MODERN ALTERNATIVE BEARING SURFACES FOR TOTAL JOINT ARTHROPLASTY

Conf. Dr. Adrian Barbilian
Army’s Central Hospital

Abstract – The biologic response to polyethylene particulate debris generated from metal-on-polyethylene bearing surfaces is thought to be largely responsible for periprosthetic osteolysis and aseptic loosening in total joint arthroplasty. As a result, there has been an interest in developing polyethylene with improved wear characteristics, as well as a renewed interest in alternative bearing surfaces for total joint arthroplasty, including ceramic-polyethylene, metal-metal, and ceramic-ceramic articulations. These alternative surfaces have demonstrated less friction and lower wear rates than metal-on-polyethylene bearing surfaces in both clinical and laboratory experiments. Clinical results, although only short- to mid-term, have been encouraging. Alternative bearing surfaces, with lower wear rates and less particulate debris formation, may have the potential to improve total joint arthroplasty survivorship by decreasing periprosthetic osteolysis, especially in younger, high-demand patients.

Keywords – metal-on-polyethylene, joint arthroplasty, bearing surfaces

The articulating bearing surface most commonly used for total hip arthroplasty (THA) is a metal femoral head manufactured of either stainless steel or cast or wrought cobalt-base alloy articulating against a high-molecularweight polyethylene acetabular component. In use since 1961, metal-on-polyethylene bearings have demonstrated good to excellent clinical results and are considered the standard against which all alternative bearings must be compared. However, wear of the polyethylene (75 to 250 µm/yr) and resultant periprosthetic osteolysis are major long-term concerns that affect implant longevity, particularly for young, active patients. Periprosthetic osteolysis and aseptic loosening are thought to be primarily due to the body’s reaction to polyethylene particulate debris generated from the metal-polyethylene articulation. Accumulation of particulate debris can result in an aggregation of macrophages that attempt to phagocytize it. The ensuing chronic inflammatory response is characterized by the release of lytic enzymes, proinflammatory cytokines, and bone-resorbing mediators, resulting in osteolysis that can cause aseptic loosening and fixation failure. Current prosthesis design utilizes strategies for minimizing the generation of polyethylene debris and its damaging effects, such as avoiding the use of large-diameter femoral heads, improving polyethylene quality, avoiding excessively thin (<5 mm) polyethylene, increasing the stability of modular connections, and avoiding the use of metal-backed cups with screw holes.4 As alternatives to metal-on-polyethylene bearings, ceramic femoral heads have been used to articulate with the polyethylene, or the polyethylene has been eliminated entirely by the use of either metal-on metal or ceramic-on-ceramic bearings. In the laboratory and clinical setting, these alternative bearings produce less particulate debris and incite a less intense chronic inflammatory reaction than standard metal-on-polyethylene articulations.

1. Ceramic-on-Polyethylene Bearings in Total Joint Arthroplasty

The most common alternative bearing used for THA is the ceramic-on-polyethylene articulating surface. The ceramic femoral head can be made of either aluminum oxide or zirconium oxide. Alumina ceramics were the first to be introduced for use in total joint arthroplasty, but there were clinical problems due to their brittleness and propensity to fracture. To combat this problem, zirconia ceramic, with improved toughness and wear properties, was introduced. Zirconia ceramic exhibits one fifth the wear of alumina ceramic on polyethylene, and its greater toughness permits the use of femoral heads with smaller diameters than those made of alumina. Nevertheless, cases of fracture of zirconia ceramic femoral heads have also been reported. Clinical and laboratory wear rates for ceramic-on-polyethylene bearings are generally considerably less than those for metal-on-polyethylene bearings. Wear rates for ceramic-on-polyethylene bearings have varied in the literature, ranging from 0 to 150 µm/yr and averaging 10% to 50% less wear than with a standard metal femoral head on polyethylene. Theoretical advantages of ceramic femoral heads
over metal femoral heads include the following: (1) Ceramics have superior lubrication properties. (2) Ceramic polishing achieves a smoother surface than can be achieved with metal, decreasing the coefficient of friction of the bearing surface and thus improving wear characteristics. (3) Ceramic femoral heads are much harder than metal femoral heads and therefore less susceptible to third-body wear and scratching of the surface. (4) Ceramics are inert and maintain their surface finish without evidence of ion release.

In contrast, metallic femoral heads undergo oxidation and resultant surface roughening; during motion, the surface can be worn away, leading to metal ion release. Despite the decreased wear rates of ceramic-polyethylene articulations, clinical reports of periprosthetic osteolysis and catastrophic polyethylene wear have also been observed. Currently, there is no evidence of a clinical benefit or reported decrease in revision rates for the ceramic-on-polyethylene bearing compared with a metal-on-polyethylene bearing.

2. New-Generation Ceramic-on-Ceramic Bearings in Total Joint Arthroplasty

In 1970, Boutin was the first to report on the use of an alumina ceramic-on-ceramic bearing for total joint arthroplasty. At about the same time, Mittelmeier also developed a ceramic-on-ceramic bearing for total joint arthroplasty consisting of a threaded noncemented cup and a press-fit femoral stem (Fig. 1). It was demonstrated that ceramics have excellent biocompatibility due to their highly oxidized state, excellent tribologic properties (lubrication, friction, wear), extreme hardness, good surface finish, and biologic inertness. Early failures with ceramic-on-ceramic articulations, arising from poor implant design and use of low-quality ceramics, dampened the initial enthusiasm engendered by low wear rates in the laboratory. Newer designs display clinical and laboratory wear rates averaging 0.5 to 2.5 μm per component per year, and ceramic quality has been strictly standardized. However, the possibility of brittle fracture and the high cost of the ceramic components are factors that must be considered before their more widespread use.

Factors associated with early failure of the initial ceramic-on-ceramic hip bearings included improper positioning of the acetabular component and small femoral head sizes. Vertical cup placement, which increased contact stresses at the rim of the cup, resulted in localized fragmentation and third-body wear.

The use of smaller ceramic femoral heads (<28 mm) also increased localized contact stresses at the acetabular component. Furthermore, the use of poorly designed taper locks that connected the femoral head to the stem resulted in increased junctional hoop stresses, which caused tensile stress and fracture.

The use of the newer-generation press-fit ceramic-on-ceramic bearings allows increased surgical ease in obtaining correct implant positioning. The ceramic bearing insert fits into the acetabular hemispherical shell through a taper lock.

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All-ceramic conical liners concerns positioning into the metal acetabular shell. The liners are not self-centering, and due to the low angle of the truncated cone and the hardness of ceramic, incorrect positioning during insertion may result in fracture of the conical liner. While several institutions in the United States are currently conducting clinical trials to evaluate this experimental press-fit design, these newer-generation ceramic-on-ceramic bearings have been used in Europe since 1990.

Clinical results at 5-year follow-up have shown that rates of patient satisfaction and radiographic evidence of loosening are similar to those obtained with standard metal-on-polyethylene bearings. These studies have demonstrated a 1% incidence of component fracture and incorrect operative positioning of the ceramic conical liner. The high modulus of elasticity of ceramic has also been linked to the early failure of the all-ceramic acetabular components in THA. Because of the high rigidity and resultant low-energy absorption of ceramic, direct transmission of loads to the periacetabular bone occurs. Early-generation ceramic-on-ceramic hip bearings demonstrated better results in younger patients due to the increased strength of the periacetabular bone. Because the periacetabular bone in elderly patients was osteoporotic, there was decreased tolerance of hip force transmission, which eventually led to acetabular component migration.

To reduce the rigidity of the ceramic-on-ceramic bearing, newer designs have combined the force-dampening qualities of polyethylene with an articulating ceramic bearing. The alumina articular liner with an outer lining of polyethylene is fitted into a modular metal-back acetabular cup. The polyethylene, with a lower modulus of elasticity, is capable of absorbing and distributing forces to a greater extent than ceramic.

The reduction of rigidity offered by the addition of polyethylene may extend the range of indications for use of ceramic-on-ceramic implants to include the elderly with poor acetabular bone stock. Early results from studies with 5-year follow-up are encouraging. Patient’s Harris hip scores improved from a preoperative mean value of 47.8 to a postoperative score of 92.6. Follow-up radiographs at 1 year displayed no change in acetabular cup position, and no evidence of wear or loosening.
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In 1984, M.ller and Weber reintroduced the concept of metal-on-metal components with new materials and implant designs. Weber fixed a 28- or 32-mm cobaltchromium-molybdenum inner bearing in the polyethylene insert of a noncemented metallic shell. At follow-up a mean of 3.5 years after THA, 98 of 100 patients had good to excellent results, and only 4% had evidence of aseptic loosening. Analysis of retrieved femoral heads demonstrated linear wear rates ranging from 4.0 to 5.9 µm per component per year values similar to the wear rates in the authors in vitro hip simulator studies. Other studies of metal-on-metal bearings have shown no aseptic loosening at short-term follow-up and consistently good to excellent clinical results.

Laboratory data for this new-generation metal-on-metal bearing surface have demonstrated improved tribologic characteristics. Wear tests in hip simulators have demonstrated that new-generation metal-on-metal bearing surfaces generate fewer particles than metal-on-polyethylene articulations. Laboratory wear rates for metal-on-metal bearings are notably lower than those for metal-on-polyethylene bearings, ranging from 2.5 to 5.0 µm per component per year. However, there remain clinical concerns about the possibility of an increased incidence of malignant disorders due to the presence of metallic particles and ions in metal-on-metal THA bearings. Visuri et al concluded that the gross variation in the incidence of different cancers among patients with THA compared with the general population is likely attributable to factors other than the particular implant used. Clinical trials are currently under way in the United States, but in Europe several metal-on-metal bearing designs are already in use, including the Weber cemented socket, the press-fit acetabular cup of Marchetti, the Wagner noncemented cup, the elastic socket of Spotorno, the St.hmer prosthesis, the Zweym.ller prosthesis, and the M.ller cemented and noncemented all-metal systems. All these metalon-metal implants have in common a forged 28-mm CoCr acetabular bearing inserted into an outer polyethylene socket or liner. While the clinical results with early metal-on-metal bearing designs were inferior to those for metal-on-polyethylene bearings, the initial follow-up results of the newer metal-on-metal THA bearings have been encouraging. Longer follow-up is necessary, and continued research in the epidemiology of possible malignant conditions due to metal-on-metal articulations is needed before these implants can be advocated for widespread clinical use.

3. New-Generation Metal-on-Metal Bearings in THA

4. Summary

The reemergence of alternative bearing surfaces for total joint arthroplasty, after the initial success of metal-on-polyethylene bearings, has been largely spurred by findings of an association between polyethylene wear debris and periprosthetic osteolysis. Periprosthetic osteolysis is often seen in the younger, more active, higher-demand patient. Alternative bearing surfaces, with lower wear rates, can potentially improve the longevity of implant survival for the higher-demand patient by decreasing particulate debris formation and the resultant osteolysis.

Patients who are older and less active will continue to be well served by metal-on-polyethylene bearings, because such bearings will undergo less cycling and thus be subject to less wear. As new advances in prosthesis design and material properties have occurred over the past 30 years, the problems of particulate debris (primarily generated at the femoral head polyethylene articulation) and periprosthetic osteolysis and aseptic loosening have become the subjects of intense clinical and laboratory research. Alternative bearing surfaces have the potential to be the next major breakthrough in thwarting these problems and increasing implant longevity, especially in younger, more active patients.

5. References


