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Retrieval analysis of squeaking ceramic implants: Are there related specific features?

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KEYWORDS
Squeaking; Total hip arthroplasty; Ceramic; Surface bearing; Metal transfer; Stripe wear

Summary

Introduction: Ceramic-on-ceramic total hip arthroplasty is routinely used for young and active patients with end stage of hip osteoarthritis. However, squeaking noise is a recently identified problem with such bearing surface. Many in vivo and in vitro studies have been conducted trying to find the potential causes of this phenomenon. However, we are not aware of any study analyzing retrieved ceramic implants for squeaking.

Hypothesis: Our primary hypothesis was that the surface analysis of retrieved ceramic implants with squeaking would present interesting deteriorations that could explain the squeaking noise.

Materials and methods: Nine retrieved squeaking implants from ceramic-on-ceramic total hip arthroplasty that were retrieved for various reasons (two exclusively for squeaking, four for recurrent dislocation, one for aseptic loosening and two for instability) were analyzed. Implant positioning was calculated, macroscopic damages were noticed and microscopic roughness was analyzed. The retrieved implants were then tested on a hip simulator reproducing flexion/extension motions in several situations in lubricated and non-lubricated conditions in order to reproduce squeaking.

Results: Five cups were considered with borderline insufficient anteversion. Gross impingement damage was visible on seven implants. All the retrieved heads had visible metal transfer on their surface. Eight implants had visible stripe wear. Microscopic analysis showed roughness higher than six microns on the retrieved heads. Squeaking was reproduced in vitro in dry conditions. In lubricated conditions, squeaking did not occur for the retrieved hips.
Discussion: This retrieval analysis suggests that problems of cup orientation and design which can lead to impingement can generate lubrication problems because of metal transfer plus/minus stripe wear which is a common theme in ceramic-on-ceramic bearings that squeak. Level of evidence: Level IV, retrospective study.

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Introduction

Ceramic-on-ceramic (COC) arthroplasty is a bearing surface routinely used in young patients who need a hip replacement [1, 2]. The major benefits of this bearing couple are excellent wear properties. Concerns related to COC include fracture that has been widely discussed and with the use of the third generation ceramics and delta ceramics its rate appears to have decreased [3, 4]. “Squeaking noise” with alumina COC bearing surface is a complication, which has gained recent attention [5–7]. Multiple potential causes have been implicated including metal transfer, stripe wear, impingement, poor offset, and vibration of metallic implants [7–10]. There is very little data looking at retrieved implants that were revised for squeaking. Our primary hypothesis was that the surface analysis of retrieved ceramic implants with squeaking would present interesting damages, which could explain the squeaking noise. The aim of the study was to analyze retrieved squeaking implants, and try to reproduce squeaking in vitro in different situations of testing.

Material and method

Nine retrieved squeaking ceramic implants of 9 different patients that were revised for various reasons were analyzed. Those implants came from two different centers, Mayo Clinic, (Rochester, Mn) and Hospital for Special Surgery (HSS), (New York). Approximately 300 revisions Total Hip Arthroplasty (THA) per year are done at Mayo Clinic, and 400 per year at HSS. In both centers, less than 2% are concerning ceramic-on-ceramic THA. This low revision rate for ceramic-on-ceramic bearing can be explained by the good survival rate for this hard bearing [11, 12], and the relative recent use on the US market, with a Food and Drug Administration (FDA) authorization in 2003, compared to metal on polyethylene bearing. For four patients, the primary surgery was done in one of the two mentioned institutions, and for five patients, it was done elsewhere. The mean age of the patients at the time of revision was 57.4 years (range, 43 to 77 years). Mean height was 1.69 m (range, 1.55 to 1.88 m), mean weight was 75.6 kg (range, 57 to 96 kg) and the mean body mass index (BMI) was 26.4 (range, 20 to 34), three patients had a BMI higher than 30. The mean duration of implantation was 25.5 months for all the implants (range, 10 to 51 months). All the 9 implants presented with squeaking. However, squeaking was the unique cause of revision only for two implants. In seven cases, squeaking was not the main cause leading to revision: four implants were revised secondary to recurrent dislocation (two episodes in two cases, three episodes in one case and five episodes in one case), one secondary to aseptic loosening of the cup and the stem and thigh pain (the cup had broken screws and a gross mobility, and the stem had also a severe loosening) and two implants were revised because of clinical impingement leading to instability with sensations of subluxation. Causes of revision are resumed in Table 1. All the removed heads were third generation alumina, produced by Ceramtec (Ceramtec, Plochingen, Germany). All heads and acetabular components had similar design (Trident, Stryker™ Kalamazoo, MI, USA). All patients had their sockets revised, femoral head exchanged, and converted to a Co-Cr-polyethylene bearing surface. One patient also had a loose stem revised (corresponding to the aseptic loosening revision). All hips had a 32 mm femoral head. The average socket size was 54 mm (range 52 to 58 mm). Implant data are resumed in Table 1. X-ray analysis was performed to analyze cup positioning, in term of abduction angle and anteversion angle. Measurements were done on antero-posterior pelvic radiographs, using the method described by Ackland et al. [13]. Data are resumed in Table 1.

The surface characteristics of the 9 explanted ceramic heads were evaluated with the use of two different methods: gross visual assessment and microscopic surface analysis with a Zygo™ NewView 6300 optical surface profilometer (Zygo Corporation, Middlefield, CT, USA).

Based on the visual assessment, the femoral head was considered to be non-damaged if nothing was visible on the ceramic head. Presence of stripe wear, metal particles or other macroscopic visible damage on the ceramic head and on the ceramic cup were noted, and the femoral head was considered to be slightly damaged if the damaged region was less than 10% of the total head surface, and it was considered to be severely damaged if the damaged region was more than 10% of the total head surface. The same method of visual assessment was done for the retrieved cups. Macroscopic traces of impingement on the metal rim of the socket (severe impingement damage corresponding to abnormal wear with neck imprint on the rim, Fig. 1) and on the neck of the stem retrieved were also reported.

Roughness measurement was done on five of the 9 retrieved implants (two squeaking, two recurrent dislocation, one instability). This surface analysis was done with a Zygo™ NewView 6300 optical surface profilometer (Zygo Corporation, Middlefield, CT, USA). This system is a non-contact, three-dimensional, scanning white light and optical phase-shifting interferometry system. Measurements were done with two different magnifications. Areas of analysis were 0.71 by 0.53 mm and 0.35 by 0.26 mm respectively. Measurements were made on damaged and non-damaged regions. Vertical resolution of the system is up to 0.1 nm. The roughness value in the non-damaged regions of each heads was used to compare the results. In addition, one similar ceramic head that had not been implanted was also analyzed to confirm the results of the non-damaged regions of the retrieved heads and to compare the results.
Table 1 Causes of revision and implant data.

<table>
<thead>
<tr>
<th>Implant no</th>
<th>Cause of revisiona</th>
<th>Type of cup</th>
<th>Head size</th>
<th>Neck size</th>
<th>Cup size</th>
<th>Abduction angle</th>
<th>Anteversion angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Instability (clinical impingement)</td>
<td>Trident</td>
<td>32</td>
<td>0+</td>
<td>52</td>
<td>45.5</td>
<td>12</td>
</tr>
<tr>
<td>2</td>
<td>Recurrent dislocation (3)</td>
<td>Trident</td>
<td>32</td>
<td>5+</td>
<td>58</td>
<td>44</td>
<td>29</td>
</tr>
<tr>
<td>3</td>
<td>Recurrent dislocation (5)</td>
<td>Trident</td>
<td>32</td>
<td>0+</td>
<td>58</td>
<td>37.2</td>
<td>15.1</td>
</tr>
<tr>
<td>4</td>
<td>Recurrent dislocation (2)</td>
<td>Trident</td>
<td>32</td>
<td>2.5+</td>
<td>54</td>
<td>44.2</td>
<td>30.2</td>
</tr>
<tr>
<td>5</td>
<td>Recurrent dislocation (2)</td>
<td>Trident</td>
<td>32</td>
<td>0+</td>
<td>54</td>
<td>53</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>Squeaking</td>
<td>Trident</td>
<td>32</td>
<td>0+</td>
<td>54</td>
<td>33.8</td>
<td>16.8</td>
</tr>
<tr>
<td>7</td>
<td>Aseptic loosening</td>
<td>Trident</td>
<td>32</td>
<td>5+</td>
<td>54</td>
<td>54</td>
<td>10</td>
</tr>
<tr>
<td>8</td>
<td>Instability (clinical impingement)</td>
<td>Trident</td>
<td>32</td>
<td>4+</td>
<td>54</td>
<td>52</td>
<td>15</td>
</tr>
<tr>
<td>9</td>
<td>Squeaking</td>
<td>Trident</td>
<td>32</td>
<td>0+</td>
<td>52</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

All the hips demonstrated squeaking before revision, but squeaking was the main reason for revision in two cases (#6 and #9). When revision was done because of instability, the number of dislocations is detailed.

The third part of the study consisted to an in vitro biomechanical testing using a hip simulator trying to reproduce the phenomena of squeaking. The automated hip simulator was used previously in an in vitro analysis of squeaking ceramic-on-ceramic bearings [8]. The femoral head component was fixed to a servo hydraulic biaxial testing machine (MTS, Eden Prairie, MN), which applied a prescribed amount of static compressive axial loading to the bearing surface of the prosthesis. The acetabular cup of the prosthesis was housed in a rotating jig which was in turn connected to a direct current electricity (DC) motor via a bar linkage system. The acetabular components were positioned in 45° of abduction (lateral opening) and 20° of antversion (Fig. 2). Different clinical situations were tested, in lubricated conditions with a 25% bovine serum and in dry conditions:

- normal gait situation with normal loading. A physiologic normal loading was applied to the implants, defined as two times normal body weight of 70 kg. The speed of rotation was approximately two cycles per second;
- extreme loading. This was performed using the same model as above and applying 2000 N of force on the testing machine. Each situation was tested up to 15,000 cycles in order to try to reproduce a squeaking noise.

Figure 1 Impingement damage on the cup (a), and on the femoral neck (b).

Figure 2 Custom made testing device hip simulator.

Results

All the removed heads and cups were third generation alumina ceramic using a 32 mm bearing components. All the components removed were from one manufacturer (Stryker® Trident shell, Stryker, Kalamazoo, MI, USA). Visual assessment data are resumed in Table 2. Impingement damage on the metallic rim was macroscopically visible on seven implants: two "squeaking" implant, two "recurrent
Table 2  Macroscopical analysis of the retrieved implants.

<table>
<thead>
<tr>
<th>Implant no</th>
<th>Cause of revision</th>
<th>Cup/Rim impingement</th>
<th>Metal particles on ceramic liner</th>
<th>Head damage</th>
<th>Head Stripe wear</th>
<th>Head Metal transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Instability (clinical impingement)</td>
<td>1</td>
<td>0</td>
<td>Severely</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Recurrent dislocation (3)</td>
<td>1</td>
<td>1</td>
<td>Severely</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Recurrent dislocation (5)</td>
<td>0</td>
<td>1</td>
<td>Severely</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Recurrent dislocation (2)</td>
<td>0</td>
<td>1</td>
<td>Severely</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>Recurrent dislocation (2)</td>
<td>0</td>
<td>1</td>
<td>Severely</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>Squeaking</td>
<td>1</td>
<td>1</td>
<td>Slightly</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>Aseptic loosening (femoral and cup)</td>
<td>1</td>
<td>0</td>
<td>Severely</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>Instability (clinical impingement)</td>
<td>1</td>
<td>1</td>
<td>Slightly</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>Squeaking</td>
<td>1</td>
<td>1</td>
<td>Severely</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

* All the hips demonstrated squeaking before revision, but squeaking was the main reason for revision in two cases (#6 and #9). When revision was done because of instability, the number of dislocations is detailed.

Figure 3  Metal transfer (a) and stripe wear (b) on the ceramic head.

dislocation’’ implants, two ’’instability implant’’ and on the ’’aseptic loosening implant’’ (Fig. 1a). The one stem retrieved, corresponding to the aseptic loosening case of revision, had severe impingement damage on the neck, corresponding to an impingement damage with the metallic rim (Fig. 1b). A gross mobility of the loosed components was found during the revision surgery of the former case.

All of the retrieved heads were damaged. Seven head were severely damaged, and two heads slightly damaged (one squeaking implant, one instability implant). Metal transfer was noticed on all of the 9 heads (Fig. 3a), and visible stripe wear was reported for eight of the 9 heads (except for one instability implant) (Fig. 3b). Five ceramic liners had metal particles on their surface: two ’’squeaking’’ implants and three ’’recurrent dislocation’’ implants (Fig. 4).

Roughness analysis of the ceramic heads revealed pits and scratches on the surface of all the retrieved damaged heads. Roughness of the damaged area was higher (0.6 μm) (Fig. 5) than the non-damaged areas. The mean roughness

Figure 4  Metal transfer on the ceramic liner.
Figure 5  Surface analysis of a damaged ceramic head with Zygo™ profilometer (Zygo Corporation, Middlefield, CT, USA).

of the non-damaged areas and for the non-inserted ceramic head was similar, around 0.1 μm.
Cup orientation analysis was only available for eight implants. Mean abduction angle was 45.4°, varying from 33.8° (squeaking implant n°6) to 54° (aseptic loosening implant n°7). Mean anteversion angle was 16.6°, varying from 5° (recurrent dislocation implant n°5) to 30.2° (recurrent dislocation implant n°2). Data are resumed in Table 1.
Squeaking was easily reproduced in all dry conditions. For normal gait situations without lubrication, squeaking occurred after about 300 cycles. The squeaking noise was constant and did not disappear with time. This was constant for all the retrieved ceramics heads and corresponding liner. Under high load situation, squeaking occurred after the same number of cycles. Again, it did not disappear and remained constant. In all of the dry conditions, when a small amount of lubricant was continually added to the test condition, squeaking would disappear. Once the lubricant was stopped, the squeaking would reappear and remain constant. For the lubricated condition, we were not able to reproduce squeaking even after more than 15,000 cycles.

Our study has some limitations. First, we only had a limited number (9) of retrieved squeaking implants. Unfortunately, the number of ceramic revision in the two institutions is small compared to the high number of THA revision, because of the good survival rate for this hard bearing [11,12], and the relative recent use on the US market, and also because, unlikely to Europe, ceramic-on-ceramic is not the first choice is the US for young and active patients. Moreover, even if squeaking was not the main cause of revision, all the 9 implants presented a squeaking noise. Second, we did not examine method of head removing which could affect the ceramic head surface. Third, we did not examine impingement or extreme motion with the hip simulator. It was unlikely that the head and the corresponding ceramic liner where placed in the same position they were in vivo which potentially alters the loading pattern. Despite these limitations, we believe this in vitro study reported interesting analysis.
Walter et al. [7] reported a higher incidence of squeaking for younger, heavier and taller patients. Our retrieval group cannot confirm this statement. In our retrieved group, the height and weight was similar to the “non-squeaking” group reported by Walter et al. [7]. Mean weight of our patients was 75.6 kg (range, 57 to 96 kg), it was 76 kg (range, 40 to 130 kg) for control group reported in the study of Walter et al. [7]. Similarly, the mean patient size in the current study was 1.69 m (range, 1.55 to 1.88 m), and it was 1.69 m (range, 1.37 to 1.98 m) for the control group reported by Walter et al. [7]. The mean age of our patients was 57.4 years (range, 43 to 77 years), and was similar to the squeaking patients reported by Walter et al. [7] (56 years range, 35 to 79 years) versus his control group (65 years; range, 18 to 95 years) [7]. Our results are in accordance with Stanat and Capozzi meta-analysis [15], where age, sex, height and weight were not statistically different between squeakers and non-squeakers patients.
A higher prevalence of squeaking has also been reported in the literature for abnormal situations like a mismatched

Discussion
Noise can occur after any hip arthroplasty, including metal-on-metal [14] and ceramic-on-ceramic arthroplasty [6]. Squeaking with ceramic-on-ceramic bearing has been reported in previous studies, varying from less than 1% [3] to more than 20% [10]. The exact etiology of this phenomenon remains unclear and like many other problems in joint arthroplasty, implants factors, patient factors and surgical factors have been described responsible for squeaking.
The aim of our study was to analyze the surface of retrieved squeaking implants in order to find damages that could explain mechanism generating squeaking noise, and try to reproduce squeaking in an in vitro testing situation.
ceramic couple [16], and with component malpositioning [17,18]. Walter found that squeakers tend to have too much or insufficient anteversion in their cup, considering the acceptable range of anteversion to be between 15° and 35° [17,18]. Those extreme placements could lead to anterior or posterior ceramic edge loading when casual walking or bending [18]. When analyzing our results, five cups had limit insufficient anteversion (between 5° to 15.1°) and only three had “correct” anteversion. This insufficient anteversion can lead to uncovering posteriorly the ceramic femoral head when hip is flexed, leading to posterior edge loading. Potential causes of squeaking for those patients with insufficient anteversion are impingement between the neck of the femoral component and the titanium rim of the acetabular component, generating titanium third body particles, or posterior edge loading of the ceramic head against the ceramic insert. Those situations are generating third body particles (titanium or ceramic), between the two surfaces, generating a break of the film lubrication, as described with an in vitro study reproducing squeaking with ceramic-on-ceramic [8,19].

In our study, all the retrieved components were similar. The ceramic liner was housed in a metal backing with an elevated metal rim. This design was made to protect the ceramic component from impingement and to hopefully reduce the risk of ceramic fracture [20]. However, this design is well known to reduce range of motion, leading to femoral neck impingement. Barrack et al. [21] found that this design leads to metal-metal impingement and decreases the motion arc by 10° to 15°. Our macroscopic retrievals, with metal particles observed on all the retrieved ceramic heads, stripe wear on eight heads, and seven of the 9 implants with visible traces of impingement confirm those findings. The design of this cup, associated with the malpositioning can explain the importance of our macroscopic retrievals. Dorlot [22] noticed the presence of stripe wear on retrieved ceramic heads, however, did not notice problems of squeaking. Restrepo et al. [6] noticed presence of stripe wear in four retrieved implants for squeaking, and presence of metal transfer in two of the four implants. In all of those implants, signs of femoral neck—acetabular rim impingement were also reported [6]. Walter et al. [7] noticed all of their retrieved implants showed evidence of edge loading and had evidence of impingement between the femoral neck and the metal rim of the acetabular component. The same observation was made by Muralli et al. [5]. They also found during revision subsynovial fibrous tissue containing abundant black granular metallic debris associated with a mild mononuclear inflammatory infiltrate. Those results are consistent and tend to demonstrate that third bodies (metal particles) may play a role with squeaking. The role of implant design and cup positioning seems to be an essential factor to avoid or to generate impingement, which could produce metal transfer leading to squeaking.

Chevillotte et al. [8] have demonstrated in vitro that metal transfer can lead to fluid lubrication disruption and squeaking. Moreover, the microscopical analysis of the head roughness showed that the macroscopically damaged surface was corresponding to a marked increase of the surface roughness. Kim et al. [23] demonstrated that metallic transfer onto the ceramic femoral head increases the surface roughness of the femoral head leading to increasing the wear of the polyethylene liner. They also suggest that an increase in surface roughness and wear as a result of transferred metal debris could be an explanation for the sporadic cases of excessive wear of ceramic-on-ceramic bearings [23]. We were not able to analyze wear of the retrieved implants in this study. However, we can conclude that all the squeaking hips in our study have a damage surface, leading to an increase in the surface roughness of the ceramic head, and corresponding acetabular bearing.

In vitro testing of the retrieved ceramics demonstrates that squeaking was constant in dry conditions but constant lubrication stopped squeaking noise. We were not able to reproduce squeaking in lubricated conditions with the damaged heads and cups. One explanation could be that the hip simulator did not allow extreme motion and impingement between the neck and the cup. Moreover, we did not add metal transfer on the ceramics heads and the implants were rinsed with the 25% bovine serum before testing. In a previous study [8], we were able to reproduce squeaking in lubricated conditions for ceramic heads with metal transfer (using a different manufacturer’s ceramics). Sarialy et al. [19] reproduced in vitro squeaking under lubricated conditions with the presence of a large alumina chip between the head and the edge of the cup and extreme edge loading. However, like Ecker et al. [24], our retrieval analysis did not show a large alumina defect, because of the implant design, with the ceramic liner protected by the titanium rim. This suggests that for this design of implant, metal transfer plus/minus stripe wear is a common theme in COC bearings that squeak.

Conclusion

Squeaking with ceramic-on-ceramic seems to be a multifactor problem: cup design, implant positioning and damage surface are important factors in generating squeaking. All of these parameters may play a role in the disruption of film fluid lubrication, secondary to an abnormal roughness of the ceramic head, leading to squeaking.

Disclosure of interest

Dr Robert Trousdale receives royalties from DePuy Johnson & Johnson, Wright Medical and Ortho Dvp.

Drs. Christophe Chevillotte, Kai-Nan An, Douglas Padgett, and Timothy Wright have no conflicts to disclose.

References