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Review article

New alternate bearing surfaces in total hip arthroplasty: A review of the current literature

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ABSTRACT

As indications for total hip arthroplasty (THA) have expanded, the incidence of THA has increased among younger patients, who live longer and tend to place more strain on implants via higher activity levels. This demographical shift accentuates the importance of advancing innovation to ensure implant longevity for younger and more active patients. Future innovation, as it pertains to THA components, is likely to focus on modifying implant designs and tribology in conjunction with identification and application of newer biomaterials. By reviewing the literature for development status of various materials and novel design advancements in THA component outside of the standard highly cross-linked polyethylene, this investigation provided an update on the current and future status of design initiatives as they pertain to THA. Though the highlighted alternative bearing surfaces have shown promising *in vitro* and limited, yet encouraging clinical data, they lack larger and longer-term clinical trial results. Further research and innovation is warranted to identify the optimal bearing surface to most effectively accommodate for the trend of younger and more active patients undergoing THA. Implant longevity is crucial if the clinical success of THA is to be maintained.

1. Introduction

As the indications for total hip arthroplasty (THA) have expanded, the incidence of THAs being performed in younger patients has increased, with patients younger than 65 years expected to account for more than 52% of primary THAs in 2030.[1] Moreover, younger patients who undergo THA tend to place more strain on their implants via higher activity levels and also live longer, which may place them at higher risk for a revision procedure.[2,3] This shift in demographics accentuates the importance of continued innovation to ensure implant longevity for younger and more active patients.[4]

Ideal THA components should mimic normal physiology with respect to tribology.[5,6] In addition, the bearing couples should have a low coefficient of friction, high surface hardness with low ductility and scratch resistance, and generate a low volume of wear particles (Fig. 1).[5] Moreover, surfaces exposed to tissues should be non-cytotoxic, biocompatible, and bioinert.[5,6] There is evidence suggesting that it may be beneficial for the elastic modulus of the components to be similar to bone.[7–12] The likely direction of future innovation as it pertains to THA components will be focused on modifying implant designs in conjunction with the use of newer biomaterials.[5,6]

Given the predominance of highly cross-linked polyethylene (HXLPE) as the standard for bearing surfaces,[5,13] the purpose of this review was to provide an update on the development status of various materials and design advancements in THA components. Specifically, we evaluated: 1) the properties of new materials being developed for use in THA; and 2) any studies with limited clinical data to support larger, clinical trials of these materials.

2. Materials and methods

A search of the PubMed, Embase, and Scopus databases was undertaken in July 2017. The following search terms were used in individual searches: “alternative bearing surfaces,” “total hip in young patients,” “highly cross-linked PE,” “vitamin E cross-linked PE,” “oxinium,” “oxidized zirconia,” “yttria, zirconia, hip,” “silicon nitride, hip,” “silicon nitride, joint,” “horseshoe cup,” “Cambridge

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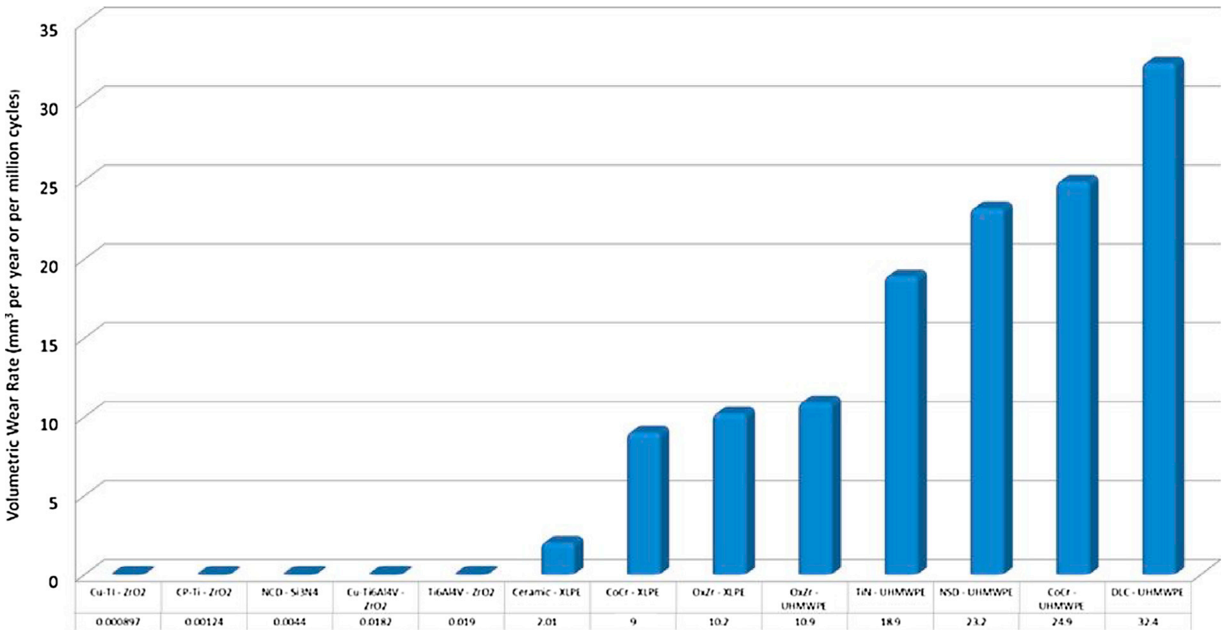

Fig. 1. Comparison of volumetric wear rates (mm^3 per year or per million cycles) among THA bearing surfaces.[27,43,46,62,63].
*The materials are labeled as the alternate bearing – articulating surface.
CoCr = cobalt chrome; UHMWPE = ultra-high molecular weight polyethylene; HXLPE = highly cross-linked polyethylene; XLPE OxZr = oxidized zirconium; TiN = Titanium nitride; DLC = diamond-like carbon; CP-Ti = commercially pure titanium; NCD = nanocrystalline diamond; Cu = copper; Ti6Al4V = titanium alloy; NSD = nanostructured diamond.

cup," "titanium nitride hip," "titanium nitride joint," "MITCH PCR," "sapphire hip," "aluminum oxide hip," "HMU-CVD," "SMS-CVD," "P25-CVD," and "carbon composite hip." After removal of duplicates, this search returned 187 unique articles. For the most updated review, studies published from January 2015 and later (and more recently than 2005 in the case of the Cambridge cup and MITCH-PCR search terms) with full text in the English language were selected for further review. Animal studies, abstracts from meetings, case reports, materials science or computer model articles with focus only on molecular structure without tribological data, review articles, articles with sole focus on non-hip joint arthroplasty, studies that discussed metal-on-metal (MoM) bearing surfaces due to the current controversies were excluded. After these exclusions, 127 articles were reviewed for relevance. Reference lists of these publications were also reviewed and articles were included when appropriate. A total of 46 were selected for full analysis. Of these articles, studies with non-clinical or limited yet encouraging clinical data were focused on.

3. Results

3.1. Innovations in ceramics

The favorable tribology of ceramics as a THA bearing surface has made them an attractive option compared to earlier implant designs that were fraught with issues related to durability and survivorship.[14] Traditionally, ceramic components were composed of alumina and zirconia, with alumina being more common. Ceramics are biologically inert, have a very low coefficient of friction and improved lubrication and wettability properties making them a promising orthopaedic bearing surface.[15] Multiple studies have demonstrated the advantageous wear characteristics of ceramic-on-ceramic surfaces, with *in vitro* studies demonstrating up to two to three orders of magnitude in improvement of wear rates between ceramic-on-ceramic and standard cobalt-chrome (CoCr) on conventional polyethylene.[16,17]

Although alumina and other ceramics were selected as bearing materials due to their superior wear properties, scratch resistance and hardness, they were found to be brittle and predisposed to fracture.[14] To combat this, newer generation composite ceramic bearings such as Biolox Delta (Ceramtec, Plochigen, Germany) have incorporated zirconia as well as chromium oxide, yttrium and strontium to prevent crack formation and propagation.[5] Fractures of ceramic implants are rare events, and reports of incidence vary in the literature. It has been estimated that the risk of fracture over the implant lifespan is around 0.03–0.05% for femoral heads and 0.013 to 0.017% for ceramic inserts.[18]

3.1.1. Sapphire

Sapphire has been explored as a potential bearing surface given its many physical and mechanical similarities to alumina. These crystals, which contain 99.99% aluminum oxide, are placed in a vacuum at 2100° Celsius, and are then prepared from single crystal formations.[19] These bearings were shown to be inert, have low friction, high wear resistance, and biologically compatible. In a small study, 5 patients received THAs that contained sapphire femoral heads and had good results at 1- and 5-year follow-up.[20,21] Further clinical testing is needed in order to validate the widespread use of this bearing surface.

3.2. Innovations in metals

In an effort to reduce the rate of complications and improve the tribological characteristics of metal-on- polyethylene (PE) and MoM bearing couples, design changes are being implemented to decrease PE wear and metal ion release, as well as the coefficient of friction for articulation.[22] Various coatings are being tested that can increase the surface hardness and smoothness of metal alloys and provide a non-metal interface, such as "ceramicizing" the femoral head with alumina composites, or titanium nitride.[22,23] The benefits of diamond and diamond-like carbon are also being explored, as well as methods for changing the composition of the underlying metal alloy.