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Editorial

The Hard on Hard Bearings in THA – Current concepts

1. Introduction

Total hip arthroplasty has been one of the most successful inventions of the last century with useful results in decreasing pain and improving function in patients with degenerative disease of the hip. Improvements in prosthetic materials, designs and implant fixation have now resulted in wear of the bearing surface being the limitation of this technology, and a number of hard-on-hard bearings have been used to address this Problem. Metal-on-metal total hip replacements were first implanted by Wiles in the 1930s and later developed in the 1950s and 1960s by pioneering surgeons like McKee and Ring. Latest ceramic-on-ceramic bearings have demonstrated excellent survival with very low wear rates and virtually no local side effects. Hard-on-hard bearings for total hip arthroplasty have improved dramatically over the past several decades. With the introduction of new materials in bearing surface options, it is likely that the use of hard-on-hard bearings will continue to increase, especially in young.

THA patients are becoming younger it was indicated for patients over 60 years old. Now the average age is somewhere between 50 and 60. Around 15% of all hip replacements finally will require a revision, the major reason being aseptic loosening. The numbers are going to increase, as the disease process is becoming more common in younger group. This has placed very high demands on the implants and materials used, particularly their wear proneness. The major invention of the last century was Charnley's low friction concept but wear that his implants produced over time triggered many important advances in alternate bearing surfaces. The major advances in ceramic manufacture is the attempt to reduce inclusions, reduce grain boundaries to improve strength, and improved quality assurance of manufactured ceramic components. Surface roughness is lower in ceramics than with metal, and we realize the lowest wear rate with ceramic-on-ceramic couples. There are mixed reports about ceramic-on-polyethylene vs. metal-on-polyethylene wear rates. Crosslinked polyethylenes have performed satisfactorily when used in combination with either. A concern of crosslinked polys is their relative reduction in mechanical properties particularly fracture toughness which can influence liner integrity in modular cups particularly at locking mechanism sites or when used with large diameter heads which result in reduced liner thickness. Large-diameter bearings can be successful if the wear rate is low. Any area of these cups where one experience a radical change in curvature can create a stress riser. Once one get an initiated crack as a result of a stress riser in a crosslinked poly, it will propagate very quickly. It is well established that particulate debris generated from the hard-on-soft articulating surfaces initiates a cascade of adverse tissue response leading to osteolysis and in certain cases loosening of the components. Extending the longevity of total joint replacements using alternative bearing technologies with improved wear behavior has been the subject of ongoing research in the orthopaedics.

2. Hard-on-hard bearing surface

Periprosthetic osteolysis and aseptic loosening are serious problems affecting the outcome of total joint replacement. Polyethylene particulate debris generated from metal-on-polyethylene bearing surfaces and the resulting biologic response to this debris are thought to be largely responsible. The new-generation all-ceramic and all-metal prostheses have demonstrated, both clinically and in the laboratory, lower friction and wear rates than metal-on-polyethylene bearing surfaces.[1] Improvements in prosthetic materials, designs, and implant fixation for THA have led to bearing surface wear being the limitation of this technology. Because of the projected substantial future increase in the need for THA and the increasing demands placed on prostheses by a younger and generally more active patient population than previously treated by surgery, there has been renewed interest in developing new technologies.[2] The second approach to the development of more wear-resistant bearings has involved the use of hard-on-hard bearing couples. These bearings have the potential to provide advantages in terms of improved implant tribology (lubrication, friction, wear), increased longevity, and reduced dislocation rates.[2] Despite the popularity of metal-on-polyethylene articulation usage since THA was first popularized a half-century ago, hard-on-hard bearings have consistently been used, though to a lesser extent. Thus a layer of the weaker material lines the stronger material, changing the interface at which movement takes place. During mechanical action, these micro-junctions are torn off, and fragments may become particles or be transferred from body to counterbody and vice versa, bringing about surface damage in the form of flakes and pitting. If the generated flakes and particles are bigger than the clearance of the bearing, they may act as abrasive particles or even block the joint. The availability of near-anatomic femoral head sizes and the extremely low in vitro wear rates of these bearings, even when compared to modern crosslinked polyethylene liners, theoretically make them an appropriate choice in young and highly active patients.[2] Despite the recognized success and worldwide acceptance of total hip arthroplasty, wear of the UHMWPE component is a major obstacle limiting the longevity of these reconstructions. Recently, some authors have recommended the use of a ceramic-on-highly-crosslinked polyethylene bearing in younger active patients, which is postulated to provide low wear rates while minimizing the possibility of component chipping or squeaking, the use of ceramic-on-metal bearing couples has been proposed as an alternative that may provide benefits in terms of wear similar to those of ceramic-on-ceramic articulations, while further decreasing the incidence of component chipping or squeaking.[2] When contact occurs between metal and polyethylene components, both surfaces deform, but the deformation of the metal component is negligible and the metal component behaves like a rigid indenter. Thus, when an artificial joint is loaded, the polyethylene is squeezed between the rigid metal component and the supporting material (bone, cement, or metal backing), and in the region of contact, the articulating surface of the polyethylene is forced to conform to the shape of the metal surface. The resulting deformation causes compressive, tensile, and shear stresses in the polyethylene. The magnitude of the stress depends on the magnitude of the joint load. Hard-on-hard bearings (metal-on-metal [MOM] and ceramic-on-ceramic [COC]) have been increasingly utilized in the past decade in an attempt to improve the long-term results of THA. One presumed advantage is lower wear rate and debris generation from the articulating surface. Wear rates of MOM and COC hip prostheses reportedly have two to three times less volumetric wear than metal-on-polyethylene (MOP) when tested in laboratory settings. MOM articulations allow for larger head-neck ratios than current options for MOP, which allows for a larger ROM before impingement and stability. Recent studies demonstrated larger-diameter metal heads decreased dislocation rates to as low as 0.05% and were able to better approximate anatomic femoral heads in primary arthroplasty, Surgeons should be guarded when considering the use of current MOM technology in female patients.[3] At the surface, the largest compressive stresses are the contact stresses that act perpendicular to the surface. They decrease nonlinearly with depth through the thickness of the polyethylene. Joint contact also produces compressive and tensile stresses within the polyethylene component that act tangent to the articulating surface. Tangential compressive stresses occur because the polyethylene under the center of the contact area expands radially as the component is compressed. This expansion is resisted by the surrounding material, and tangential compressive stresses are produced. Tangential tensile stresses near the articulating surface occur because the surface must stretch as the polyethylene conforms to the shape of the metal component when the joint is loaded. The stretching occurs near the edge of the contact area. The resulting tensile stresses are largest at the surface of the component. Surface damage is most likely due to combinations of stress components. Through recent decades, many solutions have been introduced to improve the survivorship of THA including bearing surfaces such as alumina-on-alumina and metal-on-metal. Survival improved by working on the nature and the quality of the head. Improvements might also be obtained by working on the quality and the hardness of the acetabular socket.[4] The risk of short-term complication (including dislocation) and revision THA were similar among appropriately matched THA patients regardless of bearing surface.[5] The aluminium oxide femoral head, showed no signs of macroscopic indentations or scratches, suggesting that an aluminium oxide bearing surface, which is significantly harder than the CoCrMo debris, is not significantly affected by metal debris embedment in the counterface material In porous metal surface THA, ceramic-on-ceramic bearing couples should, due to their superior hardness, be considered to prevent excessive wear, including debris embedment and scratching of the bearing surfaces, especially in revision cases.[6] The most common polymer particles encountered in association with joint prostheses are PMMA and UHMWPE particles. Many long-term studies of total hip arthroplasty (THA) show excellent results. This long-term success depends on many factors, including implant fixation and bearing surface wear. As THA is commonly performed on patients with a steadily increasing life span and activity level, the issue of wear has become critical. Advances in the wear properties of polyethylene have been significant, but, in the search for low long-term wear rates, hard bearing surfaces are frequently used.[7] In the non-weight-bearing area PE, in contrast, discoloration and oxidation were hard to detect. The weight-bearing surface of the PE head became smoother with time after THA. Scanning electron microscopy showed a fine undulating pattern, which suggested that hydrodynamic lubrication could occur in the rotating PE-head system.[8] Whereas historically THA implant failure was frequently the result of aseptic loosening associated with failure of fixation and implant fracture, improvements in prosthetic materials, designs, and implant fixation resulted in wear of the bearing surface being the primary mechanical limitation of this technology in otherwise correctly implanted metal-on-polyethylene components.[9] Alternative bearing surfaces are of two types: low-wear metal-on-polyethylene articulations and bearing surfaces using couples other than metal-on-crosslinked polyethylene bearings are being used in an estimated 70% of primary and revision THAs.[10] Although national joint registry data suggest overall revision rates of modern standard head size metal-on-metal articulations appear to be similar to, or lower than, those found with metal-on-ceramic and ceramic-on-ceramic articulations.[11] Specific increases in wear rate are dependent on the nature of the damage to the femoral head. Ceramics are harder and therefore more resistant to damage by third-body particles than metal counterfaces. For this reason, the increased hardness of ceramic materials is considered advantageous. The pattern of damage by a hard third body in metals and ceramics differs.[12] Interestingly, in the metal-on-metal group with large femoral heads (52 mm), all patients experienced very high separation values after heel-strike in the first 30% of stance phase, which decreased to a no-separation condition during midstance. In the metal-on-metal group with small-size femoral heads (38 mm), the trend was similar to the other bearings with small femoral heads.[13]

3. Metal-on-metal bearings

It is also apparent that metal-on-metal implants have the ability to self-heal, that is, to polish-out isolated surface scratches caused by third-body particles or subluxation damage. The overall clinical performance of second-generation metal-on-metal hips to date has been comparable to that of conventional metal-on-polyethylene hips. MOM hip bearings produce wear particles by some combination of the four classic mechanisms of adhesion, abrasion, corrosion, and surface fatigue, with an emphasis on abrasion and surface fatigue.[14] Wear in metal-on-metal total hip arthroplasty implants is known to consist of two distinct phases. A relatively high-wear running-in phase, which lasts for between 0.5 and 2 $\times$ 106 cycles, is followed by a steady-state phase, during which the wear rate is constant and much lower. This decrease in wear has been demonstrated to be secondary to the so-called self-polishing effect of metal-on-metal bearing surfaces. Metal-on-metal total hip arthroplasty implants can operate in the mild mixed lubrication regime in which much of the applied load is supported by elastohydrodynamic films. Promotion of the most effective elastohydrodynamic films calls for the largest possible head diameters and the smallest clearances that can be reasonably adopted consistent with fine surface finishes, good sphericity, polar contact, and minimal structural elastic deformation of the cup on its foundations[15] in vitro study. Affatato et al. demonstrated that femoral heads of 36 mm in diameter work in the mixed-lubrication regime and 28-mm diameter heads work in the boundary-lubrication regime, with substantially higher volume depletion due to wear.[16] With the 32-mm heads, operating in the mixed lubrication regime.[17] An increase in diameter up to 54 mm resulted in a marked reduction in wear rates, which was attributable to growing support from the fluid-film action in a mixed-lubrication regime. Alloys of cobalt (Co) and chromium (Cr) have been preferred for MOM bearings in THR because of their hardness. Contact stresses are a function of material properties and are inversely proportional to contact area. Smaller clearances encourage fluid film lubrication. Large clearances lead to a reduced contact area, loss of effective lubrication, and more rapid wear.[18] However, too little clearance may lead to equatorial contact, very high frictional forces, high torque, and loosening of the implant.[19] Equatorial bearing may have been a factor associated with failure of some early MOM THRs, and this is supported by retrieval studies. Consequently, relatively polar contact is preferred.[20] For MOM bearings, in distinction from PE bearings, larger diameters can actually produce lower wear rates for similar manufacturing parameters.[21] It appears that a patient with normal renal function is capable of clearing cobalt and chromium ions. The incidence of osteolysis associated with MOM bearings has not been well established but appears to be comparatively low.[22] A histological study of tissues surrounding MOPE and MOM THAs showed that fewer macrophages were present in the tissues surrounding MOM THAs than in the tissues surrounding MOPE THAs.[23] It is demonstrated that tissues surrounding failed MOM THAs with low to moderate quantities of metal particles could induce the production of potentially osteolytic cytokines.[24] These authors described this reaction as an aseptic lymphocytedominated vasculitis-associated lesion (ALVAL) or as a lymphocyte-dominated immunologic (LYDIA) answer.[24] The transplacental transfer rate was in excess of 95% in the controls for both metals, but only 29% for chromium and 60% for cobalt in study patients, suggesting that the placenta exerts a modulatory effect on the rate of metal ion transfer.[25] On the basis of these findings and the lack of comprehensive knowledge regarding the potential effects of metal ions on fetal development, metal-on-metal total hip arthroplasty probably should not be performed in women of child-bearing age until additional information is available.[26]

4. Ceramic bearings

Ceramics are hydrophilic, permitting a better wettability of the surface. This ensures that the synovial fluid-film is uniformly distributed over the whole bearing surface area. The alumina on alumina bearing is considered the standard ceramic on ceramic articulation.[27] Alumina ceramic bearings have been in clinical use for more than three decades, and significant basic science and clinical research support their use. Most important, the incidence of osteolysis associated with use of ceramic on ceramic bearings appears to be minimal or nonexistent.[28] Polyethylene will mold around a femoral head if there is an initial, small incongruity, which is not true with ceramics, and poor manufacturing can lead to high wear rates. The lack of ceramic deformation makes the contact areas between the head and socket smaller as compared with metal on polyethylene articulations. Improved manufacturing techniques have resulted in smaller grain size and smoother finish helping to reduce the fracture risk that was encountered when using earlier generations.[27] The ceramic-on-metal articulations produced slightly smaller particles although they were far fewer in number.[29] The potential advantage of this novel ceramic-on-metal bearing is lower wear and the generation of significantly fewer metal particles compared with currently available metal-on-metal bearing surfaces. This bearing combination allows for the use of large femoral heads, similar to metal-on-metal bearings. Potential disadvantages of this new bearing articulation include the risk of a ceramic femoral head fracture and its as-yet unknown clinical performance.[27] A third body (bone cement or bone fragment) left in the taper interface or impingement of the femoral component on the rim of the ceramic acetabular liner secondary to malpositioning of the components could also initiate ceramic fracture.[30]

5. Conclusion

As bearing designs continue to improve with new and modified materials and improved manufacturing techniques, it is likely that the use of hard-on-hard bearings will continue to increase, especially in young and active patients. Osteolysis from wear debris is commonly viewed as the major obstacle blocking the development of a "lifetime" hip. Normal cartilage is an example of a compliant bearing that has a low modulus but is capable of large deformation without failure scientific expectation is invention of a similar articulation which is yet to be materialized. Improvements in the manufacturing of bearings over the past 50 years have resulted in implants that provide low wear rates and allow for the use of large femoral heads.

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