INTRODUCTION

Total hip arthroplasty (THA), a surgical orthopedic intervention, stands as a paragon of success and cost-efficiency within the medical sphere. This well-established procedure consistently affords substantial advantages to individuals afflicted with advanced degenerative hip osteoarthritis (OA). It bestows respite from debilitating pain, reinstates functional prowess, and elevates the overall quality of life for the patient.

Hip OA represents the foremost indication for THA, with an annual prevalence of roughly 88 symptomatic cases per 100,000 patients in the United States. However, THA’s utility extends beyond this singular domain. It also proves indispensable for addressing a spectrum of conditions, including inflammatory arthritis, congenital hip abnormalities, and hip osteonecrosis (ON). These varied conditions present unique clinical profiles and demand meticulous surgical considerations.
A significant limitation associated with the metal-on-polyethylene (MoP) bearing surface is the occurrence of polyethylene wear particle generation. This phenomenon has been causally linked to the onset of periprosthetic inflammatory responses and osteolysis. This sequence of events can culminate in the ultimate malfunction and failure of the implanted prosthesis, as substantiated by previous investigations 4-8.

Likewise, patients with metal-on-metal (MoM) articulations have displayed increased serum concentrations of metal ions. These escalated metal ion levels are frequently associated with the potential manifestation of adverse repercussions, such as chromosomal anomalies and renal toxicity. 9-14.

Additionally, the reappearance of corrosion problems in total hip arthroplasties employing metal-on-polyethylene (MoP) and metal-on-metal (MoM) designs with larger femoral heads is a source of significant concern 15-17. These corrosion and wear byproducts have the potential to induce adverse tissue responses 17-19.

In contrast, ceramics, including inlays and heads, show favorable medium to long-term outcomes. Their exceptional tribological properties make them valuable alternatives to MoP or MoM combinations, especially for younger patients undergoing hip replacements 20-24.

Considering these advantages, the utilization of ceramic-on-ceramic hip prostheses is expected to rise significantly in the coming years 21.

**METHODS AND MATERIALS**

This review is based on a rigorous literature search for relevant studies on ceramic-on-ceramic (CoC) bearing surfaces in total hip replacement conducted across reputable academic databases, including PubMed, Scopus, Web of Science, and Google Scholar. The search criteria were defined to encompass a substantial historical scope, spanning the last 43 years (from January 1, 1980, to September 30, 2023), in order to comprehensively evaluate the evolution of research and advancements in the field, only English-language studies were considered. The search used a combination of keywords, including (ceramic-on-ceramic), (wear rates), (stability), (prosthetic joint infections), (aseptic loosening), (ceramic fractures), (squeaking), (hip dislocation) and (total hip replacement).

In addition to electronic database searches, manual searches were conducted to identify historic papers and earlier studies that might not be available electronically but were deemed valuable for this comprehensive review.

**Historic Background**

Ceramic bearings in the context of THA can be classified into two distinct types: Alumina and Zirconia. Notably, in 1970, Boutin pioneered the development of alumina (Al₂O₃) ceramics for bearing applications, marking a significant milestone despite the material’s broader potential utility 25.

Alumina ceramics initially showed exceptional durability and sliding properties, confirmed through implant evaluations and hip simulator tests. However, inherent limitations arose, primarily in the form of fracture risks and the complexities associated with achieving stability when coupling ceramic femoral heads with metal stems 26.

Of note, the renowned commercial brand name associated with aluminum ceramics is BIOLOX® (CeramTec GmbH, Plochingen, Germany), widely acknowledged as an indispensable ceramic for implementation in THA 27.

Over the past four decades, three distinct generations of Biolox® ceramics have been progressively developed. These include Biolox®, introduced first, followed by Biolox®forte in 1995, and subsequently Biolox®delta in 2003. Each successive generation is generally presumed to exhibit improvements over its predecessor, particularly in terms of grain size, purity, and density 28.

This technology has undergone rigorous in vitro testing and extensive clinical evaluation before its widespread application. To date, more than 11 million Biolox® bearings (CeramTec GmbH, Plochingen, Germany) have been successfully implanted.

In comparison to aluminum, zirconia emerges as a superior choice for THA applications due to its notable toughness, outstanding mechanical properties, relatively lower wear rates, and exceptional resistance to breakage 29,30.

**Biocompatibility, tribological performance, and mechanical attributes**

In the assessment of total hip arthroplasty (THA) bearing surfaces, pivotal factors encompass biocompatibility, tribological characteristics, and mechanical performance. Ceramic-on-ceramic (CoC) surfaces are
renowned for their exceptionally low wear rates. Among different bearing surfaces, ceramic-on-ceramic (CoC) exhibits the lowest wear rate, with less than 0.001 mm per year. In contrast, metal-on-conventional polyethylene has a wear rate of 0.137 mm per year, while ceramic-on-conventional polyethylene shows 0.072 mm per year. Metal-on-highly cross-linked polyethylene has a wear rate of 0.042 mm per year, and ceramic-on-highly cross-linked polyethylene demonstrates 0.030 mm per year. Metal-on-metal also maintains a low wear rate, with 0.005 mm per year.

This exceptional resistance to wear renders CoC bearings an optimal choice, particularly for younger and more active patients. The inherent hydrophilic nature of ceramic surfaces further contributes to reduced friction between moving components, ensuring effective lubrication.

Furthermore, ceramic bearings are deemed safe owing to their low release of metal ions and the exceptional biocompatibility of wear particles. Notably, no documented instances have linked pseudotumors or systemic reactions to wear particles originating from Ceramic-on-Ceramic (CoC) bearings. Hernigou et al.’s study supports alumina-alumina (Al-Al) bearings over polyethylene in reducing wear and osteolysis. In a 20-year study with bilateral arthroplasties, patients with CoC bearings experienced no hip loosening or revisions.

Osteolysis assessment, using X-rays and CT scans, consistently showed less osteolysis in CoC hips. Comparing CoP and CoC hips within patients favored CoC-bearing hips, with significantly smaller osteolysis volumes. CoC bearings have the potential to nearly eliminate radiographic osteolysis.

Additionally, several arthroplasty registries worldwide have reported a favorable association between the utilization of ceramic heads and reduced revision rates in comparison to their metallic counterparts. Implants that incorporated traditional polyethylene exhibited poorer outcomes concerning implant longevity, hip functionality, and rates of wear. In contrast, implants that included traditional polyethylene showed inferior performance in terms of implant longevity, hip function, and wear rates.

In conclusion, while hypersensitivities and metallosis are rare, ceramic heads are particularly indicated in cases where cobalt-chromium (CoCr) heads may jeopardize patient health, especially among individuals known to have metal hypersensitivity, impaired renal functions, or other relevant comorbidities.

**Stability and Dislocations**

Dislocation remains a prominent cause of revisions following primary THA procedures. At present, approximately 8% to 12% of annual hip surgeries are revision surgeries, with a notable 11% to 24% of these revisions addressing THA dislocations.

In a study conducted by Woo and Morrey involving 10,500 patients, a dislocation rate of 3.2% was reported. It is worth noting that nearly half of all dislocations occur within the initial 3 months post-surgery, and more than three-quarters take place within the first year.

Patients who have previously experienced one dislocation are at an increased risk of subsequent dislocations. Enhanced joint stability can be attributed to greater excursion distance and range of motion before dislocation, particularly when larger-diameter femoral heads are used.

CoC bearings enable the use of larger femoral heads while maintaining the dimensions of the acetabular component. This is primarily due to the reduced material thickness requirement and serves as the main rationale for their preference over other options.

In contrast to polyethylene bearings, several studies have demonstrated lower risks of late dislocations when CoC bearings are employed.

**Ceramic-on-Ceramic and prosthetic joint infections (PJI)**

Lenguerrand et al. examined numerous risk factors and their connections to PJI revision surgery. They analyzed patient-related factors like age and gender, health system-related factors such as surgical facility location and caseload, and surgery-related factors including osteoarthritis and femoral neck fractures. The study also explored various joint arthroplasty bearings and their impact on PJI occurrence. Importantly, ceramic bearings were found to be associated with a lower likelihood of PJI revision compared to metallic bearings.

An analysis of the Australian register conducted by Madanat et al. showed a higher rate of revision related to infections in both MoP and CoP hips when compared to CoC. The use of ceramic bearings led to a significantly reduced incidence of infection revision.
for patients younger than 70. These differences were observed regardless of the type of prosthesis used 53.

**Aseptic Loosening**

The concept of aseptic loosening involves debris wearing 54, and investigations conducted on hip simulators indicated a reduction in wear rates while using CoC bearings as against the MoP variants.

A hip simulator research showed an alumina liner wear rate of 0.004 mm³ in every million cycles for over 14 million cycles in steady-state for the combinations of alumina head-alumina cup. In contrast, the values observed when using polyethylene liners, as with MoP bearing, was 13 mm³ in every million cycles 55.

According to Stewart et al. (2001), hip simulator investigations previously performed under extreme micro separation circumstances showed a value of 1.3 mm³ in every million cycles while using the BIOLOX forte. Conversely, the value observed while using the BIOLOX delta component was 0.12 mm³ in every million cycles 56.

It was reported that the retrieved CoC bearings of BIOLOX forte had a mean wear rate of 0.5 and 0.6 mm³/year, respectively, for acetabular liners and femoral heads, after a minimum of six months duration in situ 57.

As in simulator studies, less wear has been observed using CoC bearings. Moreover, aseptic loosening in THAs can be reduced by applying CoC and featuring debris that appears more bioinert than the polyethylene variant 5.

Although previous studies have not yet demonstrated this outcome, it can only become evident after an extended follow-up period. The current investigation, as well as previously discussed research featuring short-term to medium-term follow-ups, showed the tendency for revisions resulting from aseptic loosening to undoubtedly be connected to component fixations when compared to the phenomenon of wear 58-60.

Even though they demonstrate more intraoperative implant fractures and squeaking, the meta-analysis data observed from the randomized controlled trial studies by Hu et al. showed support for the application of CoC bearing surfaces, with lower revision rate and reduced propensity for radiolucent line, osteolysis, dislocation, and aseptic loosening to occur, when compared to MoP 61.

Furthermore, a study based on the midterm follow-up by Bouras et al. demonstrated a good survival rate and a lower revision rate in terms of aseptic loosening following the use of Zweymuller-Plus THAs characterized by the CoC bearing 62.

**Ceramic fracture**

A commonly discussed concern regarding CoC bearing surfaces is the possibility of ceramic fractures, as noted in reference 58. Studies have reported that the incidence of fractures associated with ceramic components ranges from 0.01% to 3.5% of all cases 21,36,63.

In recent years, modern ceramic materials used in joint arthroplasty differ significantly from their counterparts in the 1970s, which were notorious for their high fracture rates 64,65.

Contemporary ceramics in the field demonstrate improved mechanical attributes, primarily attributed to heightened density and decreased grain size achieved through sophisticated manufacturing methods such as hot isostatic pressing and enhanced material compositions. Ceramic fractures typically stem from the progression of cracks induced by inherent material flaws or specific events, which extend, induce fatigue, and ultimately culminate in fractures. Consequently, meticulous attention to precise component assembly prior to implantation is of paramount importance 66. Improper engagement between titanium shell tapers and ceramic liners can potentially trigger ceramic liner fractures or chipping during insertion.

A study conducted by Koo et al. involving 24 patients who received BIOLOX forte CoC bearings after ceramic head fractures revealed that five patients required a second revision, with two patients undergoing three revisions. The reported incidence of fractures associated with ceramic components varies between 0.01% and 3.5% in the literature 61. Notably, the cup angle of CoC bearings may influence the wear patterns and fracture risk, as suggested by Leslie IJ et al. 67.

Another study by Ha et al. observed 144 hips in 122 patients over a minimum 36-month follow-up period, revealing that acetabular cups with fractures had a higher anteversion incidence than those without fractures. Fractures tended to occur during squatting, hyperflexion, and broad hip abduction, highlighting the role of impingement, particularly in patients from cultures where squatting is habitual 68,69. Traina et al. found that five out of six patients requiring revision surgery due to ceramic fractures had BIOLOX
forte-on-BIOLOX forte bearings 21, while smaller series reported fracture rates ranging from 0% to 2% in BIOLOX forte components 70,71.

The introduction of zirconia platelet-based BIOLOX delta, toughened with alumina, has reduced fracture risk compared to the alumina-based BIOLOX forte. Ex vivo studies support the improved resistance to fractures following this enhancement 21.

Hoskins et al. analyzed data from the Australian Joint Replacement Registry, revealing higher breakage rates in alumina-based bearings compared to mixed ceramics, especially for heads with diameters measuring 36-38mm 72. Smaller femoral heads (28mm) also exhibited a higher propensity to break 36,73.

Traina et al. also found that 28mm heads with short neck tapers were more prone to fractures than longer tapers, although complete neck length data in device histories is lacking. Besides material factors, ceramic fractures can result from trauma, debris interference, surgical handling, dislocations, and design mismatches between ceramic heads and metal tapers 73.

Lee et al. proposed preventive measures, including the use of a metal shell with an 18° taper angle, a 32/36-mm Delta ceramic bearing, and a stem with a reduced neck outline to mitigate ceramic fractures 74.

Hernigou et al. suggest that in cases of head fracture, the intact ceramic liner should be retained, but a new head on a new taper should be inserted to prevent crack propagation. Similarly, in cases of ceramic liner fracture, replacing it with a new ceramic liner necessitates the removal of the shell to obtain a new Morse taper 39.

In contrast, Hannouche et al., in a retrospective study, reported no fractures of ceramic heads implanted on a previous titanium trunion. However, they recommend inspecting the Morse taper for imperfections or small cracks when preserving it 73.

Considering personal clinical experience, the author proposes an alternative approach involving the use of commercially available head-neck metal adapters, such as the MereteTM, BioBallTM system (Merete Medical, Berlin, Germany), often considered in off-label usage 76.

**Squeaking**

The term squeak is a sound that others can potentially hear, which develops from THAs while in motion. This sound may be described as clicking, squeaking, or grating 77. Squeaking is not limited solely to Ceramic-on-Ceramic (CoC) bearing surfaces. Historical records indicate that the occurrence of squeaking can be traced back to the introduction of Judet’s acrylic hemiarthroplasty in 1946. Furthermore, various bearing surfaces, including specific Metal-on-Metal (MoM) configurations, have also been associated with noise generation 78.

The generation of squeaking noises remains a common complication documented after THA using ceramic-on-ceramic CoC. This may be anything from 0.3 to 20.9% of the total 77,79,80.

Eiden et al. examined the synovia-like interface membrane (SLIM) in ceramic squeaking hip endoprostheses. Their subsequent studies found that squeaking revisions accounted for 0.40% of the 1733 total hip joint prosthesis pathology cases. They proposed a pathogenetic relationship between SLIM types I/IV and squeaking. These SLIM variations displayed partly independent, mainly mild inflammation, and partly relied on faint ceramic microscopic particles. Oil-Red positive macrophages and hemosiderin suggested Synovial tissue damage. These macrophages also implicated biomechanical impingement (misload) and associated dysfunction as contributors to the squeaking phenomenon 81.

Ki et al. observed a link between higher BMI and increased squeaking occurrence 82. Scott et al.‘s extensive meta-analysis similarly highlighted BMI as a significant patient-related risk factor, but no significant correlations were found with other patient demographics, including gender, age, sex, weight, height, or surgical side.

Moreover, no significant correlation was identified between squeaking and the presence of raised metallic rims on acetabular components or the orientation of the acetabular cup 78.

Chevillotte et al. examined nine ceramic implants that underwent revisions for various reasons. Two of these revisions were prompted by squeaking, four due to recurrent dislocations, one linked to aseptic loosening, and two related to instability. Their hypothesis focused on cup design and orientation issues leading to impingement, potentially causing lubrication-related problems. This can result in metal transfer and stripe wear, commonly observed in squeaking ceramic-on-ceramic bearings 83.

According to Swanson’s classification of hip squeak

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frequency, Grade I indicated that it happened less frequently than once per week, Grade II indicated that it happened between once and four times per week, Grade III indicated that it happened more frequently than four times per week but not on a daily basis, and Grade IV indicated that it happened every day.

Notwithstanding the manifold benefits associated with the utilization of ceramic-on-ceramic bearings, particularly regarding wear reduction, which holds significant appeal for the younger, more physically active patient demographic, it is imperative to engage in informed patient counseling when contemplating the implementation of ceramic-on-ceramic bearings, primarily with respect to the potential occurrence of audible squeaking phenomena.

Squeaking phenomena, as observed in ceramic-on-ceramic THAs, are typically unrelated to adverse events such as fractures, aseptic loosening, osteolysis, subsidence, heterotopic ossification, dislocation, or instability. Nevertheless, Walter et al. have postulated that ceramic-on-ceramic THAs exhibiting squeaking tendencies may exhibit elevated wear rates when compared to their non-squeaking counterparts.

CONCLUSION

In spite of their substantial promise, Ceramic-on-Ceramic bearings remain relatively infrequently employed as a bearing surface in primary total hip arthroplasty. This relative scarcity in usage may be attributed to considerations of cost-effectiveness and the requisite scrupulous surgical technique, aimed at averting recurrent complications. The intermediate-term outcomes associated with CoC bearings are poised to bolster their adoption, particularly among the youthful and highly active patient demographic.

Technological advancements in the production and fabrication of ceramic implants have notably curtailed the incidence of long-standing concerns, notably implant fractures. Notably, the generation of audible noise is generally unlinked with an increased incidence of complications. However, it is imperative to underscore that while occurrences of implant fractures and noise generation have become increasingly rare, their potential occurrence should be diligently communicated to patients as an integral component of the preoperative informed consent process.

CONFLICTS OF INTEREST

The author declares no potential conflicts of interest for this article.

ETHICAL CLEARANCE

Not applicable.

AUTHORS’ CONTRIBUTION

Data gathering, idea owner of this study, study design, writing, editing, approval of final draft and submitting manuscript: Khalid M. Alhomayani

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