Alternative Bearings in Total Knee Arthroplasty

Albert O. Gee, MD, and Gwo-Chin Lee, MD

Abstract

Total knee arthroplasty (TKA) is durable and reliable to relieve pain and improve function in patients with end stage arthritis of the knee joint. However, the demographics of patients undergoing TKA is changing; younger and more active patients are electing to undergo knee replacement surgery. In recent years, improvements in design, polyethelyne, and materials promise to reduce wear and improve the durability of TKA further. In this article we review these improvements, including cross-linked polyethelyne, mobile bearings, and alternative bearing surfaces used in TKA.

Total knee arthroplasty (TKA) has revolutionized the management of osteoarthritis of the knee, eliminating pain and improving function. With improvements in design and newer materials, modern TKAs have 10- to 15-year survivorships of 80% to 97%.[1-7] However, the need for longer lasting knee replacements continues in light of a more active, longer living patient population, as well as an increasing proportion of younger patients requiring TKA in recent years. Efforts to design a better, longer lasting knee have turned to alternative bearings and surfaces in an effort to reduce wear and osteolysis. In this article, we review the alternative bearing options for TKA.

HIGHLY CROSS-LINKED POLYETHYLENE

Advances in polymer chemistry have allowed for improvements in the wear and mechanical properties of inserts made of ultra-high molecular weight polyethylene (UHMWPE). Although some techniques, including direct compression molding and sterilization in inert gas, have improved the qualities of these inserts, others, such as carbon-reinforced polyethylene, have been promising in vitro but proved disastrous in vivo.[8,9]

A new modification of polyethylene inserts is cross-linking, a process that remains a topic of debate among experts in the field. Cross-linking of UHMWPE has been shown to improve wear resistance. Unfortunately, this process comes at the cost of reduced mechanical properties (ie, decreased ductility, less resistance to fatigue failure).

Cross-linking, most often achieved by irradiating UHMWPE, promotes formation of covalent bonds between the polymer chains in the amorphous phase. These bonds increase the wear resistance of the bearing surface over that of UHMWPE. Numerous simulator studies have borne this out in both TKA and total hip arthroplasty (THA) settings.[10-12]

Cross-linking, however, generates free radicals, which can cause oxidative degradation of polyethylene once it is removed from the vacuum packaging. Elimination of these free radicals involves annealing UHMWPE at temperatures above its melting temperature, which alters the crystalline structure of the material and subsequently decreases its mechanical properties, making it more susceptible to fatigue failure. This susceptibility is of particular concern in the knee, where contact stresses are higher than in the hip, and has led to apprehension in going forward with this new technology in TKAs, as it has in THAs.

The newest generation of highly cross-linked polyethylene, engineered to address this concern, uses several methods to preserve mechanical integrity while eradicating free radicals.

One method is to better preserve the crystallinity of UHMWPE, by annealing it at temperatures below its melting point. The result is a larger population of unquenched free radicals, an issue addressed with multiple cycles of irradiation followed by submelting-point annealing.[13-16]

Another method is to mechanically deform the irradiated UHMWPE below its melting temperature. This mobilizes the crystalline phase of the polyethylene and thereby allows quenching of free radicals that would otherwise remain trapped in that phase.[17]

A third method is to add free radical scavengers, in lieu of annealing. The most commonly investigated compound is α-tocopherol (vitamin E), a molecule that occurs naturally in cell membranes, where it has the same antioxidant role.[18,19] Studies have shown that cross-linked UHMWPE that underwent postirradiation doping with vitamin E had wear characteristics similar to those of cross-linked UHMWPE that underwent heat annealing, but had better fatigue resistance.[19]

Dr. Gee is Clinical Instructor, and Dr. Lee is Assistant Professor, Department of Orthopaedic Surgery, University of Pennsylvania, Philadelphia, Pennsylvania.

Address correspondence to: Gwo-Chin Lee, MD, Department of Orthopaedic Surgery, University of Pennsylvania School of Medicine, Penn Presbyterian Medical Center, 1 Cupp Pavilion, 39th St & Market St, Philadelphia, PA 19104 (tel, 215-662-3340; fax, 215-349-5128; e-mail, gwo-chin.lee@uphs.upenn.edu).

Am J Orthop. 2012;41(6):280-283.

Figure 1. Ceramic total knee system. Image courtesy of Kinamed (Camarillo, California).

Only a few investigators have conducted clinical studies of highly cross-linked polyethylene. Long-term data comparing highly cross-linked and conventional UHMWPE are not available. Hodrick and colleagues[20] retrospectively studied the radiographic and clinical outcomes of highly cross-linked versus conventional UHMWPE. Comparison of 200 consecutive TKAs (100 highly cross-linked, 100 conventional) performed by the same surgeon showed that there was no significant difference in the revision rate for a loose tibial component, and no catastrophic polyethylene failures were observed at a mean follow-up of 75 months. On the other hand, highly cross-linked polyethylene liners have been used in THA for significantly longer periods and studies have shown better wear resistance, compared with conventional polyethylene.[21-23] Although the loading environments of the hip and knee are beyond comparison, the improved wear resistance properties seen in these studies seem to favor similar subsequent findings for highly cross-linked liner wear in TKA. Further studies, including randomized control trials comparing highly cross-linked and conventional UHMWPE, are needed to determine the efficacy of this technology in improving implant longevity.

CERAMIC AND METAL BEARING SURFACES

Use of ceramics in TKA has been sporadic and has not achieved the level of use that it has in THA. Because of concerns regarding the brittleness of ceramic and its inability to withstand high-impact forces, its use has been limited in the United States. In mechanical studies however, ceramic components manufactured in Japan exhibited the potential to withstand forces generated at the knee.[24] Several in vivo studies have been conducted on TKAs with ceramic implants.[25,26] Akagi and colleagues[27] reported a series of 223 TKAs performed with the Bisurface total knee replacement (Kyocera, Kyoto, Japan; Kinamed, Camarillo, California), an alumina-on-polyethylene knee prosthesis with a ball-and-socket joint that, in the midposterior section of the femoral and tibial components, serves as a stabilizing cam mechanism (Figure 1). Survivorship of 94% was found at a mean follow-up of 6 years, patient satisfaction (Hospital for Special Surgery knee score) was high, and there were no revision surgeries for component fractures. However, the authors acknowledged their experience was limited to Japanese patients, and they did not rule out that, in other, heavier patient populations, ceramic fracture might be a concern.

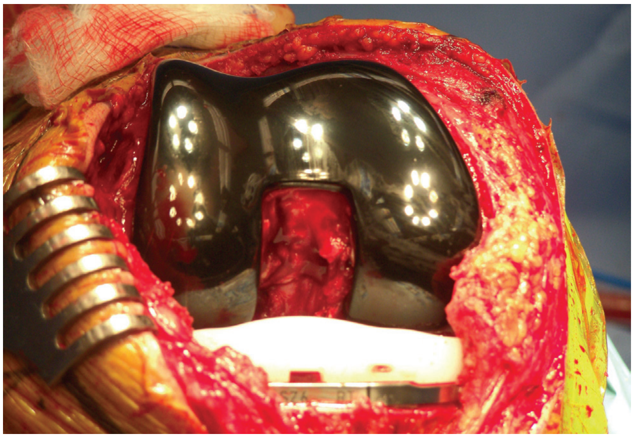

Figure 2. Oxidized zirconium femoral component (Oxinium) from Legion knee system (Smith & Nephew, Memphis, Tennessee).

Newer iterations of ceramic femoral components in TKA have turned to a new material, zirconium (Figure 2). Zirconium is a metal that can be oxidized to become zirconia, a ceramic. Femoral components are designed by heating the outer surface of zirconium in the presence of oxygen such that a layer of zirconia ceramic forms over the metal zirconium core. This process gives the prosthesis the low-wear properties of the ceramic on its articulating surface and the strength of the metal zirconium within its core, and it appears to make the prosthesis far less susceptible to the catastrophic brittle fractures that have occurred in alumina bearings in THA.[28] Simulator studies have shown as much as an 85% reduction in the wear rate at 5 million gait cycles for oxidized zirconium femoral components articulating on polyethylene, compared with cobalt-chrome-on-polyethylene TKAs.[28-30]

In 2003, Laskin[31] reported early results for the Genesis II prosthesis (Smith & Nephew, Memphis, Tennessee) and its oxidized zirconium (Oxinium) femoral component. Seventy-six patients with this component were doing well at 2-year follow-up and none required revision surgery. Another 28 patients were randomly assigned to receive the oxidized zirconium femoral component versus a standard cobalt–chromium molybdenum femur. There were no differences between

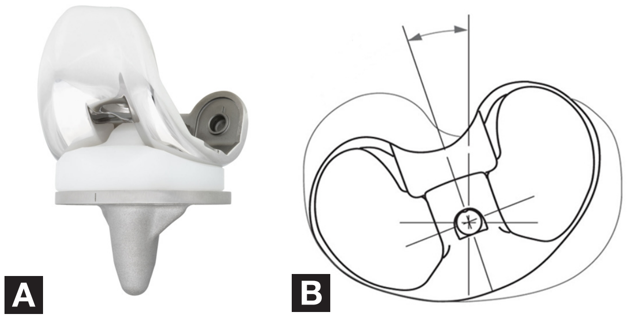

Figure 3. (A) Sigma rotating-platform mobile-bearing knee system (Depuy, Warsaw, Indiana). (B) Diagram of rotating mechanism of polyethylene insert within tibial component.

groups except for an earlier return of knee flexion after surgery in the zirconium group, which was not seen at 2 months.

MOBILE BEARINGS

Use of mobile bearings in TKA is not new. Mobile bearing arthroplasties have been in use since the 1970s.[32] However, their lower wear potential and more natural knee kinematics have been heralded as the next generation in TKA design and especially ideal for use in young, active patients.[33]

Although they have several variations, all mobile bearing knee arthroplasties consist of a moving polyethylene bearing between the femoral and tibial components (Figure 3). The different mobile bearing designs differ in the way they allow either rotation or translation of the polyethylene bearing. This includes rotation about a longitudinal axis located at different points on the tibial surface and, in newer designs, rotation and anteroposterior translation. Implants that incorporate some degree of free motion can be manufactured to have femur–polyethylene articulation that is more congruent than that provided by fixed bearing knees. This reduces contact stresses and decreases wear. With more freedom to rotate, the implant more closely mimics the normal knee throughout flexion and extension and therefore decreases the torque stress on the implant at the prosthesis–bone interface.[33,34]

Results from follow-up studies of mobile bearing knees have been consistent regarding these theoretical advantages; they have shown long survivorship and few complications. Buechel and colleagues,[35] Callaghan and colleagues,[36] and Sorrells and colleagues[37] reported excellent outcomes and survivorship rates (9 to 20 years) for several different mobile bearing knee systems.

The complications of mobile bearing knee designs include dislocation of the polyethylene platform and the potential for increased backside wear. Dislocation rates have ranged from 0% to 9%.[36,38-40] As would be expected, the surgical technique has a steep learning curve; surgeons who operate at higher volumes have fewer dislocations.[41]

CONCLUSION

Ongoing research and engineering are being focused on longer lasting and reliable TKA designs. Implant manufacturers working with adult reconstruction surgeons are trying to achieve these goals by making knee design advances that minimize wear debris and decrease risk for loosening and implant failure. The need to perform TKAs in younger, healthier patients with high demands makes this imperative. Technology development has been focused on better wear–resistant UHMWPE, femoral components that create less debris when articulating with polyethylene, and use of mobile bearings to reduce stresses within the knee.

Although prostheses and biomaterials continue to advance, it is important to remember that in vitro results may not translate to in vivo situations. That lesson was learned with carbon-reinforced polyethylene in the 1980s. Knee replacements are highly successful. Arthroplasty surgeons have at their disposal implants with varying shapes, sizes, interfaces, and fixation methods. Nevertheless, we must not forget that the most important determinant of TKA survivorship remains a well-balanced, well-aligned, well-fixed implantation procedure.

AUTHORS' DISCLOSURE STATEMENT

The authors report no actual or potential conflict of interest in relation to this article.

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Quick Poll NEW!

Which alternative bearing do you prefer in total knee arthroplasty?

○ **A.** Highly cross-linked polyethylene

○ **B.** Ceramic and metal bearing surfaces

○ **C.** Mobile bearings

○ **D.** Other ____________________

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