Advantages of Mobile-bearing Total Knee Arthroplasty

a report by

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Early historical failure of total knee arthroplasty (TKA) was frequently secondary to aseptic loosening, often associated with malalignment, instability, or use of excessively constrained prosthetic components. With the addition of better surgical instrumentation and operative techniques (ligamentous balancing, improved alignment, etc.) and the use of lower-conformity prosthetic devices, loosening rates have been minimized. However, the use of lower-conformity TKA designs resulted in a reduction of polyethylene contact area and premature polyethylene wear, and peri-prosthetic osteolysis became a predominant mode of TKA failure. The excellent 10–15-year outcomes of TKA has encouraged many surgeons to perform TKA on younger patients. Typically, these subjects have increased activity requirements and longevity expectations approaching three decades or more. To meet the demands of these younger patients, future TKA design must improve functional performance and reduce articular bearing surface wear, while maintaining the excellent long-term fixation typically obtained in properly aligned and balanced TKAs in use today. The purpose of this article is to review factors affecting polyethylene wear following TKA, particularly the design and technical problems of mobile-bearing TKA.

Polyethylene Wear Factors

Reduced polyethylene wear after TKA requires use of meticulous surgical technique, avoidance of kinematic patterns known to accelerate polyethylene wear, and innovative prosthetic design improvements. Surgeon-controlled strategies include precise ligament balancing, reproduction of anatomical extremity alignment, restoration of the proper joint-line level, and assurance of symmetry and balance of the flexion and extension gaps. Attention to these factors will encourage uniform loading of the articular surface, rather than placing eccentric medial or lateral loads.

In vivo fluoroscopic studies of multiple implant designs following TKA have demonstrated multiple kinematic variances from the normal knee, including paradoxical anterior femoral translation during deep-knee flexion, reverse axial rotational patterns, femoral condylar lift-off. Paradoxical anterior femoral translation during deep flexion increases subsurface polyethylene shear forces and risks accelerated polyethylene wear. Femoral condylar lift-off creates excessive loads on both the polyethylene bearing and subchondral bone, risking premature polyethylene wear and prosthetic loosening. These adverse effects are amplified in TKA designs that have reduced conformity in the coronal plane—flat-on-flat designs—due to edge-loading of the prosthetic components.

Design factors shown to reduce polyethylene wear include use of thicker polyethylene bearings, improvements in the polyethylene locking mechanisms of modular tibial components, use of better sterilization techniques, returning to use of TKA designs with increased articular surface conformity, and the use of mobile-bearing TKA systems.

Contact stress studies have demonstrated rapidly increasing polyethylene stresses with decreases in polyethylene thickness of less than 8mm. Wear of the inferior surface of modular fixed-bearing polyethylene inserts (backside wear) is common and contributes to microscopic polyethylene particle generation and osteolysis. This has resulted in design changes to improve the rigidity of modular locking mechanisms and minimize undersurface wear (cobot–chromium tibial trays, highly polished modular baseplate surface, etc.). Various reports have documented the association of gamma irradiation sterilization techniques in the presence of oxygen with accelerated polyethylene wear due to increased oxidation of polyethylene and disruption of polyethylene polymer chains. Numerous polyethylene sterilization techniques have been introduced to reduce polyethylene oxidation and the associated polyethylene degradation and wear, including use of gamma irradiation in an inert environment (inert gas or vacuum), ethylene oxide, or gas plasma sterilization techniques. Another method of reducing contact stresses at the articulating surface and reducing polyethylene wear is to increase implant conformity (i.e. a measure of the radius of curvature of two opposing articulating surfaces). The higher the conformity of two aligned articular surfaces, the greater the contact area and the lower the subsurface polyethylene contact stress per unit area, resulting in a reduced potential for polyethylene wear. Analysis of contact area versus contact stress demonstrates a dramatic reduction of contact stress as contact area is increased, at least until

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In order to capitalize on the benefits of a highly conforming articular interface, alternative design concepts such as the use of a mobile-bearing TKA have been adopted. Mobile-bearing TKA designs have the advantage of allowing increased implant conformity and contact area without dramatically increasing stresses transmitted to the polyethylene material or fixation interface. The presence of polyethylene-bearing mobility minimizes the transfer of torsional stresses to the fixation interface, which have been associated with failure of fixed-bearing TKA implants. This is supported by excellent long-term clinical results in numerous studies of mobile-bearing TKA, which report revision rates for aseptic loosening to be as low as 0–0.2%. By increasing sagittal plane conformity in mobile-bearing TKA, in vivo fluoroscopic analyses have demonstrated improved control of anteroposterior translation with reduced paradoxical anterior femoral translation, particularly when tested during gait. The increased coronal plane conformity typically present in mobile-bearing TKA increases the contact area and lessens the increased contact stresses that are present if femoral condylar lift-off occurs. The increased conformity and reduction in contact stresses in mobile-bearing designs have been shown to substantially lower polyethylene wear in numerous evaluations. McEwen et al. noted a four-fold reduction in wear in knee simulator testing of a rotating-platform TKA versus a fixed-bearing design with identical femoral component geometry (see Figure 2).

Advantages of self-alignment include maintenance of large, centrally located surface contact areas at the femorotibial articulation during both flexion–extension and axial rotation of the knee, the potential facilitation of central patellar tracking, and reduction of stresses transmitted to posterior cruciate substituting tibial posts. In fixed-bearing TKA, if substantial internal rotation of the tibial component relative to the femoral component is present the tibial tubercle is lateralized, allowing better centralization of the extensor mechanism. This is supported by a recent review of lateral retinacular release rate in 1,318 cases of consecutive TKA (378 fixed-bearing; 940 rotating-platform) performed by the author in which the incidence of lateral retinacular release was 14.3% in those implanted with a fixed-bearing TKA versus only 5.3% in the rotating-platform group (p<0.001). An in vivo fluoroscopic evaluation of 33 different fixed- and mobile-bearing TKA designs (>1,000 TKA) demonstrated that most TKAs experience less than 10 degrees of axial rotation with normal post-operative activities.
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However, a large number of subjects experienced axial rotational magnitudes greater than 20 degrees, which is beyond the rotational boundaries of most fixed-bearing TKA designs. Therefore, use of rotating-platform TKA designs provides the potential to accommodate a wider range of axial rotation without creation of excessive polyethylene stresses. This freedom of rotation also lessens rotational impingement and wear on posterior cruciate stabilizing posts, which has been a problem reported in fixed-bearing implants. Nakayama et al. measured contact area and polyethylene stresses on posterior cruciate, substituting posts of multiple fixed- and mobile-bearing TKA designs with the femoral and tibial components in ideal alignment and with the tibial component internally rotated 10 degrees relative to the femoral component. When the femoral and tibial components were not in ideal alignment, the highest contact area and lowest post stresses were observed in mobile-bearing implants.

In summary, the rotational freedom provided in mobile-bearing TKA assists in maintaining alignment of both the patellofemoral and femorotibial articulations throughout knee flexion. Self-alignment via polyethylene bearing rotation improves kinematics, lessens polyethylene surface stresses, and minimizes stabilizing post impingement, increasing the potential for enhanced polyethylene longevity.

Fears Associated With Mobile-bearing Total Knee Arthroplasty

Concerns expressed with the use of mobile-bearing TKA include the need for a more exacting surgical technique, the occurrence of bearing instability, the risk of enhanced polyethylene wear resulting from creation of a second articulating surface, and the hypothesis that microparticulate wear debris created from the undersurface articulation of mobile-bearing TKA designs will be smaller and have greater potential to create osteolysis. The surgical goals and techniques utilized for implantation of a mobile-bearing TKA (soft-tissue balancing, creation of equal flexion and extension gaps, precise component positioning, etc.) are no different from those utilized during implantation of fixed-bearing TKA systems.

Extension and flexion gap balance is of particular importance during implantation of a mobile-bearing TKA because imbalance risks bearing dislocation. The author has found that the use of some type of tensioning instrument (laminar spreaders, spacer blocks, or a specific gap-tensioning device) provides the most reproducible balance and tension of the extension and flexion gaps.

Specific gap-tensioning devices provide an additional advantage of facilitating equalization of the flexion gap width to the previously established extension gap. These tensioning devices have been specifically designed to allow measurements (width and tension) obtained from a balanced extension gap to direct flexion gap bone resections and femoral component rotation. Bearing instability was observed more commonly in the early years of mobile-bearing TKA use when the importance of flexion–extension gap balancing and femoral component rotation was less understood and less emphasized. With use of these modern tensioning techniques the incidence of bearing instability has been minimized, with several recent evaluations reporting an incidence of 0–2.2%.

Currently, backside polyethylene wear has not emerged as a clinically significant problem with use of rotating-platform TKA designs. Studies examining the undersurface of retrieved rotating-platform polyethylene inserts have reported minimal visual evidence of significant undersurface wear. One explanation for the lack of clinically significant backside polyethylene wear is the decoupling of multidirectional motions occurring at the articular interfaces with rotating platform TKA designs. In fixed-bearing systems, all rotational, translational, and flexion–extension motion patterns are experienced at a single (superior) articular surface, resulting in multidirectional motion pathways. In rotating-platform designs that allow no anteroposterior translation, the inferior—or tibial tray–polyethylene articulation—experiences purely rotational (unidirectional) motion patterns. Since the polyethylene bearing primarily moves with the femoral component, the superior articular surface (femoral component–polyethylene bearing interface) primarily experiences flexion–extension (unidirectional) motion since rotation is occurring on the inferior aspect of the bearing. Pooley and Tabor reported that when polyethylene is subjected to unidirectional sliding, the molecules align along the direction of motion, lowering the coefficient of friction and reducing wear of the material. Conversely, when polyethylene is exposed to multidirectional wear patterns, increased cross shear stresses are created, which cause wear. Therefore, use of rotating-platform TKA designs can reduce polyethylene wear by decoupling multidirectional motions to more monodirectional motion patterns occurring at two differencing interfaces, thus reducing cross shear stresses and wear at both interfaces.

In contrast to purely rotating-platform TKA designs, additional mobile-bearing TKA systems exist that permit both rotation and anteroposterior translation to occur on the inferior aspect of the polyethylene bearing. In these designs the inferior aspect of the polyethylene bearing is exposed to multidirectional motion patterns. Close follow-up evaluation of these mobile-bearing designs is merited to see if premature failure due to backside wear occurs.

Another explanation for minimal undersurface polyethylene wear is the high contact area (typically >700mm²) present at the inferior mobile articulation (see Figure 3). This high contact area has been shown to generate mean subsurface polyethylene stresses of less than 8MPa at this articulation when subjected to forces up to five times body weight. The fear that microparticulate debris created from mobile-bearing TKA will be smaller and more osteolytic is not supported by the recent analysis of
Brown et al. They analyzed the number, size, osteolytic potential (individual reactivity of the debris created), and functional osteolytic potential (reactivity of the individual particles plus the actual number of particles created) of microparticulate debris created in both fixed- and rotating-platform TKA during a knee simulator evaluation. No difference in particle size and, therefore, no difference in the biologic activity of the microparticulate debris of fixed- versus mobile-bearing TKA was observed. The fixed-bearing TKA group demonstrated a higher functional osteolytic potential because the magnitude of the microparticulate debris created in fixed-bearing TKA was over four times higher.

Summary
Use of mobile-bearing TKA allows the incorporation of increased implant conformity without an associated increase in fixation interface stresses and resultant aseptic loosening. The increase in sagittal conformity creates more predictable and controlled anteroposterior motion during gait, while increased coronal conformity prevents excessively high polyethylene stresses if femoral condylar lift-off occurs. Additionally, the increase in conformity increases surface contact area, decreases subsurface polyethylene stresses, and should ultimately decrease polyethylene wear. The rotating articulation is more forgiving of tibial component rotational malalignment and patient outliers who demonstrate excessive axial rotation following TKA. It facilitates some correction of patellar alignment by facilitating centralization of the extensor mechanism.

Self-alignment of the polyethylene insert with the femoral component also minimizes medial and lateral tibial post wear in situations where a posterior cruciate substituting system has been utilized.

While mobile-bearing TKA designs demonstrate a number of favorable features compared with fixed-bearing systems, it is important to remember that all mobile-bearing systems are not the same. Differences exist in both condylar geometry and bearing mobility patterns. To date, a purely rotating-platform design has emerged as the most clinically successful mobile-bearing design. However, the kinematics of mobile-bearing TKA are not perfect. Situations still exist in which femoral condylar lift-off and reverse rotational patterns occur, and paradoxical anterior sliding during deep flexion can occur in non-stabilized designs. Future goals include the development of mobile-bearing TKA designs that create better control of bearing mobility patterns.
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