixed-bearing prosthesis often had paradoxical anterior femoral translation (the femoral condyle shifting anteriorly on the tibia) with increasing knee flexion,[26,27] which was the reverse of the situation in the normal knees. Patients who had a posterior-stabilized TKR routinely demonstrated posterior femoral rollback during knee flexion, although it was lesser in magnitude than that in the normal knees.[26,27] When tested

during gait, patients who had a PCR or a posterior-stabilized TKR exhibited paradoxical anterior femoral translation, which was attributed to a lack of engagement of the cam and post of the posterior-stabilized TKR in activities that require less flexion, such as gait.[31]

Additional studies involving fluoroscopic evaluation of fixed-bearing TKRs have documented reduced amounts of axial femorotibial rotation[32] and the presence of unicondylar separation of the femoral and tibial condyles (femoral condylar lift-off).[33] We present the following report to summarize the findings of our in vivo kinematic analyses of multiple groups of patients who had been managed with various designs of mobile-bearing TKAs and to compare the in vivo knee kinematics in our patients with those reported in studies involving patients who had had a fixed-bearing TKA.

Materials and Methods

The in vivo kinematics of the knee (anterior-posterior translation, axial rotation, femoral condylar lift-off, and range of motion) have been determined in many studies of meniscal-bearing, posterior-cruciate-sacrificing (PCS) rotating-platform, and posterior-stabilized rotating-platform mobile-bearing TKA designs (LCS).[34-36] All of the TKAs in those studies were judged to have been clinically successful (an excellent result according to The Hospital for Special Surgery knee score[2]) without substantial ligamentous laxity or pain. The knees were analyzed with use of high-frequency, pulsated videofluoroscopy (Radiographic and Data Solutions, Minneapolis, MN) while the patient performed a weight-bearing deep knee bend or normal gait activity. While performing the deep knee bend, each patient placed the foot of the involved lower limb on a designated marker. For this activity, the initial fluoroscopic examination was performed with the knee in full extension. During gait analysis, the involved knee was tracked by the fluoroscopy unit,

which was moved manually to capture the knee throughout the stance phase of gait.

The fluoroscopic images were stored on videotape for subsequent redigitization with use of a frame grabber. The contact positions between the femur and the tibia were determined with use of a three-dimensional (3-D) model-fitting technique.[37] The fluoroscopic images were initially captured onto a workstation computer. The 3-D solid models of the femoral and tibial components, made with computer-aided design, were overlaid onto the two-dimensional fluoroscopic perspective images (Fig. 1). Once the 3-D components were precisely fit, the femorotibial contact positions of the medial and lateral condyles were determined with respect to the midline of the tibia in the sagittal plane with use of a sophisticated computer algorithm.[37] A contact position anterior to the midline was denoted as positive, and a position posterior to the midline was denoted as negative. During the deep knee bend, fluoroscopic images were analyzed at 0•, 30•, 60•, and 90• of flexion. Analysis of gait was performed at heel-strike (0%), at 33% and 66% of stance phase, and at toe-off (100%).

Results

Anterior-Posterior Translation Previous analysis of normal knee kinematics with use of videofluoroscopy as the subject performed a weight-bearing deep knee bend has demonstrated that the lateral femoral condyle contacts the tibia anterior to the midline of the tibia in the sagittal plane (an average of +6.5 mm) at full extension.[33] With progressive knee flexion, there is posterior translation of this condyle (posterior femoral rollback) to an average final position of –7.7 mm (an average of 14.2 mm of posterior femoral rollback)[26] (Fig. 2). In contrast, patients with a meniscal-bearing TKR exhibited a posterior contact position at full extension. A small amount of poste-

Fig. 1 Three-dimensional solid models of femoral and tibial components, made with computer-aided design, precisely fit over a two-dimensional fluoroscopic image.
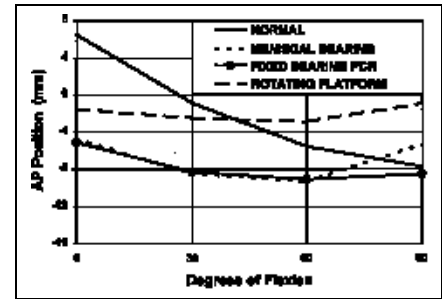

Fig. 2 Graph showing the average AP contact positions of the lateral condyle during a deep knee-bend activity in subjects with normal knees and in those with fixed-bearing PCR, meniscal-bearing, and rotating-platform TKRs.

rior femoral rollback (an average of 4.8 mm) occurred during the first 60• of flexion, followed by anterior femoral translation as the knee flexed from 60 • to 90• .[34,36] Contact pathways in patients who had a meniscal-bearing TKR proved to be quite similar to those in patients with a fixed-bearing PCR TKR. [32,33] Hence, the meniscal-bearing implant may not provide any advantage with regard to the contact pathway.

Patients with a rotating-platform TKR experienced, on the average, minimal anterior-posterior femorotibial translation during a deep knee bend, with femorotibial contact remaining near the middle of the articulating surface of the tibial component[36] (Fig. 2). Substantial variability of contact patterns among subjects managed with either a meniscal-bearing or a rotating-platform design (Fig. 3) was common.

A later analysis was performed to compare the PCS and posterior-stabilized rotating-platform designs (LCS) with regard to AP contact pathways of both the medial and the lateral condyle during a deep knee bend and during normal gait (B Haas, RD Komistek, DA Dennis, unpublished data, Rocky Mountain Musculoskeletal Research Laboratory, Denver, CO).

During a deep knee bend, patients managed with a PCS rotating-platform TKR had posterior femoral rollback of the lateral condyle (an average of 3.3 mm) from full extension to 90• of flexion, but they actually experienced anterior translation from 60• to 90• of flexion. The contact position of the medial condyle remained approximately the same (an average of –2.3 mm at 0 • and –2.2 mm at 90•) during the deep knee bend (Fig. 4). Patients who had a posterior-stabilized rotating-platform TKR exhibited more substantial posterior femoral rollback of the lateral condyle (an average of 5.9 mm) during the deep knee-bend maneuver. A minimal change in the contact position of the medial condyle was observed throughout the range of flexion (Fig. 5). Again, a high variability in contact positions among individual patients was observed in both design groups, particularly in deep flexion. This variability was attributed, at least in part, to variances in the amount of axial rotation of the bearing among the individual patients. Continual posterior femoral rollback of the lateral condyle throughout the range of flexion (an average of –0.6 mm at 0 • , –4.1 mm at 30• , –4.8 mm at 60 • , and –6.5 mm

at 90•) was observed in all patients managed with a posterior-stabilized rotating-platform design (Fig. 5); this finding was attributed to engagement of the cam-and-post mechanism. In contrast, paradoxical anterior femoral translation of the lateral condyle was observed at some point in the range of flexion in 40% of the patients managed with a PCS rotating-platform TKA.

During gait, patients managed with a PCS rotating-platform TKA experienced minimal change in the AP contact position of the lateral condyle (an average of 2.2 mm) and the medial condyle (an average of 0.2 mm) from heel-strike to toe-off (Fig. 6). Patients managed with a posterior-stabilized rotating-platform TKA also demonstrated minimal change in the AP contact position of the lateral condyle (an average of 1.2 mm) and the medial condyle (an average of 1.1 mm) from heel-strike to toe-off (Fig. 7). In contrast to testing during a deep knee-bend maneuver, testing during gait demonstrated minimal variance (less than 3.0 mm) in contact patterns either medially or laterally among individual patients in both groups.

Axial Femorotibial Rotation During a deep knee bend, patients managed with a PCS rotating-platform or posterior-stabilized rotating-platform TKA generally
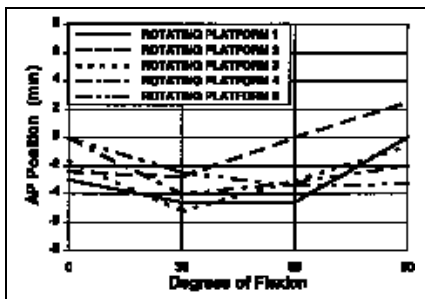
Fig. 3 Graph showing the average AP contact positions of the lateral condyle during a deep knee-bend activity for five randomly selected patients who had a PCS rotating-platform TKR. There is a high variance in contact positions among the individual subjects.
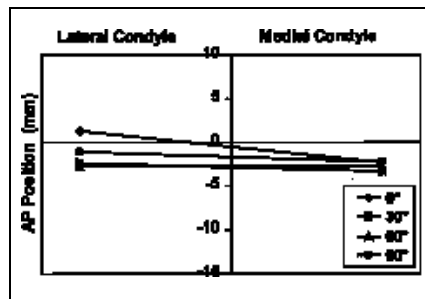

Fig. 4 Graph showing the average AP contact positions of the medial and lateral condyles during a deep knee-bend activity in patients who had a PCS rotating-platform TKR.
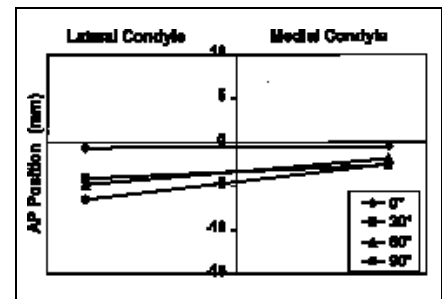

Fig. 5 Graph showing the average AP contact positions of the medial and lateral condyles during a deep knee-bend activity in patients who had a posterior stabilized rotating-platform TKR.
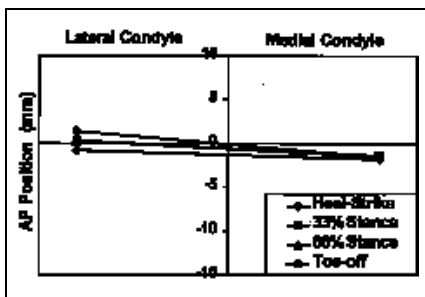

Fig. 6 Graph showing the average AP contact positions of the medial and lateral condyles during gait in patients with a PCS rotating-platform TKR.
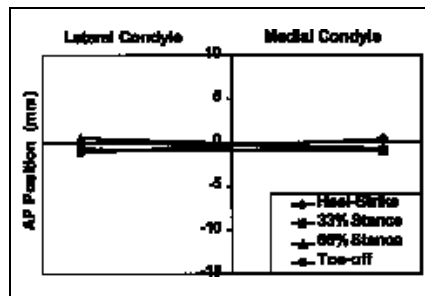

Fig. 7 Graph showing the average AP contact positions of the medial and lateral condyles during gait in patients with a posterior stabilized rotating-platform TKR.

demonstrated a normal axial femorotibial rotational pattern (that is, internal rotation of the tibia with progressive flexion), although it was typically less in magnitude than that reported for normal knees[38] (Table 1). During gait, patients who had been managed with a posterior-stabilized rotating-platform TKR demonstrated, on the average, a normal axial femorotibial rotational pattern whereas those managed with a PCS rotating-platform TKR had an abnormal, reverse rotational pattern (external rotation of the tibia with progressive flexion).

A review of average axial rotational values can be misleading because of the high variability observed among individ-

ual subjects. In a separate fluoroscopic study of the gait of 20 patients who had a PCS rotating-platform TKR (LCS), a normal axial rotational pattern was seen in only seven patients, with an abnormal, reverse rotational pattern observed in eight patients and negligible rotation (average, 0.5•) noted in five patients.[35]

Femoral Condylar Lift-Off The occurrence of femoral condylar lift-off at some point in the flexion cycle was common, with a rate of more than 90% with both the PCS and the posterior-stabilized rotating-platform designs.[32,36] This high rate of lift-off was observed during both gait and the deep knee bend maneuver. Femoral condylar lift-off was seen more commonly on the lateral side of the joint, which was attributed to the adduction moment that occurs during the mid-

stance phase of the gait cycle.[33] The magnitude of condylar separation is reported in Table 2. As in previous fluoroscopic evaluations of femoral condylar lift-off in patients managed with a fixed-bearing TKA,[33] lift-off was most commonly observed between 60• and 90• of flexion during a deep knee bend and during the midstance phase of the gait cycle.

Range of Motion The range of motion following meniscal-bearing and PCS rotating-platform TKA has been assessed under passive, non-weight-bearing and active, weight-bearing conditions and compared with previously published data obtained after fixed-bearing PCR and PCS TKAs.[39] Flexion was reduced when it was tested under weight-bearing conditions in all groups (Table 3). The greatest average range of motion was observed in patients who had had a fixed-bearing posterior-stabilized TKA.

Summary of In Vivo Kinematic Studies

In vivo fluoroscopic analyses of various designs of mobile-bearing TKRs during weight-bearing activities have demonstrated that numerous kinematic abnormalities (paradoxical anterior femoral translation, reverse axial rotational patterns, and femoral condylar lift-off) are common (B Haas, RD Komistek, DA Dennis, unpublished data Rocky Moun-

tain Musculoskeletal Research Laboratory, Denver, CO).[34-36] These kinematic abnormalities are not unlike those reported in similar fluoroscopic evaluations of fixed-bearing TKRs.[26-33]

Typically, patients who have had a mobile-bearing PCS rotating-platform or posterior-stabilized rotating-platform TKA have less anterior-posterior femorotibial translation during gait, with less variability among individual patients, than those who have had a fixed-bearing TKA. This finding is likely related to the increased AP femorotibial conformity allowed in the mobile-bearing designs. This reduction in anterior-posterior translation and intersubject variability was not observed during a deep knee bend activity, however. Posterior femoral rollback after posterior-cruciate-substituting TKAs (those involving implantation of either a mobile-bearing or a fixed-bearing design) is superior to that after PCR arthroplasties.

Axial femorotibial rotation is reduced following implantation of both fixed-bearing and mobile-bearing designs. Reverse axial rotational patterns, which can adversely affect both the range of motion and the patellar stability, are common. Substantial variability in both the magnitude and the pattern of axial rotation among patients is common with both fixed-bearing and mobile-bearing designs.

Femoral condylar lift-off is common after all types of TKAs and does not appear to be affected by bearing mobility. It occurs most commonly on the lateral side of the joint during the deep flexion portion of a deep knee bend activity and during the midstance phase of gait.

When tested under weight-bearing conditions, the amount of flexion obtained following a TKA appears to depend more on condylar geometry than on bearing mobility. The greatest range of flexion in our analyses was observed in patients with a fixed-bearing posterior-stabilized TKR, in which posterior femoral rollback routinely occurs because of engagement of the

cam-and-post mechanism, allowing improved knee flexion.[39] In contrast, the least amount of flexion during weight bearing was observed in patients managed with a PCS rotating-platform design, in which anterior femoral translation was often observed during deep flexion, moving the axis of flexion anteriorly and reducing the range of motion. Additionally, the sagittal dwell point (the point where the polyethylene is thinnest) of the PCS rotat-

ing-platform TKR evaluated in this report is positioned more anteriorly than it is in most fixed-bearing TKA designs.[39] This, again, may position the axis of flexion anteriorly and limit maximum flexion.

The Oxford Unicompartmental Knee Replacement
Background
In 1978, Goodfellow and O'Connor[40] introduced the concept of the mobile

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Table 1
Axial femorotibial rotation in the PCS rotating-platform and posterior stabilized rotating-platform TKRs

Type of TKA*		Rotation (degrees)		
	Activity	Average	Maximum	Minimum
PCS-RP	Deep knee-bend	3.4	9.6	0.5†
PS-RP	Deep knee-bend	5.2	13.9	0.1†
PCS-RP	Gait	2.5†	13.2†	0.1†
PS-RP	Gait	3.0	10.9	0.1

*PCS-RP = posterior cruciate-sacrificing rotating platform, and PS-RP = posterior stabilized rotating platform
†Abnormal, reverse rotational pattern

Table 2
Magnitude of femoral condylar lift-off in the PCS rotating-platform and posterior stabilized rotating-platform TKRs

Type of TKA*		Lift-Off (mm)		
	Activity	Average	Maximum	Minimum
PCS-RP	Deep knee-bend	1.4	2.2	1.0
PS-RP	Deep knee-bend	1.9	3.5	1.0
PCS-RP	Gait	1.5	2.2	0.8
PS-RP	Gait	1.5	2.1	0.8

*PCS-RP = posterior cruciate sacrificing rotating platform, and PS-RP = posterior stabilized rotating platform

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Table 3
Range of motion associated with different types of TKRs

Type of TKA*	Testing Condition	Average Range of Motion (degrees)
Meniscal-bearing[17]	Non-weight-bearing	121•
Meniscal-bearing[17]	Weight-bearing	100•
PCS-RP	Non-weight-bearing	108•
PCS-RP	Weight-bearing	99•
FB-PCR	Non-weight-bearing	123•
FB-PCR	Weight-bearing	103•
FB-PS	Non-weight-bearing	127•
FB-PS	Weight-bearing	113•

*PCS-RP = posterior cruciate-sacrificing rotating platform, FB-PCR = fixed-bearing posterior cruciate-retaining, and FB-PS = fixed-bearing posterior stabilized
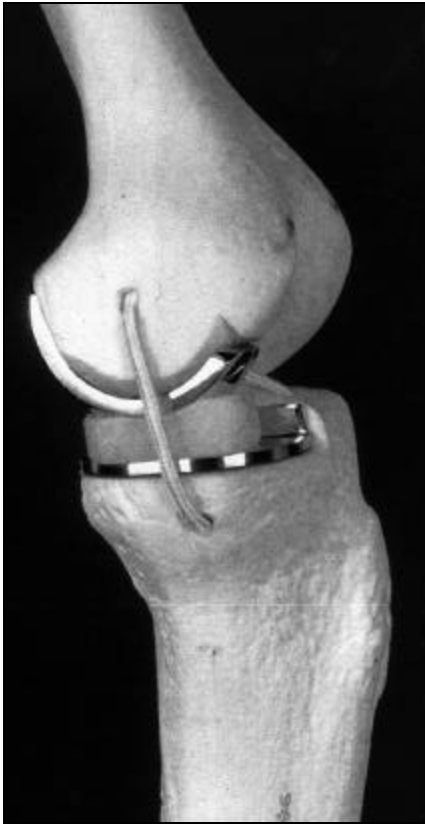
Fig. 8 Photograph of the Oxford unicompartmental knee replacement.

bearing, which is intended to mimic the function of the human meniscus. The natural meniscus makes the dissimilar surfaces of the femoral and tibial condyles congruous, doubling the area of their contact and thereby reducing by half the pressure at which loads are transmitted across the joint.[41] The natural meniscus is mobile so that it can follow the rolling and sliding movements of the femoral condyle on the tibial plateau, and it is compliant so that its shape can change to accommodate the varying curvatures that the polyradial femoral condyle presents during flexion and extension.[42]

A mobile polyethylene bearing can mimic the mobility of the natural meniscus, but it is rigid and cannot change shape. The only rigid shapes that can be congruous in all relative positions are a sphere in a spherical socket; there-

fore, if the surfaces of the prosthesis are to be congruous, the femoral condyle has to be spherical. Some designs of prostheses have a mobile bearing that articulates with a polyradial femoral condyle. These implants exhibit incongruous articulation except in the one position of the joint in which the condyle presents the same curvature as that of the bearing. As already stated, we use the description "meniscal bearing" for implants in which the condyle is spherical and the bearing can function like its analogue in nature. Not all mobile-bearing knee prostheses are meniscal-bearing knee prostheses.

Of the several advantages that might be expected from a meniscal-bearing knee replacement, reduced polyethylene wear is the most obvious. Among the potential disadvantages are the risk of dislocation and the increased dependence on the preserved ligaments to provide stability.

The Prosthesis
The Oxford meniscal-bearing prosthesis has three components (Fig. 8). The metal femoral condyle has a spherical articular surface, and the metal tibial component is flat. In between, there is a mobile polyethylene bearing, which has a spherically concave upper surface and a flat lower surface. The unconstrained bearing is entrapped by the reciprocal shapes of the metal surfaces and by the tension in the soft tissues. Both to avoid dislocation and to confer stability, it is essential that the flexion and extension gaps, defined by the tension in the ligaments, are exactly the same. With the initial design (phase 1), in which the femur was prepared with a saw, such precise ligament balance was difficult to achieve. In 1985, the phase-2 instrumentation was introduced with a spherically concave rotary mill to prepare the femoral condyle. The flexion gap is first defined by excision of thin slices of bone from the tibial plateau and from the posterior surface of the femoral condyle. The distal part of the femur is then

milled, in 1-mm increments, until the gap in extension has the same measurement as the gap in flexion. A polyethylene bearing of the appropriate thickness to fill the gap is inserted, and it maintains the ligaments at a constant tension throughout the range of movement. In 1998, the instruments were further modified (phase 3) to simplify their use and to facilitate implantation through a short parapatellar-tendon incision.

Why Unicompartmental?
Between 1977 and 1982, the Oxford implant was used bicompartmentally, with one prosthesis in each compartment of the knee. It soon became apparent that a good result depended on the presence of all of the ligaments, including, in particular, the anterior cruciate ligament (ACL). If the ACL was absent or seriously damaged, the failure rate was about six times higher.[43] Because a majority of osteoarthritic knees that need replacement lack a functional ACL, the usefulness of the implant seemed doubtful. However, during those years we observed that if osteoarthritic joints had an intact ACL, the disease was usually limited to the medial compartment of the joint. The Oxford knee has been used unicompartmentally for such knees since 1982. For knees with an absent ACL, we have preferred fixed-bearing TKRs.

One consequence of the failure of the prosthesis in knees with a deficient ACL was that we collected many used bearings and were able to measure their average wear rate. The Oxford knee provides about 6 cm² of congruous contact at both of its surfaces, and little polyethylene wear was expected. The retrieved bearings, in fact, became thinner at an average rate of only 0.03 mm/yr (a rate of 1 mm in 30 years).[44,45]

When possible, we use unicompartmental replacements because they have many advantages over total knee replacements.[46-48] They are less invasive, and because they preserve the cruciate liga-

ments they result in nearly normal kinematics. The surgery has a lower morbidity rate, blood transfusion is not required, and the implant is less expen - sive. The postoperative recovery is more rapid, and a better range of movement and more physiologic function are achieved. The concern with unicom - partmental replacements is that in gen - eral they have had a higher failure rate than TKRs. However, these failures are commonly due to polyethylene wear, which is not a problem with the Oxford meniscal-bearing knee replacement.

A Prosthesis in Search of a Disease

The criteria for use of the Oxford uni - compartmental knee are now clearly defined and are all met by the clinico - pathologic syndrome of anteromedial osteoarthritis.[49] In this condition, the ACL is intact and the cartilage and bone ero - sions are limited to the anterior part of the medial compartment. This combina - tion of a functioning ACL and healthy car - tilage at the back of the joint has an important consequence. The varus defor - mity, which is typical of the disease, is pre - sent only when the knee is extended—that is, when the eroded anterior articular sur - faces are in contact. In flexion, the femur rolls back and presents its intact posterior articular surface to the intact cartilage at the back of the tibial plateau. As a result, the varus deformity corrects every time the knee flexes, and structural shortening of the medial collateral ligament cannot occur. Rupture of the ACL leads to disor - derly movement of the femur on the tibia and extension of the cartilage and bone erosions to the back of the joint. There - after, the knee is in varus in all positions, secondary shortening of the medial col - lateral ligament ensues, and the cartilage and bone erosions begin to involve the other joint compartments. This scenario suggests that anteromedial osteoarthritis is not the early manifestation of a global dis - ease of the joint but a focal disorder of the knee and that timely replacement of the

eroded medial plateau, before the ACL has stretched or ruptured, could protect both that structure and the lateral compartment from degeneration. In a recent clinical and radiographic study by Weale and associ - ates,[50] 29 knees that had been followed for at least 10 years after an Oxford unicom - partmental arthroplasty demonstrated no deterioration of function or progression of arthritis in their retained compartments during that decade.

Anteromedial osteoarthritis, there - fore, presents with pathology that is limited to the articular surfaces of one compartment, and all of the ligaments are still normal. In theory, such a knee can be restored to normal function by a unicompartmental surface replace - ment. For this purpose, a meniscal prosthesis might have two advantages over a fixed-bearing implant: it would be less likely to fail because of polyeth - ylene wear, and its freedom from con - straint might allow the intact ligaments to perform more normally.

Indications

Use of an Oxford unicompartmental knee replacement is indicated when there is full-thickness cartilage loss in the medial compartment with or with - out bone loss. Superficial damage to the ACL, usually caused by osteophyte impingement, is not a contraindication provided that the ligament is function - ally intact. A fixed flexion deformity should be less than 15•. The varus deformity should be passively cor - rectable; this is best demonstrated by a valgus-stress radiograph made with the knee in 20• of flexion. The cartilage of the lateral compartment should be full-thickness, which would also be demon - strated by the same radiograph. At surgery, a full-thickness erosion is often found on the medial margin of the lat - eral condyle, presumably as a result of impingement on the tibial spine, but this is not a contraindication to use of the prosthesis. If the described indications

are used, this operation is suitable for about one in four osteoarthritic knees that require replacement.

Many of the contraindications pro - posed by others are, we believe, unneces - sary. In our practice, no knee is excluded because of patellofemoral erosions. Exten - sive fibrillation and erosion are commonly found on the medial patellar facet and the medial flange of the patellar groove on the femur. The operation corrects the varus deformity and unloads the damaged areas of the patellofemoral joint. We have not had to revise a knee because of patellofemoral pain. The age and weight of the patient and the presence of chon - drocalcinosis are not contraindications.

Results

In 1998, Murray and associates,[51] the designers of the Oxford prosthesis, reported the rate of survival of the pros - theses in a series of 144 knees that had a medial unicompartmental replacement (phase 1 and phase 2). One knee was lost to follow-up, one phase-1 knee had dis - location of the bearing that was reduced by closed manipulation, and there were no dislocations in the phase 2 knees. The patients ranged in age from 35 to 90 years. The 10-year rate of survival was 98% (95% confidence limits, 93% to 100%). The worst-case rate of survival, derived by assuming that the knee lost to follow-up was a failure, was 97% at 10 years.

The designers' results after the use of the implants need to be regarded with caution as they are susceptible to bias. However, Price and Svard[52] reported on an independent series of patients treated by three surgeons at a nonteaching hos - pital in Sweden. The study involved 378 medial unicompartmental replacements in knees with anteromedial osteoarthritis, and no patient was lost to follow-up. The 10-year survival rate was 95% (95% con - fidence limits, 93% to 98%). The worst-case rate of survival was also 95%. Three phase 1 knees had a dislocation of the
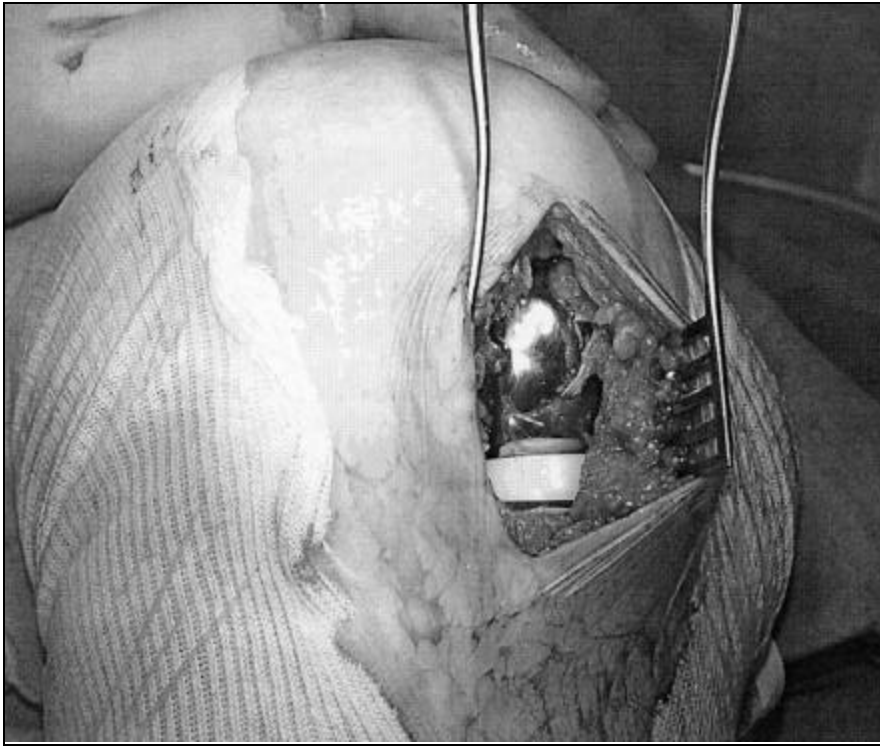
Fig. 9 Intraoperative photograph of the Oxford unicompartmental knee replacement implanted through a short incision.

bearing, and none of the phase 2 knees had a dislocation.

In contrast, Lewold and associates[53] reported a 5-year rate of survival of only 90% after 699 phase 1 and phase 2 Oxford unicompartmental medial and lateral replacements in the National Arthroplasty Study performed at 19 centers in Sweden. Thirty-seven of the 50 failures occurred less than 2 years after surgery, and the most common cause of early failure was dislocation of the bearing, a complication that occurred only once in the first 2 years in the 522 cases in the series of Murray and associates[51] and Price and Svard.[52] We were able to obtain data from 13 of the 19 centers and found 944 Oxford unicompartmental implants, suggesting that the Swedish register failed to identify more than 25% of the patients. The failure rate from center to center ranged from 0% to as high as 30%. The results reported by Lewold and associates[53] reflect the learn-ing curves associated with a novel tech-nique at 19 centers. The investigators exerted no control over, and collected no information about, the indications that were used. The report by Larsson and associates,[54] who performed a uni-compartmental arthroplasty in 71% (102) of all knees that had an arthro-plasty for the treatment of osteoarthritis, and the report by Christensen,[55] who performed the procedure in 90% (575) of all such knees, suggest that the indi-cations for the procedure in Sweden may have been wide.

Minimally Invasive Surgery
Since 1998, we have performed the sur-gical procedure through a short incision from the medial pole of the patella to the tibial tuberosity with use of phase 3 instruments (Fig. 9). With the limited approach, there is minimal damage to the extensor mechanism because the patella is not dislocated and the suprap-atellar synovial pouch remains intact. As a result, patients recover much more rapidly.[56] Webb and associates[57] showed that patients achieve straight-leg raising, knee flexion, and independent stair-climbing about three times faster after this procedure than they do after TKR. Furthermore, a comparison of the post-operative radiographs has shown that the operation can be done as reliably through the limited approach with use of the phase 3 instruments as it can be done through a wide incision with use of the phase 2 instruments.

Overview
The Oxford unicompartmental prosthesis has a fully congruent, unconstrained mobile bearing. Retrieval studies have shown that the average wear rate of the polyethylene bearings is very slow (approx-imately 0.03 mm/yr).[44,45] The indications for use of the implant for the treatment of medial compartment osteo-arthritis are clearly defined and are satisfied in approx-imately one in four osteoarthritic knees that need replacement.

The 10-year rate of survival of the prosthesis was 98% (95% confidence lim-its, 93% to 100%) in the designers' series of 144 knees[51] and 95% (95% confidence limits, 93% to 98%) in an independent series of 378 knees.[52] Recent modifications to the instrumentation allow the device to be implanted through a small parapatellar-tendon incision without disturbing the patellofemoral mechanism. This further reduces the perioperative morbidity and allows even more rapid recovery.

When appropriate expertise is available, one fourth of patients who need a knee arthroplasty can enjoy the advantages of unicompartmental rather than tricompart-mental replacement without incurring an increased risk of failure in the first 10 years.

Rationale for and Results of the Self-Aligning TKR
In the mid 1980s, a rotating-platform TKR, which provided a congruous

articulation from 5• of hyperextension to 90• of flexion and allowed uncon-strained rotation as well as anterior-posterior translation limited only by the soft tissues of the knee, was developed at our center (Fig.10). This report describes the results of 172 SAL TKAs performed, between 1990 and 1994, in 141 patients with osteoarthritis of the knee. Twenty-three knees had under-gone a prior high tibial valgus osteo-tomy. All surgery was performed in a laminar airflow theater, with the surgi-cal teams wearing body-exhaust suits. Cefazolin was administered in the peri-operative period for antibiotic prophy-laxis. All patients were managed with Coumadin (warfarin) as prophylaxis against deep vein thrombosis.

Preoperatively, all patients were assessed by a single observer with use of the Knee Society clinical rating scale,[58] the Western Ontario and McMaster Univer-sity Osteoarthritis Index,[59] and the Short Form-36 survey.[60] Preoperative evaluation included standing long-leg radiographs, standard AP standing radiographs, and a lateral and axial patellar radiograph of the affected knee. Postoperatively, the same independent observer examined the patient clinically and radiographically at 3 months, 6 months, and yearly thereafter. All radiographs were reviewed by the two senior authors (RBB and CHR).

Results

Ninety-five knees were in men and 75 were in women. The patients had an average age of 71 years (range, 47 to 90 years). The average height was 169 cm (range, 147 to 200 cm), and the average weight was 83 kg (range, 50 to 109 kg). All femoral and tibial components were fixed with cement, with the exception of 61 femoral components that were press-fit. Of this group of 61 knees, four were revised because of aseptic loosening of the femoral component. None of the cemented femoral components were revised. An all-polyethylene patellar
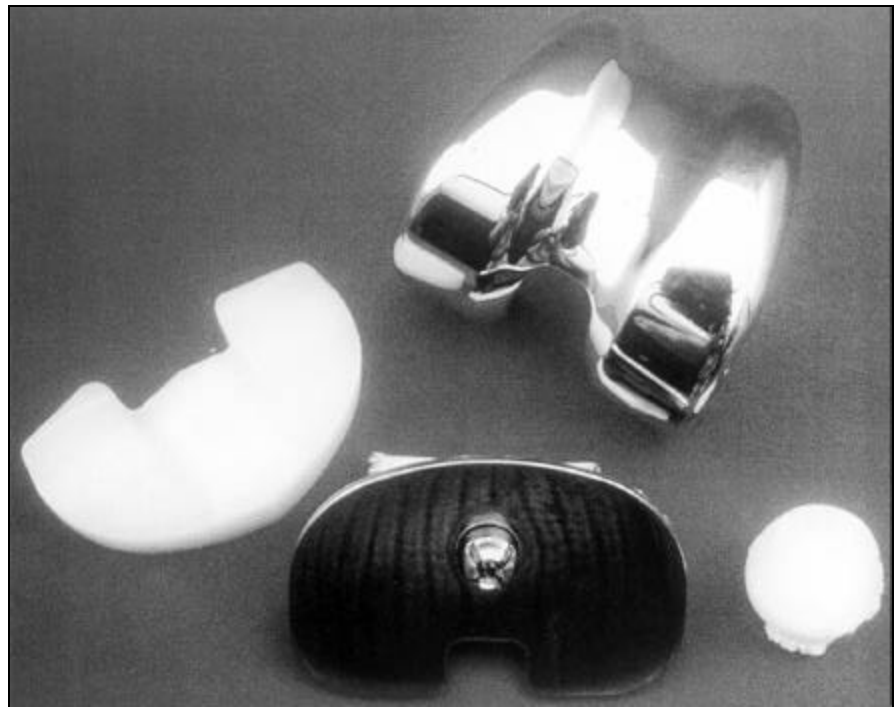

Fig. 10 Photograph of the components of the Self-Aligning-I TKA system, showing a chromium-cobalt femoral component, a nitrite-coated titanium tibial baseplate, a mobile-bearing polyethylene tibial insert, and an all-polyethylene patellar component.

component was press-fit in 48 knees and cemented in the remaining 124 knees.

At the time of the most recent follow-up, 42 patients had died of causes unre-lated to their knee replacement (Table 4). The SAL knee replacements had been functioning well in all of these patients at the time of death. No other patients were lost to follow-up. Eight patients had a revision. Two knees were revised because of polyethylene wear and four, because the press-fit, non porous-coated femoral component had become loose. One patient underwent a revision because of persistent pain, and aseptic loosening of a cemented patellar component was noted intraoperatively. One patient had a revision to exchange a tibial polyethylene insert because of postoperative stiffness.

Fourteen patients needed a reoper-ation (Table 5). In addition to the eight revisions, a reoperation was performed in four patients because of a deep infec-tion. Three of these patients were

treated with a two-stage revision arthro-plasty, and the fourth was treated with irrigation, débridement, retention of the components, and suppressive antibi-otics. Three traumatic patellar fractures were noted, but only one required revi-sion surgery. One patient had a periprosthetic fracture 6 years postop-eratively. The fracture was treated sur-gically, with a satisfactory outcome. Three patients required manipulation under anesthesia because of postopera-tive arthrofibrosis.

After 5 to 8 years (average, 5.6 years) of follow-up, 115 knees were available for review. The Knee Society clinical rating had improved from an average of 81 points preoperatively to an average of 155 points at the time of the latest follow-up. The average pre-operative range of motion was from 6 • ± 7• of extension to 110• ± 15• of flexion. Postoperatively, the average range of motion was from 0 • ± 1• to

Table 4
Outcomes after TKA with the Self-Aligning-I prosthesis

Clinical Outcome	No. of Knees
Patients who had died*	
< 5 years of follow-up	3 8
< 5 years of follow-up	4
Patients excluded because of reoperation	1 4
Patients excluded because of other medical reasons	1 †
Patients followed for minimum of 5 years	1 1 5

*These patients all had a successful outcome at the time of the last follow-up examination

†This patient had a satisfactory outcome at the time of the last follow-up examination, 3 years after the surgery

Table 5
Reoperations after TKA with the Self-Aligning-I prosthesis*

Indications for Reoperation	No. of Knees
Infection	4
Aseptic loosening of press-fit	4
Femoral component	4
Polyethylene wear	2
Fracture	2
Stiffness	1
Pain	1

*All of these knees were excluded from the present study group

Table 6
Clinical scores according to the system of the Knee Society[58] and range of motion for all Self-Aligning-I TKAs*

	Clinical Score (points)			Range of Motion (degrees)	
	Pain	Function	Total Score	Extension	Flexion
Preoperative	35 ± 15	46 ± 16	81 ± 24	6 ± 7	110 ± 15
Postoperative†	84 ± 7	71 ± 23	155 ± 19	0 ± 1	111 ± 7

*Data are given for the 115 knees that had at least 5 years of follow-up, and the values are given as the average and the standard deviation

†Data are from the latest follow-up examination, which was an average of 5.6 years after the surgery

Fig. 11 Photograph of the Self-Aligning-II total knee prosthesis. Note the maintenance of the single axis of curvature for the J-curve of the femoral component, the newer rounded femoral condyles in the medio-lateral plane designed to avoid edge-loading, and the change to a chromium-cobalt tibial baseplate from a titanium tibial baseplate.

111• ± 7• (Table 6). Postoperative alignment was neutral in 98 knees, 0 • to 5• of varus in 72 knees, and 10 • to 15• of valgus in 2 knees. No gross instability was noted in any knee. No rotating-bearing polyethylene insert had dislocated at the time of writing. Radiographic review revealed no evi-dence of osteolysis or implant loosen-ing at the time of the latest follow-up. No additional cases of asymptomatic polyethylene wear were noted. Patellar tracking was noted to be central in 154 knees, and 18 knees required lateral retinacular release to improve patellofemoral tracking. Nine patients required anticoagulant therapy for deep vein thrombosis, and no patient had a clinical pulmonary embolus.

After 5 to 8 years of follow-up, 94% of the patients were satisfied (a good or very good outcome) with the function of the knee and the outcome of the surgery. The remaining 6% rated the outcome as fair.

The results of the SAL total knee replacements in the present investigation are similar to those reported for other rotating-platform TKRs, notably the LCS TKR.[25,61,62] These studies demon-strated a reduction in polyethylene wear. None of the SAL TKRs had a bearing dislocation, and only four (9.3%) of 43 LCS rotating-platform devices had a bearing dislocation in another study.[63] The present series of SAL TKRs repre-sents the initial learning curve with this device. The encouraging results in this prototype series led to the development of the current SAL TKR with improved instrumentation, a dedicated femoral component, a lower-contact-stress tibial component, and sterilization of the poly-ethylene in an inert environment (Fig. 11). On the basis of the results with this prosthesis, we concluded that rotating-platform TKRs have the potential to

extend the indications for and the longevity of TKR.

The LCS Mobile-Bearing Knee
Design Rationale

The rationale for the design of the LCS mobile-bearing knee was to allow mobility with congruity [7,62,64,65] (Fig. 12). Along these lines, the femoral and tibial compo-nents are conforming, in the sagittal plane, from full extension to 30• of flexion to optimize the contact areas and are less conforming from 30• of flexion to full flexion to allow better mobility. The sur-face geometry of the femoral component in the sagittal plane is demonstrated in Figure 13. The tibial component includes a medial and lateral meniscal-bearing design with a tray cutout to preserve one or both of the cruciate ligaments (hence allowing rotation and anterior-posterior translation) and a rotating-platform design (allowing only rotation) with a relatively deep sagittal-plane conformity for PCS procedures (Fig. 14). The tibial polyethyl-ene insert has a center post that mates with the hollowed-out tibial tray post to allow rotation but no translation. The patellar component is metal-backed and mobile-bearing, with a surface congruent with the patellar groove articulation of the femoral component. All metal backings are porous-coated to allow fixation without cement. The bicruciate-retaining, rotat-ing-platform, and revision knee-device configurations were approved by the FDA and indicated for use with cement in 1985, the PCR device was approved by the FDA for cementless fixation in 1990, and the rotating platform was approved for cementless fixation in 1994.

Summary of Surgical Procedure

The surgical procedure is based on the principle of creating equal flexion and extension gaps while providing a poste-rior slope to the tibia to prevent shear at the tibial interface. The flexion gap is ini-tially created by resecting the proximal part of the tibial bone (a cut is made per-
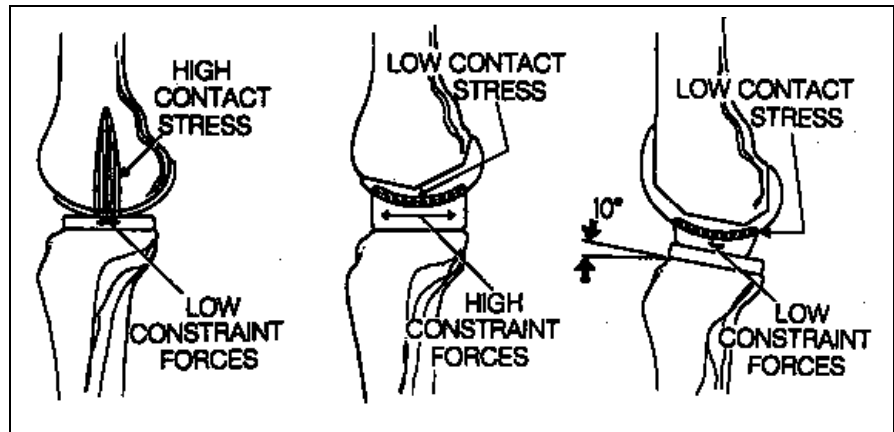

Fig. 12 Illustrations of the three types of knee bearing configurations, showing a point or line-contact device with poor congruity (*left*), a congruent-contact device without inherent axial rotation (*middle*), and a meniscal-bearing congruent-contact device with good mobility (*right*). (Reproduced with permission from Buechel FF, Pappas MJ: New Jersey Low Contact Stress knee replacement system: Ten-year evaluation of meniscal bearings. *Orthop Clin North Am* 1989;20:148.)
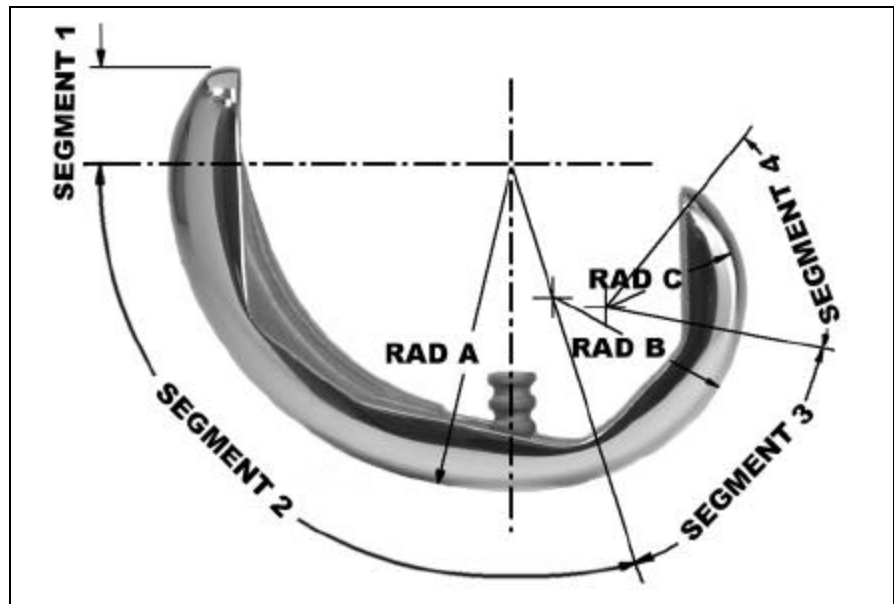

Fig. 13 The geometry of the lateral surface of the New Jersey LCS femoral component. segment 1 represents the patellofemoral bearing surface in full extension, segment 2 is the primary load-bearing surface of the femoral component for both patellar and tibial articulation, and segment 3 and segment 4 are the posterior bearing surfaces used during full flexion. (Reproduced with permission from Buechel FF, Pappas MJ: New Jersey Low Contact Stress knee replacement system: Ten-year evaluation of meniscal bearings. *Orthop Clin North Am* 1989;20:153.)

pendicular to the tibial shaft in the coro-nal plane and is tilted 7• to 10• poste-riorly in the sagittal plane). The AP dimension of the femoral component is

then sized, and the posterior femoral condyle resection is performed. The flex-ion gap is checked with a spacer block. Finally, the extension gap is created by
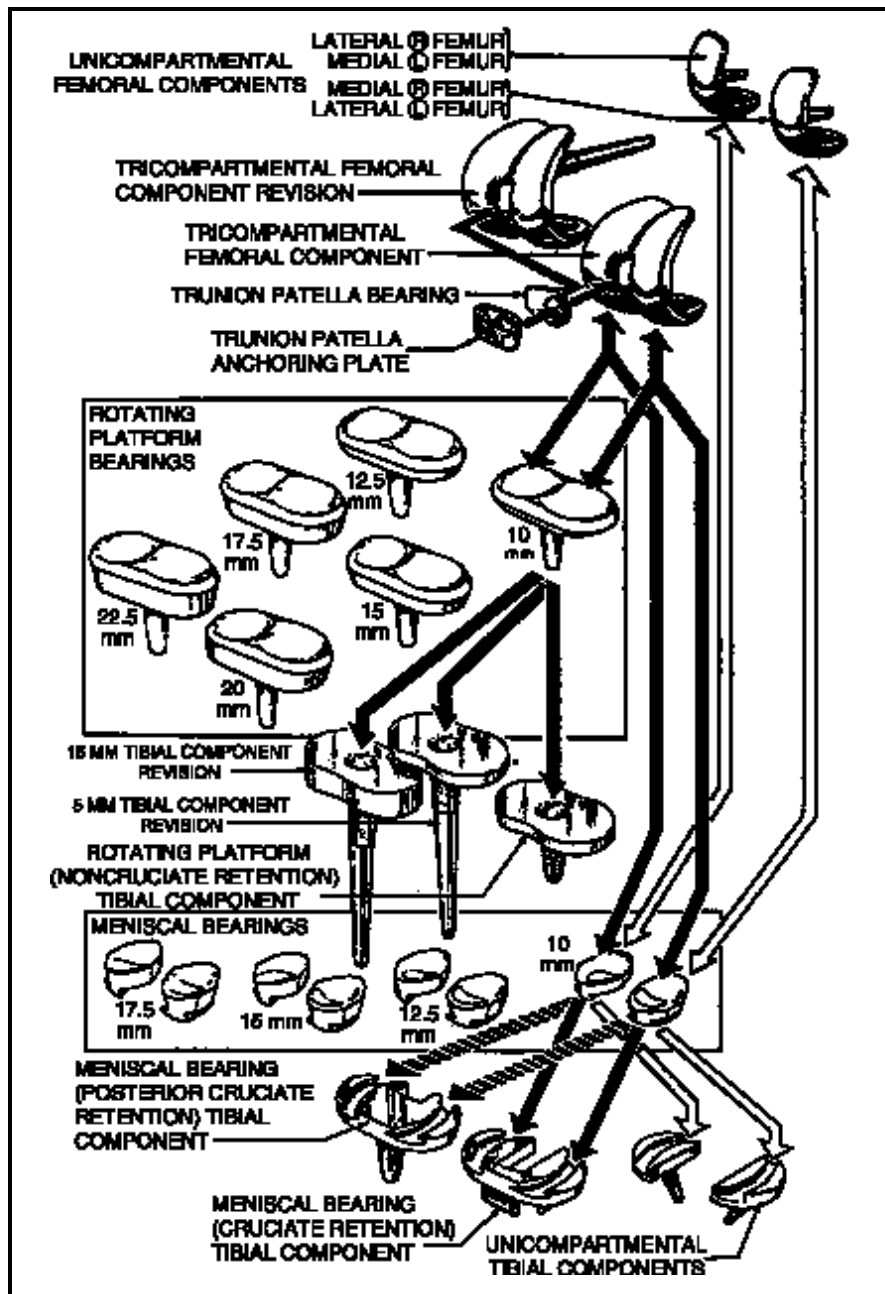
Fig. 14 Drawing of the components of the New Jersey LCS knee replacement system. (Reproduced with permission from Buechel FF, Pappas MJ: New Jersey Low Contact Stress knee replacement system: Ten-year evaluation of meniscal bearings. *Orthop Clin North Am* 1989;20:153.)

removing the amount of the distal aspect of the femur that is necessary to allow the extension gap to equal the flexion gap. The gaps are checked for symmetry with use of spacer blocks. To accommodate a deep patellofemoral groove in the femoral implant, the distal part of the

femur is cut in a 17• anterior-to-posterior slope. This cut is accommodated by the posterior slope in the tibia (Fig. 15).

Results
Buechel and Pappas[19] followed 46 knees that had a bicruciate-retaining LCS pros-

thesis for up to 12 years, 57 knees that had a PCR prosthesis for up to 6 years, and 108 knees that had a rotating-platform prosthesis for up to 10 years. Sixty-four knees were fixed with cement, and 147 were fixed without cement. The 12-year rate of survival (with revision as the end point) of the 21 knees with a cemented bicruciate-retaining prosthesis was 90.9%, and the 6-year rate of survival (with revision as the end point) of the 25 knees with a cementless bicruciate-retaining prosthesis was 100%. The 6-year rate of survival of the 57 knees with a cementless PCR meniscal-bearing implant was 97.9%. The 10-year rate of survival of the 43 knees with a cemented rotating-platform design was 97.5%, and the 6-year rate of survival of the 65 knees with a cementless rotating-platform implant was 98.1%.

Sorrells[66] evaluated the results of 665 cementless rotating-platform LCS knee arthroplasties performed between September 1984 and August 1995. Survivorship analysis demonstrated that 94.7% of the components had survived at 11 years, with 13 (2%) revised. Jordan and associates[62] evaluated the results of 473 cementless meniscal-bearing LCS knee arthroplasties performed between May 1985 and February 1991. Seventeen (3.6%) were revised because of mechanical failure. The survival rate of the implant, with revision because of mechanical failure as the end point, was 94.6% at 8 years.

The results of 119 arthroplasties with a cemented LCS rotating-platform TKR and a cemented all-polyethylene patellar component after 9 to 12 years of follow-up were reviewed.[65] There were no mechanical failures, and none of the components had been revised. The average Hospital for Special Surgery knee rating was 84 points. Knee flexion averaged 102•.

Complications associated with the LCS mobile-bearing knee have included dislocation of the bearings; meniscal,

rotating-platform, and patellar dislocations have all been reported. [62,66,67] In the previously discussed series, dislocation occurred in less than 0.5% of cases; however, Bert[63] reported a prevalence of dislocation of 9.3% (4) of 43 knees. Breakage or wear of the bearings has been reported in less than 2% of cases. [19,62] Even with use of cementless fixation, rates of loosening have been less than 2% in all of the reported series. [19,62,66]

In summary, the LCS mobile-bearing knee prosthesis has been used for 15 years. Although there are few long-term studies, the results reported in the literature are comparable with the best results reported with fixed-bearing devices.

Why Should We Question the Enthusiasm for Mobile-Bearing Knees?

In order to fully endorse a technological design, one must have data that overwhelmingly supports its superiority to its temporal peers. To date, even those who choose to accept the risks associated with use of a prosthesis that has additional moving parts do not have evidence that the mobile-bearing knee design has demonstrated any superiority over fixed-bearing designs. Moving parts always require a mechanical link for attachment, which could fail and result in excessive motion or dislocation of the part and in increased debris within the joint. This complication has occurred with mobile-bearing knees. Weaver and associates[68] and Bert[63] reported that revision was necessary because of failure of the mobile tibial components in the LCS TKR.

Why would a surgeon choose to use a mobile-bearing design? One reason would be an improved functional performance of the knee. However, we know of no reports that have demonstrated that the functional performance of a mobile-bearing knee is better than that of a fixed-bearing knee. Stiehl and associates[29] used fluoroscopy to evaluate
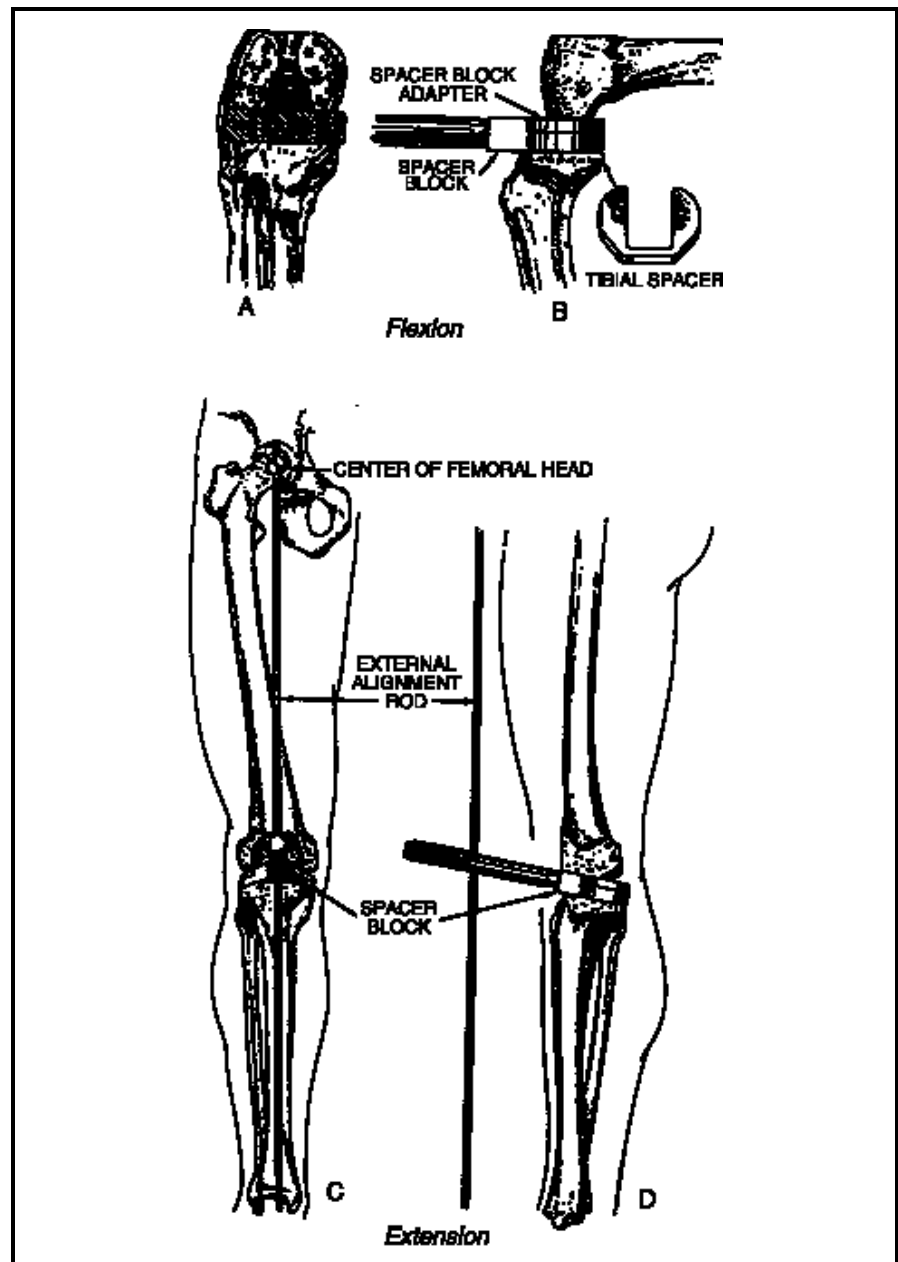

Fig. 15 Illustration showing use of a spacer block to check resection gaps during flexion and extension. **A**, AP view of flexion gap, **B**, lateral view of flexion gap, **C**, AP view of extension gap, and **D**, lateral view of extension gap. (Reproduced with permission from Buechel FF, Pappas MJ: New Jersey Low Contact Stress knee replacement system: Ten-year evaluation of meniscal bearings. *Orthop Clin North Am* 1989;20:160.)

the functional kinematics of both fixed-bearing and mobile-bearing knees. They observed that the same paradoxical anterior slide in flexion that occurs with fixed-bearing knees occurs with mobile-bearing knees. Furthermore, Dennis and associates[39] reported an average arc of flexion of 105• with the LCS knee replacement. This flexion range is less than the 110• to 120• that has been reported with some fixed-bearing knees.[69] With flexion averaging only

Table 7
Results after arthroplasty with mobile-bearing knee designs

Study	Design*	Intended Motion of Mobile Bearing	No. of Knees	Average Duration of Follow-up (Years)	Rate of Survival (%)
Murray et al[61]	Oxford unicompartmental	Anterior-posterior translation	144	10	98
Lewold et al[63]	Oxford unicompartmental	Anterior-posterior translation	699	5	90
Price and Svard[52]	Oxford unicompartmental	Anterior-posterior translation	378	10	95
Kaper et al[76]	SAL	Anterior-posterior translation, rotation	61	5.6	95
Buechel and Pappas[19]	LCS posterior-cruciate-retaining meniscal-bearing	Anterior-posterior translation, rotation	57	6	98
Jordan et al[62]	LCS posterior-cruciate-retaining meniscal-bearing	Anterior-posterior translation, rotation	473	8	95
Sorrell[66]	LCS rotating-platform	Rotation	665	11	95
Callaghan et al[15]	LCS rotating-platform	Rotation	119	9	100

*LCS = Low-Contact Stress, and SAL = Self-Aligning

105•, patients can have some difficulty in descending stairs. None of these clinical series[29,39,69] suggested that the mobile-bearing design is superior to the fixed-bearing design with regard to providing ligamentous stability and soft-tissue balance of the TKR. Therefore, no functional superiority has been demonstrated with this design concept.

A second reason for choosing a mobile-bearing knee design would be a reduction in the number of mechanical failures and in the rate of revision. To our knowledge, no reports have indicated that the rate of mechanical failure of mobile-bearing knee replacements is superior to that of good fixed-bearing designs. Scuderi and Insall[70] reported that the rate of survival of the metal-backed Insall-Burstein design (Zimmer, Warsaw, IN) was 98.7% at 14 years. Ritter[3] reported that the rate of survival of the AGC knee design (Biomet, Warsaw, IN) was 98% at 15 years. Buechel and Pappas[19] reported that the rate of survival of the rotating-platform design of the LCS knee was 97.5% at 12 years. Jordan and associates[62] reported that 3.6% of 473 LCS knees had been revised at the time of the 8-year follow-up. Clearly, the mobile-bearing design is not superior with regard to the prevention of mechanical failure and revision.

One commonly stated reason for using a mobile-bearing design is that it allows younger patients to be more active. However, this is a theoretical argument because there are no data in the literature that supports this concept, as far as we know. The patients in the series reported by Buechel and Pappas[19] were an average of 64 years old, and those in the study by Jordan and associates[62] were an average of 68 years old. The mobile-bearing design was used in a typical TKR population in both studies. Therefore, no conclusion can be drawn with regard to the superiority of the device for patients who have a high activity level. Furthermore, Ranawat (unpublished data, 1998) reported that a high percentage of patients with a fixed-bearing knee were very active. Eighty-six percent of the 96 patients walked for exercise. These patients also participated in many other sporting activities, including golf, tennis, and gymnasium activities. Fixed-bearing knees provide almost all patients with the ability to participate in their desired activities.

Perhaps the most common argument for the use of a mobile-bearing design is that wear is reduced because the articulation surfaces are more congruent.[71] To date, this improved congruency has been seen only in full extension and perhaps between full extension and 30• of flexion.[25] This large extension contact arc cannot be maintained in flexion because a curvature mismatch of the articulation occurs. Matsuda and associates[72] showed that there are fixed-bearing knees that have better contact stresses and reduced contact forces at 60• and 90• of flexion compared with LCS knee replacements.[73] A study of the Tricon-II mobile-bearing knee (Smith & Nephew Richards, Memphis, TN), by Parks and associates,[16] indicated that the difference between fixed-bearing and mobile-bearing knees with respect to the average and peak stresses on the upper surface is only 2 to 3 MPa. Parks and associates[16] found that there was undersurface stress between the mobile-bearing undersurface of the polyethylene and the metal tray that was 40% of the upper surface stress. We know of no

implant-retrieval studies that have shown that the mobile-bearing concept does in fact reduce wear. Long-term studies of fixed-bearing and mobile-bearing knees have shown no difference in the rate of osteolysis.[19,62,70,74] The concept that a mobile-bearing design is associated with less wear than is a well-designed fixed-bearing knee has not been proved and remains a theoretical argument. Perhaps the best argument in favor of the mobile-bearing design is that the undersurface wear is better controlled than it is with some modular tibial designs, which were shown by Parks and associates[16] to be associated with particle formation. Maybe the best knee replacement is a fixed-bearing knee with an all-polyethylene tibial component cemented into the tibial bone.

The increased attention on mobile-bearing knee replacements might be best confined to investigators who desire to do controlled studies in an attempt to prove the superiority of the design. Certainly, a mobile-bearing knee design can be selected by surgeons who prefer it, even though the results will not be different from those with a good fixed-bearing design. However, these surgeons must be willing to accept a 1% to 2% rate of mechanical failure associated with use of a mobile tibial insert.[62,75] It is also important that surgeons do not select the mobile-bearing design because of the expectation that placement of the tibial component does not need to be as accurate as that with a fixed-bearing design and that the mobile insert will correct for malrotation of the tibial component. Again, we know of no data that support this argument, and it is incumbent on the surgeon to perform a good operation no matter what the design because bad surgery always has a much greater chance of leading to a bad result. Furthermore, the findings of Parks and associates[16] suggest that undersurface wear increases with malrotation of a mobile-bearing design.

Summary

In summary, if TKRs are to be performed in patients who are younger and more active than those who had the initial procedures in the 1970s and 1980s, better wear performance is imperative for long-term durability, especially if surgeons continue to consider the versatility associated with modular knee-replacement systems to be a necessity. At least with some designs, including the Oxford knee and the LCS knee, the results after a minimum follow-up of 10 years are comparable with the best results after arthroplasty with fixed-bearing designs in terms of wear, loosening, and osteolysis[4,19,51-53,62,65,66,76] (Table 7). As with fixed-bearing designs, there are additional challenges in terms of optimizing bearing-surface conformity and improving kinematics. Improvements in future designs of mobile-bearing total knee replacements should include better control of bearing mobility patterns to reduce the prevalence of the abnormal kinematic motions that have been observed in fluoroscopic evaluations.

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