

**EXPERT  
REVIEWS**

# State of the art in hard-on-hard bearings: how did we get here and what have we achieved?

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Total hip arthroplasty has shown excellent 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 couples have been introduced to address this concern. The purpose of this article is to review the origins, development, survival rates and potential advantages and disadvantages of the following hard-on-hard bearings for total hip arthroplasty: metal-on-metal standard total hip arthroplasty; metal-on-metal hip resurfacing arthroplasty, ceramic-on-ceramic total hip arthroplasty; and ceramic-on-metal bearings. Improvements in the manufacturing of metal-on-metal bearings over the past 50 years have resulted in implants that provide low wear rates and allow for the use of large femoral heads. However, concerns remain regarding elevated serum metal ion levels, potential teratogenic effects and potentially devastating adverse local tissue reactions, whose incidence and pathogenesis remains unclear. Modern total hip resurfacing has shown excellent outcomes over 10 years in the hands of experienced surgeons. Current ceramic-on-ceramic bearings have demonstrated excellent survival with exceptionally low wear rates and virtually no local adverse effects. Concerns remain for insertional chipping, *in vivo* fracture and the variable incidence of squeaking. Contemporary ceramic-on-metal interfaces are in the early stages of clinical use, with little data reported to date. Hard-on-hard bearings for total hip arthroplasty have improved dramatically over the past 50 years. 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.

**KEYWORDS:** alumina • ceramic-on-ceramic • ceramic-on-metal • cross-linked polyethylene • hip resurfacing • metal-on-metal • pseudotumor • total hip arthroplasty

Since its introduction approximately 50 years ago, contemporary total hip arthroplasty has been shown to be reliably effective at reducing pain and improving function at follow-up times of a decade or more in the large majority of patients. Initially, this procedure was primarily intended for use in older, low-demand patients with end-stage degenerative joint disease, with the goal of reducing disease-related pain and affording sufficient mobility for activities of daily living. However, the life expectancy in developed countries continues to increase, and many patients with degenerative hip disease wish to maintain high activity levels well into older age [1]. In addition, the use of hip arthroplasty

in young patients has been increasing [301], and this population typically places higher demands and stresses onto orthopedic implants, while also having several decades of life expectancy remaining. As a result, total hip arthroplasty is frequently being used in patients who expect to maintain highly active lifestyles for decades following the procedure [2–4].

Historically, the dominant bearing surface in total hip arthroplasty was a metal head articulating with a polyethylene acetabular component. Initially, implant loosening due to any of a number of factors, such as implant fracture, failure of cement fixation, osteolysis or stress shielding, was the primary mode of failure with hip

arthroplasty prostheses [5]. However, improvements in prosthetic materials, implant designs and methods of fixation led to bearing materials being a major limitation of this technology. Ever since associations were described between higher activity levels, increased polyethylene wear rates, polyethylene debris and early implant failure due to aseptic loosening [6–8], renewed efforts have been made to develop more advanced bearings to both decrease wear rates and reduce bearing dislocation rates. In general, these efforts can be categorized into one of two groups: modification of the traditional metal-on-polyethylene bearings; and the development of alternative hard-on-hard interfaces. Highly cross-linked polyethylene, manufactured by  $\gamma$ -irradiation of the base material, has increased in popularity substantially over the past decade. In 2008, cross-linked polyethylene was used in approximately 75% of hip replacements performed in the USA, more than ten-times the number of cases performed using standard polyethylene [9]. While cross-linking of polyethylene has been demonstrated to reduce wear rates [10,11], concerns remain regarding decreased resistance to fatigue following irradiation, despite anti-oxidation strategies, such as serial melting or doping with vitamin E [12–14]. The second approach has involved the development of bearing couples with hard materials, such as metal and ceramic, that promised to increase implant longevity through improved tribology (more uniform lubrication and decreased friction), lower dislocation rates and decreased wear.

The purpose of this article is to review the origins, development, survival rates and potential advantages and disadvantages of the following hard-on-hard bearings for total hip arthroplasty:

- Metal-on-metal standard total hip arthroplasty;
- Metal-on-metal hip resurfacing arthroplasty;
- Ceramic-on-ceramic total hip arthroplasty;
- Ceramic-on-metal bearings.

### Search strategy

A thorough search was performed of the PubMed and EMBASE databases to identify all relevant articles using combinations of the following keywords: metal-on-metal, ceramic-on-ceramic, ceramic, alumina, hip arthroplasty, hip resurfacing and hip replacement. Any articles that reported either *in vitro* or *in vivo* results of, or complications with, the use of metal-on-metal, ceramic-on-ceramic or ceramic-on-metal bearings for hip arthroplasty, as well as review articles addressing these topics, were retrieved and reviewed. Only English language articles, or those with English abstracts were included. Any reports of studies that evaluated revision hip arthroplasties, or that included fewer than 20 hips, were excluded. The reference lists of all relevant manuscripts were referenced against the list of those retrieved from the database search, and any that were not present were sourced and retrieved for review. Primary source articles were grouped by the type of bearing interface addressed, and the following data were extracted to a spreadsheet for each *in vivo* study: the number of hips studied, follow-up times, the type of implant and bearing, including method of fixation, survival rates, the incidence

and type of complications, and wear rates if reported. For all *in vitro* studies, the data extracted included: the number and type of bearings studied, the experimental methodology used and the reported findings, including wear rates. The extracted data were then systematically reviewed and summarized. In addition, the potential advantages of decreased wear, decreased osteolysis and lower incidence of dislocation were assessed for each bearing couple. The reported complications were reviewed to identify any potential disadvantages related to the individual interfaces.

### Metal-on-metal standard total hip arthroplasty

#### Origins, development & results

Metal-on-metal total hip arthroplasty prostheses were reported as early as the 1930s, but the first modern stemmed femoral designs appeared around 1960, at approximately the same time as metal-on-polyethylene articulations. In 1966, McKee and Watson-Farrar reported that 94% of the first 50 patients treated with their prosthesis had no pain and ambulated with minimal or no limp at follow-up times of 2–4 years [15], and design improvements were made based on this initial experience in an attempt to further improve the outcomes with this implant [16,17]. However, there were concerns that these first-generation metal-on-metal prostheses had a higher rate of aseptic loosening than the Charnley metal-on-polyethylene implants and despite the incomplete understanding of the mechanisms of failure, these bearings were largely abandoned by the mid-1970s [18–20]. Nevertheless, some investigators have reported good long-term survival rates for these first-generation devices ranging from 74 to 85% at follow-up times from 20 to 28 years [21,22]. An overview of selected survival rates of early and contemporary metal-on-metal total hip arthroplasty can be found in TABLE 1.

Some authors have suggested that limitations in manufacturing technology may have resulted in inconsistent and suboptimal dimensions of these early-generation metal-on-metal prostheses [23–25], leading to excessive friction, seizing and implant loosening. While the importance of consistent component sphericity and avoidance of equatorial articulation (a condition where the acetabular inner diameter is smaller than the outer diameter of the femoral head, leading to loading of the rim-head interface, see FIGURE 1) have been demonstrated in *in vitro* studies, neither of these phenomena have been consistently demonstrated in an analysis of explanted failed implants [26]. However, some retrieval studies revealed signs of impingement between the femoral neck and acetabular rim. Walker *et al.* reported impingement abrasion in a case report of a retrieved femoral stem [27]; Willert *et al.* reported impingement abrasion in two of eight retrieved femoral stems [28]; and Howie *et al.* reported impingement damage in nine of 24 retrieved McKee–Farrar stems [29]. These reports suggested that component design issues, such as inadequate offset of the head, and/or an excessively thick or poorly positioned neck, perhaps exacerbated by malpositioning of the acetabular cup, may have been responsible for the higher failure rates reported with these components.

In the late 1980s to early 1990s, a second generation of metal-on-metal devices was introduced in an attempt to reduce the substantial incidence of osteolysis and aseptic loosening associated

