A Review Paper

Alternative Bearing Surfaces—Do We Need Them?

Gerald R. Williams, Jr., MD, and Joseph P. Iannotti, MD, PhD

Abstract

In this article, we describe briefly the biological mechanisms responsible for aseptic glenoid loosening, review current alternative bearing surfaces, and provide data supporting use of these surfaces for glenoid components.

Shoulder arthroplasty provides reliable pain relief and improved function in more than 90% of patients with glenohumeral arthritis. In patients with an intact rotator cuff and mild to moderate deformity, functional improvement can be spectacular. Although some controversy still exists regarding the relative roles of hemiarthroplasty and total shoulder arthroplasty (TSA), the preponderance of world literature supports glenoid resurfacing with ultra-high molecular weight polyethylene (UHMWPE) as providing more predictable pain relief than hemiarthroplasty alone. However, TSA survivorship, currently 80% to 87% at 15 years, is limited primarily by the durability of polyethylene glenoid components.[1-3]

Aseptic glenoid component loosening is the most common prosthesis-related cause of failure after TSA.[4,5] The etiology of aseptic glenoid loosening is obviously multifactorial. However, glenoid component wear, with generation of polyethylene wear debris, is likely a major factor. The rate of particle generation through polyethylene wear may be partially mitigated by proper positioning of the components and modification of patient activity. Modification of the polyethylene chemical structure or substitution of the metal-on-polyethylene bearing surfaces with alternative bearing surfaces (eg, metal on metal, ceramic on polyethylene, ceramic on ceramic) may produce dramatic decreases in component wear.

In this article, we describe briefly the biological mechanisms responsible for aseptic glenoid loosening, review current alternative bearing surfaces, and provide data supporting use of these surfaces for glenoid components.

Dr. Williams is Professor, Orthopaedic Surgery, The Rothman Institute at Thomas Jefferson University, Philadelphia, Pennsylvania.

Dr. Iannotti is Maynard Madden Professor and Chairman, Department of Orthopaedic Surgery, Cleveland Clinic, Cleveland, Ohio.

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Aseptic Glenoid Loosening

Aseptic component loosening in prosthetic joints with metal-on-polyethylene bearings is thought to result largely from progressive, periprosthetic osteolysis. This osteolysis, a biological response to polyethylene wear particles, depends on the size, shape, material composition, number, and composite volume of the particles. Cytokines released by macrophages and giant cells that phagocytize polyethylene wear debris mediate this osteolytic response. Polyethylene glenoid wear is thought to contribute to 20% of prosthetic failure after TSA.[6] Therefore, development of bearing surfaces with wear characteristics better than those of metal-on-polyethylene surfaces seems logical.

Alternative Bearing Surfaces

Alternative bearing surfaces have been used in total hip arthroplasty and to a lesser extent in total knee arthroplasty. Metal-on-metal, ceramic-on-ceramic, and ceramic-on-polyethylene bearings have all been found to decrease wear rates, both in vitro and in vivo, when compared with traditional metal-on-polyethylene bearing surfaces. However, each of these bearing combinations poses real and potential difficulties, and none has been in use for as long a time as traditional metal-on-polyethylene bearings.

Metal-on-metal bearings produce metal particles through standard wear mechanisms and metal ions from corrosion. Metal particles are smaller than polyethylene particles and are produced at a slower rate, thus yielding a lower volume. Therefore, the biological response to metal wear particles is presumably less pronounced, with a potentially lower aseptic loosening rate. Metal ions (especially chromium and cobalt) are electrically charged and combine with proteins to form ion-protein complexes. These complexes may be responsible for activation of the immune system and generation of hypersensitivity responses. These metal hypersensitivity responses are uncommon but may cause progressive osteolysis and aseptic component loosening. Although literature confirming metal toxicity is lacking, some surgeons are still concerned about organ toxicity and cancer resulting from metal-on-metal articulations. In addition, many total joint arthroplasty surgeons will not use a metal-on-metal

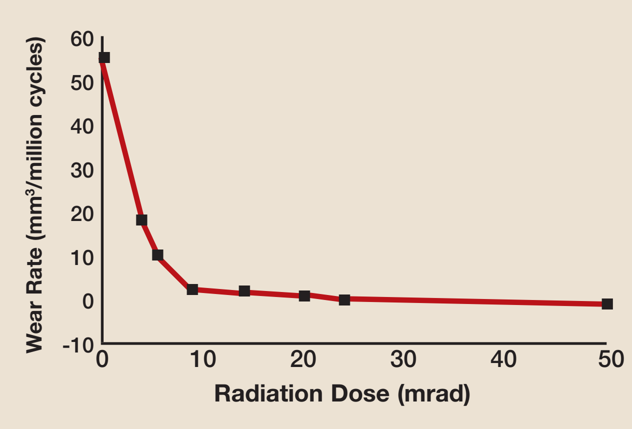

Figure 1. Polyethylene wear versus radiation dose in acetabular components. From: McKellop and colleagues. Development of an extremely wear-resistant ultra high molecular weight polyethylene for total hip replacements. *J Orthop Res.* 1999;17:157-167. Reprinted with permission of Wiley—Liss, Inc., a subsidiary of John Wiley & Sons, Inc.[7]

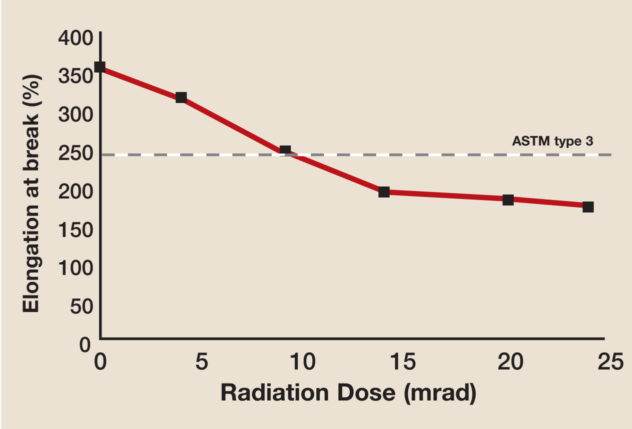

Figure 2. Elongation to break (ie, failure) versus radiation dose in acetabular components. Dotted line represents the threshold recommended for medical devices. ASTM indicates American Society for Testing and Materials. From: McKellop and colleagues. Development of an extremely wear-resistant ultra high molecular weight polyethylene for total hip replacements. *J Orthop Res.* 1999;17:157-167. Reprinted with permission of Wiley—Liss, Inc., a subsidiary of John Wiley & Sons, Inc.[7]

prosthesis in female patients of childbearing age, because of potential ion interaction issues. Currently, there are no metal-on-metal bearings for TSA.

Ceramic bearing surfaces (both ceramic on ceramic and ceramic on polyethylene) have been used in hip replacements for more than 20 years. As with other hard-on-hard bearing surfaces (eg, metal-on-metal), wear rates of ceramic-on-ceramic articulations are dramatically lower than those of traditional hard-on-soft bearings (eg, metal-on-polyethylene). The catastrophic femoral head failures that were reported early on have been reduced or eliminated with changes in materials and processing. However, anecdotal reports of acetabular loosening and squeaking in ceramic-on-ceramic joints have contributed to the popularity of ceramic-on-polyethylene bearings. The need for a thin glenoid component and the desirability of a male taper on the head, with the resultant stress riser at the head–male taper junction, provide significant challenges for adapting ceramic bearing surfaces to the shoulder. No ceramic shoulder bearing surfaces are commercially available, but the favorable wear characteristics may drive development in this area.

Using gamma irradiation and heat to alter the chemical structure of UHMWPE improves the wear characteristics of this material. Gamma irradiation produces cross-linking of the polyethylene molecules to an extent proportional to the radiation dose. This cross-linking reduces mobility of adjacent polyethylene chains and increases the resistance of the material to deformation and wear. This cross-linked material may be further processed by heating or remelting. Remelting forces molecular recombination, extinguishes free radicals, and reduces oxidative potential. Polyethylene components are sold in oxygen-free packages, as oxygenation dramatically reduces mechanical properties over time and reduces shelf life.

Although cross-linking improves the wear characteristics of UHMWPE, it also diminishes important mechanical properties, such as yield strength, ultimate tensile strength, and elongation to break.[7] Therefore, it is important to select an irradiation dose that substantially improves deformation and wear characteristics but does not alter mechanical properties in a clinically relevant way. Treating UHMWPE with 10 mrad and 5 mrad produces highly and moderately cross-linked polyethylenes, respectively. Moderately cross-linked polyethylene offers up to 80% less wear than conventional polyethylene and 27% more elongation to break (ie, failure) than highly cross-linked polyethylene (Figures 1, 2).[7] Short-term follow-up studies of total hip arthroplasty have confirmed 72% less wear in moderately cross-linked acetabular components than in conventional polyethylene when adjusted for patient activity.[8] Cross-linked polyethylene tibial components have not been used as much in total knee arthroplasties, in which the loading characteristics (high forces, nonconforming surfaces) may make the trade-off of improved wear and decreased mechanical properties less desirable.

Cross-Linked Polyethylene Glenoid Components

The loading environments in the shoulder and knee are similar in that motion is a combination of gliding and rolling. However, shoulder loads are substantially less than knee loads. Early clinical and laboratory experience with hip replacement led to investigation of using moderately cross-linked glenoid components in shoulder replacement. This investigation confirmed favorable wear characteristics of moderately cross-linked polyethylene in a shoulder-specific wear simulator.

One result of that finding is that a glenoid component (Global Anchor Peg and keel components; DePuy Orthopaedics, Inc., Warsaw, Ind) is now being manufactured from moderately cross-linked polyethylene (Marathon; DePuy Orthopaedics, Inc., Warsaw, Ind). It is hoped that the significant decrease in the gravimetric in vitro wear rate of this component will increase its durability. Until the clinical data become available, however, continued research into other alternative bearing surfaces for TSA is justified. The ultimate goal is to produce a glenoid component that, for all potential TSA recipients, will last a lifetime.

Authors' Disclosure Statement

Both authors wish to note they are consultants for DePuy Orthopaedics, Inc., and receive royalty payment for some of the DePuy shoulder prosthetics.

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