



Review

What's next? Alternative materials for articulation in total joint replacement

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ABSTRACT

The use of an artificial joint is always related to a certain amount of wear. Its biological effects, e.g., the osteolysis potential, are a function of the bulk material as well as its debris. Following comprehensive experiences with polyethylene (PE) wear, material science is tracking two ways to minimize the risk of a particle-induced aseptic implant loosening: (i) reduction of the PE debris by a low-wearing articulation partner; and (ii) replacement of the PE by other materials. Therefore, new ceramics (e.g., ZTA, Si_3N_4), as well as coatings (e.g., TiN, “diamond-like” carbon) and modifications of a bulk metal (e.g., oxidizes zirconium) or cushion bearings (polyurethane, hydrogels), are currently available for total joint replacements or have been used for pre-clinical testing. This review gives a brief overview and evaluates the potential of those that have recently been published in literature.

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1. Introduction

The development of Sir John Charnley's concept of low friction arthroplasty and the introduction of polyethylene (PE) in the 1960s paved the way for modern materials research in orthopedic tribology. Today, total replacement of the large natural joints, both hip and knee, has evolved into a reliable and appropriate surgical intervention for patients who suffer intractable pain due to excessive joint degeneration [1]. It is performed 2–3 million times per year worldwide, with survival rates of ~90% after 10 years for total hip (THA) and total knee arthroplasty (TKA) [2].

Current material standards include conventional ultrahigh molecular weight PE, its younger cross-linked variant (XPE), cobalt chromium (CoCr) metal alloys and alumina (Al_2O_3) or zirconia-toughened alumina (ZTA) ceramics. Their wear performances are summarized in Fig. 1 [3–8]. As one can see, new so-called hard–hard bearings that consist of only metal or ceramic materials possess an extremely low *in vitro* wear rate in the range of the detection limit. PE has been the preferred bearing material in total joint replacement (TJR) for the last 40 years. However, in more than 70% of all THA revisions, implant loosening has proved to be the major reason for premature failure and is mainly associated with the biological potential of conventional PE debris [9]. With the introduction of XPE in the late 1990s, this failure mechanism has been addressed, so that XPE can certainly be described as the current “gold standard” in THA. Good wear performance as well as lower biological potential following mid-term results have

been clearly established [6,10–12]. To date, XPE is the material that will serve as a reference in THA and against which future bearing materials need to be evaluated. CoCr offers a wide range of positive mechanical properties such as high strength, hardness and elasticity. However, tribo-corrosive processes increase the levels of metal ions in local tissues and systemically (e.g., in blood) [13], sometimes causing dramatic necrotic and inflammatory changes [14] in the implant-surrounding tissue. For ceramics, foreign body reaction to debris is supposed to be negligible [15]. However, component fracture (incidence 0.004–2%) [16] and squeaking (incidence 0.7–20.9%) [17] have been reported as severe and complex problems. Current demographic developments and modern lifestyles are posing dramatic challenges for implant design and materials. The increasing numbers of younger and more active patients, in particular, mean that today's TJR might not be an adequate solution in the longer term for either the patient's compliance or the national health care systems worldwide [18]. In 1988, Mallory [19] eloquently described this situation when he stated: “all prostheses will fail sometime. It is a race between the life of the patient and the life of the prosthesis”.

With appropriate biocompatibility of the bulk material and its wear particles as minimal preconditions, new approaches can be classified according to Fig. 2. In this context, new hard bulk materials for one or both articulation partners are an option, but not mandatory for superior tribological properties. Bearings with one or both articulation partners made of a soft material (“cushion bearings”) are also considered. Other approaches are aimed at adapting the top surface layers (“coatings” or “surface modifications”) without affecting the properties of the bulk material.

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