Retrieval analysis of squeaking alumina ceramic-on-ceramic bearings

This multicentre study analysed 12 alumina ceramic-on-ceramic components retrieved from squeaking total hip replacements after a mean of 23 months in situ (11 to 61). The rates and patterns of wear seen in these squeaking hips were compared with those seen in matched controls using retrieval data from 33 ‘silent’ hip replacements with similar ceramic bearings. All 12 bearings showed evidence characteristic of edge-loading wear. The median rate of volumetric wear was 3.4 mm³/year for the acetabular component, 2.9 mm³/year on the femoral heads and 6.3 mm³/year for head and insert combined. This was up to 45 times greater than that of previously reported silent ceramic-on-ceramic retrievals. The rate of wear seen in ceramic components revised for squeaking hips appears to be much greater than in that seen in retrievals from ‘silent’ hips.

Audible squeaking of a hip replacement is a complication that is almost as old as hip replacements themselves, being reported as early as the 1950s with Judet’s acrylic hemiarthroplasty.\(^1\) Charnley\(^2\) noted in vitro squeaking when he tested one of Boutin’s ceramic-on-ceramic bearings in his ‘pendulum friction comparator’. Squeaking can occur with polyethylene bearings if there is penetrating wear or displacement of the polyethylene allowing metal-to-metal or ceramic-to-metal contact, such as with metal-backed tibiae in knee replacements\(^3\) and metal-backed polyethylene acetabular components.\(^4,7\)

In the modern era of total hip replacements, however, squeaking is more commonly a complication of hard-on-hard bearing surfaces. The incidence of squeaking in ceramic-on-ceramic bearings ranges from < 1% to 21%, depending on how the sound is defined.\(^8-12\)

Transient squeaking from metal-on-metal resurfacing hip replacements has been reported with an incidence of 3.9% at a mean follow-up of three years, and 5.3% at a mean follow-up of five years.\(^13,14\)

Squeaking of ceramic-on-ceramic bearings may be related to patient, implant or surgical factors. In the patient category, weight, height and age have been shown to influence the rates of squeaking,\(^15\) probably owing to increased mechanical demands on the implants.

Implant characteristics are probably important: for example, recent studies have shown that the design of the femoral component may explain why certain hip systems have a higher incidence of squeaking than others.\(^16,17\) The noise has also been reported following fracture of the ceramic liner,\(^18,19\) and in a patient where a zirconium ceramic head was coupled with an alumina ceramic cup.\(^20\)

Surgical technique is important in preventing malpositioning of the acetabular component and impingement, which have been associated with squeaking.\(^7\) However, it can also occur with correctly positioned implants.\(^15\)

This multicentre study investigated the location, pattern and quantity of wear in ceramic hip components that were revised for audible squeaking. We hypothesised that squeaking bearings would exhibit greater surface damage and wear rates than silent bearings. In particular, we sought to determine whether the squeaking could be attributed to edge loading, neck–rim impingement and/or clearance.

Patients and Methods

We analysed 12 alumina ceramic-on-ceramic bearings from squeaking hips collected at revision surgery by 11 surgeons in Australia, New Zealand and the USA, including four authors (WLW, WH, KGH and JGP). Eleven hips made a squeaking sound and one a grating noise. The mean age of the patients was 48 years (26 to 65); seven were men. In five hips the patients also complained of pain. The original hip arthroplasty was performed through a modified Hardinge approach in five hips. The activity that produced the squeak was walking in ten hips, bending in one hip, and unknown in the other. Bearings were retrieved after a
The retrieved components were studied with a 10× magnification loupe and a stereomicroscope with up to 40× magnification. Areas of wear on the ceramic surface were coloured with a blue felt-tip pen or by rubbing with pencil lead.21,22 Once the ink had dried, any excess was wiped away with a cloth. Wear length and width dimensions were measured with a digital calliper as a straight line (segment length) and converted to arc length with trigonometry. In addition, the rim of the titanium acetabular shell was examined for signs of impingement.

Equatorial and true polar two-dimensional roundness traces were measured with a Mitutoyo Roundtest RA 300 machine (Mitutoyo, Andover, United Kingdom), which has an accuracy of 0.01 μm and records full and partial circles, as used previously to measure the diameter of the component and the depth of the wear scar.22 The surface shape of the wear patch was mapped and its depth calculated as a change in depth from an intact part of the component. Wear scar volume was calculated using the scar surface area dimensions, the depth and the diameter of the component, and by three-dimensional modelling of the defect using SolidWorks Office Premium 2007 software (Dassault Systèmes, Paris, France).

We compared the measured wear rate seen in these squeaking bearings with a control group of 33 previously published ‘silent’ retrievals, where the analysis of wear had been conducted in an identical manner.22 These 33 retrievals were from hips where the index procedure was a primary THR in 21 cases and a revision in 12.

The clearance of the retrieved components from nine of the 12 squeaking hips was calculated by measuring the diameter of the head and liner. We compared these clearances to a subset of ten of the 33 ‘silent’ bearings from the previous series as a control. These ‘control’ bearings were all revised at one centre in Sydney, Australia. They had been in use for a mean of 29 months (39 to 78) in nine patients with a mean age of 61 years (39 to 78) at the time of implantation. The index procedure was a primary THR in five cases and a revision in five cases with a diagnosis of aseptic loosening in one, peri-prosthetic femoral fracture in one, psoas tendonitis in one and acetabular osteolysis in two. The femoral components were Securfit in three cases, ABG or ABG2 in four (all from Stryker Orthopaedics) and SROM (DePuy, Warsaw, Indiana) in three. The acetabular components were Osteonics ABC in seven cases, ABG2 in two (all from Stryker Orthopaedics) and Duraloc (DePuy) in one case. There were nine 32 mm bearings and one 28 mm bearing. All bearings were alumina ceramic (Biolox Forte; Ceramtec).

**Statistical analysis.** The wear volumes were not normally distributed, therefore we reported the median and range and compared the wear rate for the controls with that of the squeaking bearings using Wilcoxon’s non-parametric test. Clearance was normally distributed, and therefore we reported mean values and compared the study group with the control group using a non-paired Student’s t-test. We considered a p-value < 0.05 to be statistically significant. Statistical analysis was carried out using JMP software (version 7.0; SAS, Cary, North Carolina).

**Results**

All 12 bearings from the squeaking hips showed wear on the rim of the acetabular component or edge-loading wear (Table I). The median dimensions of the wear patch were 32 mm × 14 mm × 35 μm on the femoral heads and 39 mm × 15 mm × 68 μm on the acetabular components. The median wear rate per year was 2.9 mm³/year (0.1 to 21.0) on the femoral heads and 3.4 mm³/year (0.2 to 20.6) on the acetabular components.

In comparison, the 33 retrievals from previously reported ‘silent’ hips had a mean wear rate of the femoral head of 0.6 mm³/year (0.0 to 3.6) (p = 0.0003) and a mean wear rate of the acetabular component of 0.5 mm³/year (0.0 to 3.8) (p = 0.001).25 There was wear due to edge loading in 24 of the 33 retrieved bearings, including all 12 of the revision hips and 12 of the 21 primary hips. The wear rates seen in the ceramic femoral heads and acetabular components of the squeaking hips were 29 times and 85 times greater than those seen in the respective components of the control group. The median rate of combined wear (head and insert) of these noisy bearings was 6.7 mm³/year (mean 11.3 mm³/year (0.3 to 41.6)), compared with a median of 0.14 mm³/year in the previously reported21 group of silent ceramic-on-ceramic retrievals, which represents a 45-fold increase.

Mean clearance in the squeaking retrievals was 94 μm (61 to 153) and in the control group of ten silent retrievals was 72 μm (59 to 87), a difference which was not statistically significant (p = 0.23).

In seven of the 12 implants there was evidence of impingement of the femoral neck against the elevated metallic rim or the ceramic insert or both (Fig. 1), but this was absent in the remaining five (Fig. 2). There was no chipping or fracture of any of the ceramic components.
The mechanics behind the production of sound by a squeaking hip replacement remain unknown. There may be an increase in friction due to a breakdown of fluid film lubrication, which requires a delicate balance of a number of factors to maintain it, including sliding speed, lubricating fluid viscosity, bearing roughness, clearance and contact pressure. Edge loading will result in a dramatic and transitory reduction in contact area and a corresponding rise in contact pressure, with a resulting breakdown of fluid film lubrication. Laboratory experiments have demonstrated that wear due to edge loading can increase friction and lead to squeaking in ceramic bearings. However, other mechanisms may be involved.

In the laboratory noise can also be generated with ceramic-on-ceramic implants running dry in the absence of edge-loading wear. Ceramic breakage is reported to cause squeaking, and ceramic fragments have been aspirated from squeaking ceramic bearings, suggesting third-body effects. Surface damage to the bearing, which produces an increase in roughness, may lead to a loss of fluid film lubrication. Movement between the liner and the shell may contribute. Nine of 12 ceramic components in this study had a metal-backed ceramic liner (Fig. 3). This may be an important aetiological factor, along with the seating of these components. There are undoubtedly several different mechanisms that can lead to noise production. However, in the bearings that we examined in this study, abnormal edge loading seemed the most likely explanation.

This phenomenon is seen on the rim of the acetabular component and is due to unintentional contact with the ceramic femoral head. The resulting wear may form a ‘stripe’ pattern on the head and on the edge of the liner, sometimes called ‘stripe wear’. The mechanisms...
behind edge-loading wear include impingement, which may be either prosthetic impingement or bone and soft-tissue impingement. The orientation of the acetabular component may contribute, as it has been shown that anteversion < 15° is associated with a higher rate of this type of wear. The range of movement of the hip may also be an important factor.

Edge loading is seen in the majority of ceramic-on-ceramic hip bearings on the rim of the acetabular component retrieved after more than six months in situ, so it may be a normal occurrence and fairly common in unrevised bearings. However, squeaking is rare. Therefore, the majority of ceramic-on-ceramic bearings that edge load do not squeak. The reasons why some do and others do not are not clear. Laboratory experiments suggest that the roughened regions of ceramic surface must align during load bearing in order for squeaking to occur. The kinematics of the roughened bearing surfaces during load-bearing may also be important for noise generation. It is also not clear why some hips that squeak eventually stop squeaking after a period of months or years.

Low bearing clearance was implicated as a reason for failure in first-generation metal-on-metal hip bearings. However, in our study there was a mean difference of only 21 μm between the clearances of the squeaking and the silent ceramic bearings, which was not significant, and this difference in clearance was extremely small by manufacturing standards, considering the range of designs that are represented. Six of the 12 squeaking bearings had clearance values that fell within the range of the silent bearings. Therefore, differences in clearance did not appear to explain squeaking in this collection of retrievals. A recent experimental study also found that clearance did not play a role in squeaking.

If the neck of the femoral component impinges on the rim of the ceramic liner, metal staining may be evident on the ceramic at revision surgery. In some types of hip the metal shell has an elevated rim, proud of the ceramic liner, which is intended to protect the ceramic from direct contact with the femoral neck. This naturally reduces the available range of movement. In addition, some investigators have postulated that such neck–rim impingement can cause squeaking. However, in this study there was one case of squeaking in which the acetabular shell did not have an elevated rim and five cases where there was no evidence of neck-rim impingement. We therefore feel that neck-rim impingement by a proud metallic rim is not the main cause of a squeaking hip.

Our findings strongly suggest that the squeaking of ceramic-on-ceramic bearings may be associated with increased wear rates compared to silent bearings. We accept that the control group used in the previous silent bearing retrieval study was from a single centre, unlike the 12 retrievals in the squeaking hip group, which were from a variety of institutions. We are also uncertain as to whether these increased rates of wear in squeaking bearings will result in a clinically discernible adverse outcome to the patient if left unrevised.

Edge-loading wear was the common factor in all our cases, and this may prove to be a critical mechanism in producing squeaking. Ceramic-on-ceramic remains an excellent bearing surface because of its low rates of wear and osteolysis. Efforts to reduce edge loading may reduce wear further and help keep the incidence of squeaking to a minimum.

Supplementary material

Two tables detailing the clinical information on the bearings revised for squeaking and the information of the control group of ‘silent’ total hip replacements.
revised are available with the electronic version of this paper on our website at www.jbjs.org.uk

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References


