Ceramic-Ceramic Bearing: Too Unpredictable to Use it Regularly

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Abstract

Background: Ceramic-on-ceramic (CoC) bearings have excellent tribologic properties because of the smoothness, hardness, and wettability of the material. Therefore, their use has been proposed in younger, active patients who may wear out a traditional metal-on-polyethylene bearing. The same material properties that are beneficial to tribology may also create problems, however. For example, squeaking and fracture of the bearing materials have been reported to occur.

Purpose: The purpose of this paper was to investigate the literature reporting the complications of ceramic bearings and attempt to provide insight into their implications.

Methods: The US National Library of Medicine Database (PubMed) was searched using the terms “ceramic-ceramic total hip replacement,” “complications,” “squeaking,” and “fracture.” Only clinical studies with a clear reporting of the incidence of these complications were included.

Results: The literature reports that squeaking of the CoC bearing occurs in a certain percentage of patients and is likely indicative of edge loading and excessive wear. Other factors, such as patient height, weight, range of motion, and implant design, may contribute to the propensity for squeaking. Fracture is a unique risk of the CoC articulation that requires revision surgery. Though improvements in manufacturing techniques have reduced the fracture risk to a very low percentage, the ceramic material remains susceptible to this complication by impingement and component malposition.

Conclusions: Because of these possible negative outcomes associated with the ceramic material, the CoC bearing is too

unpredictable to use regularly, and its use should be limited to patients who would benefit the most from it.

Keywords ceramic · total hip arthroplasty · squeaking · complications · bearing surfaces

Introduction

Ceramic-on-ceramic (CoC) bearings have become popularized for use in younger, active patients because of their excellent tribologic properties, biocompatibility, and promise of increased longevity. However, the physical properties of CoC that lead to these theoretical benefits may also result in problems. After its most recent introduction in the early 2000s, multiple reports of audible squeaking, emanating from the bearing, have led to a decline in usage of CoC articulations [14, 21, 32]. Furthermore, evidence on retrieval studies of ceramic bearings showing “stripe wear” has led to concerns about edge loading [30]. Concurrently, excellent clinical results from highly cross-linked polyethylene have been reported, with minimal wear and osteolysis seen at intermediate follow-up [3, 19].

The purpose of this paper is to investigate the literature reporting problems pertaining to the CoC bearing and to better understand the incidence of these complications and the implications of their occurrences. Once performed, one can make a conclusion about whether or not CoC bearings are too unpredictable to use regularly.

Search Strategies and Criteria

The National Library of Medicine PubMed database was searched using the criteria “ceramic-ceramic total hip replacement” and “complications,” “squeaking,” and “fracture.” A total of 34 articles from the dates 2001 to 2009 were found. For articles pertaining to squeaking and fracture, only clinical studies with a clear reporting of incidence were included. Expert opinion papers (level 5), basic science articles without clinical relevance, and revision articles were

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excluded, leaving a base material of 27 articles. Of these articles, the 18 studies, utilizing FDA-approved implants with a defined methodology for determining squeaking and fracture, were reviewed [2, 5, 7, 9–13, 15, 16, 18, 20–22, 24, 26, 27, 31].

Results

Background

The physical properties of ceramics that promote excellent tribology include: extreme hardness, a high elastic modulus, and a high degree of wettability (i.e., hydrophilic). The extreme hardness allows the surface to be highly polished and scratch resistant. These properties are conducive to thin-film, hydrodynamic lubrication when used as a bearing couple. Furthermore, the biocompatibility of ceramics is thought to make the debris less likely to cause osteolysis.

The most commonly used ceramic materials for bearing surfaces are zirconia oxide and alumina oxide. When originally introduced in the 1970s, the ceramic heads used were alumina oxide, which has better wear characteristics than zirconia oxide. Although initial results were favorable, this first generation of alumina oxide had a fracture risk as high as 13% [28]. Improvements in manufacturing techniques over the next decade made the grain sizes smaller with reduction in residual voids, thus improving fracture toughness to an estimated risk of <1%. Finally, the addition of hot isostatic pressing (HIP) further improved toughness of alumina oxide in the 1990s, leading to the current third generation, also known as BioloX Forte (CeramTec, Inc.; Baden-Württemberg, Germany). Zirconia oxide is less stiff and, therefore, more fracture resistant, but has poorer tribologic properties than alumina, and so it is commonly only used against polyethylene surfaces. In 2003, an alumina–alumina bearing couple was approved for use in total hip replacement (THR) by the US FDA, leading to a renewed interest in this combination of materials.

Squeaking

Squeaking is defined as a high-pitched, audible sound emanating from the total hip bearing couple, which is produced by movement of the two surfaces across one another. It has become recognized as a complication occurring after CoC THR, with reports in the scientific literature and lay press. In the scientific literature, the incidence was varied based upon implant design, surgical technique, patient characteristics, and investigator query. Incidences have varied from 0.3% [17] to as high as 10.7% [14] in some series. Factors that may play a role in the generation of squeaking include: impingement, edge loading, and third body debris. The composition and geometry of the stem and socket and whether the ceramic is encased in a titanium sleeve may also play a role, as resonance of metallic parts has been suggested to contribute [23]. Nevertheless, it is a real phenomenon that causes a certain percentage of patients to be unsatisfied with their THR and require a revision to a non-CoC articulation.

Patient factors that may contribute to squeaking in a CoC bearing are patient height, weight, and range of motion, with a direct correlation to these patient characteristics [25]. With regard to implant position, high inclination and anteversion were associated with squeaking [31].

The implications of squeaking are unknown, but it likely represents an increased friction within the joint, with resultant excessive wear. This would seem to be confirmed by a recent study by Walter et al. [33] that analyzed squeaking CoC components and found them to have significantly greater wear when compared to silent CoC component retrievals. In these hips, the wear was up to 45 times greater than that of previously reported retrievals. All of the squeaking retrievals had evidence of edge loading, and seven showed impingement. Clearly surgical positioning of the implants is an important factor in the generation of squeaking.

Squeaking has also been reproduced by dry running the CoC articulation, thereby increasing the friction within the joint [6]. Loss of fluid-film lubrication may occur at different stages of the gait cycle and is affected by component positioning. Again, this scenario is likely to lead to increased wear and debris generation.

Finally, a study by Toni et al. [29] demonstrated that joint aspirates from squeaking CoC hips had evidence of ceramic particles and that a certain percentage of squeakers had subclinical liner fractures. Thus, the authors of that study recommended that all squeaking hips be investigated for liner fracture and undergo early revision if fracture is suspected.

Fracture

Fracture is a complication of CoC articulations that is unique to this bearing couple. Fractures in ceramics occur by subcritical crack growth. This means that once a crack has formed, it can continue to propagate with little force, much like a crack in a car windshield. Since a fracture will necessitate a revision, this complication is more problematic than squeaking. As stated earlier, the first generation of alumina oxide femoral heads had estimated rates of fracture as high as 13% [28]. However, improvements in manufacturing techniques allowed the grain size to be smaller and more densely packed, lowering the fracture risk dramatically in the 1980s. However, problems with manufacturing tolerances of the stem trunnions, mating with the ceramic heads, also resulted in a high fracture rate [4].

Continued improvements in reducing grain size and porosity of the ceramics, as well as HIPing, have lowered the fracture risk to an estimated 1 per 25,000 (0.004%) [34] for the current third-generation alumina ceramics, which have been in use since 1994. Additionally, each ceramic component is proof-tested, meaning that it is subjected to forces well beyond that seen in the human body. Current protocols are to proof-test each component to approximately eight times body weight, providing certification that each femoral head and acetabular insert have met manufacturing standards. Therefore, the fracture risk of alumina oxide components should be extremely low.

Unfortunately, fracture of the ceramic components can still be seen with the current generation of alumina oxide. Edge loading and impingement play a significant role in the generation of fracture. One acetabular design attempted to reduce prosthetic neck against acetabular insert impingement by encasing the liner in a titanium sleeve. However, a recent report of Chotai and Su [8] found that the metal rim of the encasement reduced the available range of motion and created femoral neck to metal rim impingement, resulting in contrecoup edge loading and fracture of an acetabular insert. Again, implant position is critically important in avoiding edge loading and possibly making the CoC bearing susceptible to fracture.

When there is a fracture of a ceramic component, there is tremendous generation of sand-like particles within the joint. It is believed that these particles can create abrasive third body wear in the revised joint; one study found that the revision rate of a fractured ceramic head was 31% at 5 years, with rapid polyethylene wear as one of the causes [1]. Thus, the authors recommended revision of a fractured ceramic head to another CoC bearing in order to avoid the runaway wear created by the residual particulate debris.

Questionable Clinical Benefit

In the meanwhile, highly cross-linked polyethylene is nearing a decade of use. The clinical results have been excellent in the intermediate term, with negligible wear and osteolysis in multiple studies [3, 19]. Thus, the benefit of a CoC articulation over a standard metal on polyethylene bearing may not be as great as was once believed.

Future Considerations

To address the fracture risk of alumina oxide, a combination of alumina and zirconia oxide, called Biolox Delta (Ceram-Tec) has been formulated. New Biolox delta-on-delta articulations have been used in Europe and Australia since 2008 and are undergoing investigational device exemption studies in the USA. A short-term report of the delta-on-delta experience thus far has not demonstrated any squeaking in 264 hips and 0.4% incidence of fracture [12]. The hope is that the combination of improved tribology and fracture toughness will reduce the risk of squeaking and fracture.

Conclusions

CoC is an attractive bearing couple due to the excellent tribologic properties that can produce an almost frictionless surface. However, these same properties lead to brittleness and possibility of squeaking and fracture. Although the rate of squeaking and fracture are extremely low, they are possible complications that will not occur with the alternative. Therefore, it is necessary to balance the potential benefits of the CoC bearing with the additional risks that it poses over the standard metal-on-polyethylene. Furthermore, the hard-on-hard nature of CoC makes it more sensitive to component malposition, or else the squeaking and fracture may result. In my experience, discussing the risks of squeaking and

fracture of a CoC bearing with a patient often leads to a reluctance to commit to its unpredictable nature.

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References

- Allain J, Roudot-Thoraval F, Delecrin J, Anract P, Migaud H, Goutallier D. Revision total hip arthroplasty performed after fracture of a ceramic femoral head. A multicenter survivorship study. *J Bone Joint Surg Am.* May 2003;85-A(5):825-830.
- Bernasek T, Fisher D, Dalury D, Levering M, Dimitris K. Is metal-on-metal squeaking related to acetabular angle of inclination? *Clin Orthop Relat Res.* Sep 2011;469(9):2577-2582.
- Bragdon CR, Kwon YM, Geller JA, et al. Minimum 6-year followup of highly cross-linked polyethylene in THA. *Clin Orthop Relat Res.* Dec 2007;465:122-127.
- Callaway GH, Flynn W, Ranawat CS, Sculco TP. Fracture of the femoral head after ceramic-on-polyethylene total hip arthroplasty. *J Arthroplasty.* Dec 1995;10(6):855-859.
- Capello WN, D'Antonio JA, Feinberg JR, Manley MT, Naughton M. Ceramic-on-ceramic total hip arthroplasty: update. *J Arthroplasty.* Oct 2008;23(7 Suppl):39-43.
- Chevillotte C, Trousdale RT, Chen Q, Guyen O, An KN. The 2009 Frank Stinchfield Award: "Hip squeaking": a biomechanical study of ceramic-on-ceramic bearing surfaces. *Clin Orthop Relat Res.* Feb 2010;468(2):345-350.
- Choi IY, Kim YS, Hwang KT, Kim YH. Incidence and factors associated with squeaking in alumina-on-alumina THA. *Clin Orthop Relat Res.* Dec 2010;468(12):3234-3239.
- Chotai PN, Su EP. Fracture of a titanium sleeve-encased third-generation ceramic liner in a modern THA. *Orthopedics.* Oct 2011;34(10):e682-684.
- Esposito C, Walter WL, Campbell P, Roques A. Squeaking in metal-on-metal hip resurfacing arthroplasties. *Clin Orthop Relat Res.* Sep 2010;468(9):2333-2339.
- Ha YC, Kim SY, Kim HJ, Yoo JJ, Koo KH. Ceramic liner fracture after cementless alumina-on-alumina total hip arthroplasty. *Clin Orthop Relat Res.* May 2007;458:106-110.
- Habermann B, Ewald W, Rauschmann M, Zichner L, Kurth AA. Fracture of ceramic heads in total hip replacement. *Arch Orthop Trauma Surg.* Sep 2006;126(7):464-470.
- Hamilton WG, McAuley JP, Dennis DA, Murphy JA, Blumenfeld TJ, Politi J. THA with Delta ceramic on ceramic: results of a multicenter investigational device exemption trial. *Clin Orthop Relat Res.* Feb 2010;468(2):358-366.
- Hannouche D, Zaoui A, Zadegan F, Sedel L, Nizard R. Thirty years of experience with alumina-on-alumina bearings in total hip arthroplasty. *Int Orthop.* Feb 2011;35(2):207-213.
- Jarrett CA, Ranawat AS, Bruzzone M, Blum YC, Rodriguez JA, Ranawat CS. The squeaking hip: a phenomenon of ceramic-on-ceramic total hip arthroplasty. *J Bone Joint Surg Am.* Jun 2009;91(6):1344-1349.
- Keurentjes JC, Kuipers RM, Wever DJ, Schreurs BW. High incidence of squeaking in THAs with alumina ceramic-on-ceramic bearings. *Clin Orthop Relat Res.* Jun 2008;466(6):1438-1443.
- Kim YH, Choi Y, Kim JS. Cementless total hip arthroplasty with ceramic-on-ceramic bearing in patients younger than 45 years with femoral-head osteonecrosis. *Int Orthop.* Dec 2010;34(8):1123-1127.
- Lusty PJ, Tai CC, Sew-Hoy RP, Walter WL, Walter WK, Zicat BA. Third-generation alumina-on-alumina ceramic bearings in cementless total hip arthroplasty. *J Bone Joint Surg Am.* Dec 2007;89(12):2676-2683.
- Mai K, Verioti C, Ezzet KA, Copp SN, Walker RH, Colwell CW, Jr. Incidence of 'squeaking' after ceramic-on-ceramic total hip arthroplasty. *Clin Orthop Relat Res.* Feb 2010;468(2):413-417.

19. McCalden RW, MacDonald SJ, Rorabeck CH, Bourne RB, Chess DG, Charron KD. Wear rate of highly cross-linked polyethylene in total hip arthroplasty. A randomized controlled trial. *J Bone Joint Surg Am.* Apr 2009;91(4):773-782.
20. Parvizi J, Adeli B, Wong JC, Restrepo C, Rothman RH. A squeaky reputation: the problem may be design-dependent. *Clin Orthop Relat Res.* Jun 2011;469(6):1598-1605.
21. Restrepo C, Parvizi J, Kurtz SM, Sharkey PF, Hozack WJ, Rothman RH. The noisy ceramic hip: is component malpositioning the cause? *J Arthroplasty.* Aug 2008;23(5):643-649.
22. Restrepo C, Matar WY, Parvizi J, Rothman RH, Hozack WJ. Natural history of squeaking after total hip arthroplasty. *Clin Orthop Relat Res.* Sep 2010;468(9):2340-2345.
23. Restrepo C, Post ZD, Kai B, Hozack WJ. The effect of stem design on the prevalence of squeaking following ceramic-on-ceramic bearing total hip arthroplasty. *J Bone Joint Surg Am.* Mar 2010;92(3):550-557.
24. Schroder D, Bornstein L, Bostrom MP, Nestor BJ, Padgett DE, Westrich GH. Ceramic-on-ceramic total hip arthroplasty: incidence of instability and noise. *Clin Orthop Relat Res.* Feb 2011;469(2):437-442.
25. Sexton SA, Yeung E, Jackson MP, et al. The role of patient factors and implant position in squeaking of ceramic-on-ceramic total hip replacements. *J Bone Joint Surg Br.* Apr 2011;93(4):439-442.
26. Stafford GH, Islam SU, Witt JD. Early to mid-term results of ceramic-on-ceramic total hip replacement: analysis of bearing-surface-related complications. *J Bone Joint Surg Br.* Aug 2011;93(8):1017-1020.
27. Swanson TV, Peterson DJ, Seethala R, Bliss RL, Spellmon CA. Influence of prosthetic design on squeaking after ceramic-on-ceramic total hip arthroplasty. *J Arthroplasty.* Sep 2010;25(6 Suppl):36-42.
28. Toni A, Sudanese A, Terzi S. Ceramics in Total Hip Arthroplasty. In: Wise DL, Trantolo DJ, Altobelli DE, eds. *Encyclopedic Handbook of Biomaterials and Bioengineering.* New York: Marcel Dekker, Inc.; 1995:1501-1544.
29. Toni A, Traina F, Stea S, et al. Early diagnosis of ceramic liner fracture. Guidelines based on a twelve-year clinical experience. *J Bone Joint Surg Am.* Dec 2006;88 Suppl 4:55-63.
30. Walter WL, Insley GM, Walter WK, Tuke MA. Edge loading in third generation alumina ceramic-on-ceramic bearings: stripe wear. *J Arthroplasty.* Jun 2004;19(4):402-413.
31. Walter WL, O'Toole GC, Walter WK, Ellis A, Zicat BA. Squeaking in ceramic-on-ceramic hips: the importance of acetabular component orientation. *J Arthroplasty.* Jun 2007;22(4):496-503.
32. Walter WL, Waters TS, Gillies M, et al. Squeaking hips. *J Bone Joint Surg Am.* Nov 2008;90 Suppl 4:102-111.
33. Walter WL, Kurtz SM, Esposito C, et al. Retrieval analysis of squeaking alumina ceramic-on-ceramic bearings. *J Bone Joint Surg Br.* Dec 2011;93(12):1597-1601.
34. Willmann G. Ceramic femoral head retrieval data. *Clin Orthop Relat Res.* Oct 2000(379):22-28.