In Vivo Wear of a Squeaky Alumina-on-Alumina Hip Prosthesis

A Case Report

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Alumina-on-alumina bearings for total hip replacement have been in use for over three decades and are associated with good long-term clinical performance^{1,2}. However, recently there have been anecdotal reports of audible noise, usually characterized as squeaking, in ceramic-on-ceramic joints, which have been publicized even in the media³. The reported prevalence of squeaking and noise in these bearings has varied from <3% (as reported by Walter et al.⁴, Toni et al.⁵, and Restrepo et al.⁶) to >10% (as reported by Varnum et al.⁷, Keurentjes et al.⁸, and Jarrett et al.⁹). The etiology of hip squeaking remains unclear and is undoubtedly a multifactorial phenomenon that may involve component femoral neck-cup impingement, microseparation, and subluxation¹⁰. Although limited in number, case reports on squeaky ceramic hip bearings appear to reflect this varied etiology. Thus, squeaking was seen in connection with the use of a mismatched zirconia head and alumina cup wear couple¹¹, femoral neck-socket impingement^{12,13}, and acetabular cup abduction and retroversion coupled with leg-length discrepancy¹⁴. There is an ongoing debate about whether squeaking of ceramic hips is a cause for concern¹⁵ or not¹⁶. Regardless of its prevalence, squeaking of ceramic-on-ceramic joints warrants investigation as it may signal abnormal wear of the bearing surfaces, which, in view of the brittle nature of ceramics, may progressively increase in severity. In the present case study, we had the opportunity to examine an alumina-on-alumina hip that was explanted because of severe persistent squeaking with all activities. The purpose of the present study was to determine if the severe noise was accompanied by substantial joint wear. We hypothesized that the squeaking was associated with degradation of the bearing surfaces. We also sought to establish the cause of any such degradation.

The patient consented to the publication of data concerning his case. This study was approved by the institutional review board of the Rush University Medical Center.

Case Report

A sixty-four-year-old man underwent primary total hip replacement surgery on the left hip for the treatment of end-stage osteoarthritis. A 58-mm-outer-diameter Trident ceramic acetabular system coupled with an Accolade hip stem (Stryker, Kalamazoo, Michigan) was implanted through an anterolateral approach. A 36-mm-diameter alumina femoral head with a 5-mm femoral neck length articulated against a titanium alloy-backed alumina acetabular cup insert; the alumina was BioloX Forte (CeramTec AG, Plochingen, Germany). Approximately six months after the operation, the patient reported popping in the hip, coupled with intermittent squeaking. The hip, although pain-free, had a unique palpable snapping over the greater trochanter that the patient described as a loud clunk as he walked. An iliotibial band release that was performed eleven months after the initial procedure and a release of more tendinous and scar tissue that was performed fifteen months following the initial procedure did not eliminate the popping. By eighteen months postoperatively, the patient was experiencing severe audible squeaking in the hip with all activity, although the hip was stable, had an excellent range of motion, and was not associated with pain. In addition to the severe bothersome squeaking, the patient experienced snapping of the iliotibial band. He was also found to have markedly malpositioned components, with a radiographic angle of inclination of the acetabular cup of 68° and an anteversion angle of approximately 48° as determined on an anteroposterior radiograph^{17,18} (Fig. 1), compared¹⁷ with operative inclination and anteversion angles of 39° and 71°, respectively. It should be noted that radiographic angles are relative to a projection of the acetabular axis on the frontal plane, whereas operative angles are relative to a projection of the acetabular axis on the sagittal plane¹⁷. Despite the high radiographic acetabular cup inclination angle, the patient did not have an episode of dislocation. Component malpositioning and the severe squeaking were the

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Fig. 1
Anteroposterior radiograph of the left hip, showing the total hip replacement.

indications for revision surgery at thirty-two months after the initial procedure. Intraoperatively, the acetabular cup was found to be excessively abducted and anteverted as seen on the pre-operative radiographs. No osteolysis was seen radiographically, and none was encountered when the acetabular implant was removed.

Surface Examination

The surfaces were examined under magnification of up to $\times 50$ with a stereomicroscope (Stemi 200-C; Carl Zeiss, Heidenheim, Germany) and with a Leo Gemini 1530 field emission scanning electron microscope (Carl Zeiss MicroImaging, Hamburg, Germany). The scanning electron microscope was fitted with an energy dispersive x-ray unit for elemental analysis. Surface roughness measurements of the articular surfaces were performed with a NewView 6300 white light interferometric microscope (Zygo Corp., Middlefield, Connecticut) with use of a $20\times$ Mirau objective. The alumina grain size was determined per ASTM Standard E112-96¹⁹.

Wear Measurements

Metrology measurements to determine wear patterns and to estimate total wear on the femoral head and the acetabular cup were performed with the SmartScope Flash coordinate measuring machine (Optical Gaging Products, Rochester, New York) with use of a previously developed method²⁰. This machine has a measurement precision of $2\text{ }\mu\text{m}$ in the x-y plane and $3\text{ }\mu\text{m}$ in the z direction. The components were scanned with a 3-mm ruby ball stylus attached to a low force precision touch trigger probe (Model TP200; Renishaw, Gloucestershire, United Kingdom).

Fig. 2
a: Photograph showing of the top view of the head and the cup insert. The roughened areas are highlighted with a green tint. The dark streaks on the femoral head are smeared metal. The red oval denotes the area where the femoral head is thought to have impinged the acetabular cup metal overhang during dislocation at the time of revision to create the major dark streak. b: Illustration showing the bottom view of the femoral head, depicted as a see-through diagram to visualize the match between the head and cup wear scars. The dark disk represents the head taper, and the rings denote the flat area and the chamfer at the bottom of the head.

Fig. 3
Scanning electron micrographs showing the articular surface of the head in the polished area (left) and the roughened area (right).

Statistics

Averages and standard deviations are reported. The Student *t* test was used to compare the surface roughness values with use of a significance level of $p \leq 0.05$.

Results

The femoral head and acetabular cup both exhibited large, slightly matte worn areas. These areas are highlighted with a green tint in Figure 2 and constitute the wear scars on these components. The wear scar on the acetabular cup was funnel-shaped, spanning approximately 50 mm (157°) along the superior equatorial region and progressively narrowing toward the pole, indicative of edge loading. The wear scar on the femoral head was roughly elliptical, with long and short axes of 42 and 20 mm, respectively. The prominent dark metallic streak on the femoral head was formed by impingement on the overhanging edge of the titanium alloy backing during dislocation of the hip at the time of revision surgery. The iatrogenic origin of the streak was confirmed by means of scanning electron microscopic examination, which revealed the surface of the streak to be devoid of scratches or other indications of

articulation. Energy dispersive x-ray analysis verified that the streak material was smeared titanium.

The surface roughness of the wear scar area on the femoral head near the pole was 133 ± 36 nm Ra, compared with 3.8 ± 0.7 nm Ra in a nearby still-polished area. This considerable difference ($p < 0.0001$) was reflected in the appearance of these surfaces under scanning electron microscopic examination. The alumina grain structure was clearly visible for both surfaces, but pitting was far more extensive in the roughened area (Fig. 3). A striking feature of this pitting is that it is mostly associated with transgranular and intergranular cracking, as seen from the extensive faceting, resulting in partial and whole grain pullout, rather than arising from intragranular fracture. The grain size was 2.36 ± 1.34 µm. The corresponding acetabular cup surfaces exhibited similar morphological characteristics, with grain pullout also being the dominant wear mode in the matte areas, as clearly seen in the micrograph shown in Figure 4. An irregularly shaped, speckled residue was found adhering to areas on the inferior aspect of the articular surface of the cup (Fig. 5). The residue was identified as organic material.

Fig. 4
Scanning electron micrograph showing an intergranular fracture in the high-wear area of the articular surface of the cup.

Fig. 5
Scanning electron micrograph demonstrating the organic material found on the articular surface on the inferior aspect of the cup.

Fig. 6
Contour maps of deviations from the 36-mm hemisphere for the bearing surfaces of the femoral head (left) and the acetabular cup (right). Scale values are given in millimeters.

The metrology scan of the bearing surfaces revealed substantial deviations from the original hemisphere, yielding the wear maps shown in Figure 6, assuming that the deviations were essentially due to wear rather than initial nonsphericity. The high-deviation areas match the wear scars (Fig. 2). Head and cup penetration values were 85 and 120 μm , respectively, corresponding with annualized penetration values of 32 and 45 $\mu\text{m}/\text{yr}$. The estimated volumetric wear was 23 mm^3 for the femoral head and 102 mm^3 for the acetabular cup, corresponding with wear rates of 8.6 and 38 mm^3/yr .

Discussion

The femoral head and acetabular cup penetration values (32 and 45 $\mu\text{m}/\text{yr}$, respectively) in the present study markedly exceed those reported for well-functioning alumina-on-alumina joints ($<5 \mu\text{m}/\text{yr}$)²¹. They are higher than the average

head and cup values of 25 and 17 $\mu\text{m}/\text{yr}$ for stripe wear but are lower than the average values of 246 and 162 $\mu\text{m}/\text{yr}$ for severe wear that were calculated from data reported for a set of ten Mittelmeier Autophor alumina-on-alumina hip prostheses that were explanted for revision²². To our knowledge, we are the first to report on the wear volume and distribution for the head and cup of a squeaky alumina-on-alumina hip prosthesis. The substantial total volume of wear debris, 125 mm^3 , generated after only thirty-two months of implantation, suggests that the bearing-degradation process accompanying squeaking, if left unchecked, could lead to osteolysis in some cases. Such a possibility is supported by clinical reports of osteolysis in association with alumina-on-alumina hip bearing surfaces^{13,23} and the reported macrophage cytokine release and apoptotic response induced by alumina particles^{24,25}. The predominance of grain pullout rather than grain fracture in the high-wear

areas suggests that the observed wear features are unrelated to the previously reported microseparation or lateralization of ceramic-on-ceramic joints. The latter mechanism would tend to produce extensive grain fracture through impact processes. The equatorial span of the wear scar on the acetabular cup is consistent with the steep radiographic inclination angle of the cup (68°) and is clearly indicative of edge loading against the femoral head. Such edge loading will increase the contact stresses and will decrease the fluid film lubrication, resulting in increased frictional forces, leading to intergranular fatigue crack growth, grain pullout, and roughening of the contact surfaces. The higher surface roughness will itself further disrupt fluid film lubrication by decreasing the lambda ratio (a parameter to describe the fluid film thickness relative to the roughness of the contacting materials²⁶), further increasing friction, making grain pullout and surface roughening a progressive process. The squeaking sound may then result from so-called stick-slip of the roughened surfaces sliding against each other under load. Stick-slip refers to the stop-go sliding of the bearing surfaces due to the alternating buildup of frictional forces and their release as the driving force from hip motion overcomes them. The stick-slip forces can induce resonant vibrations in some of the total hip replacement components, resulting in the emission of audible frequencies²⁷⁻²⁹.

The intraoperative anteversion angle of approximately 71° estimated for this acetabular cup was well outside the range of 15° to 35° defined as acceptable in a recent study in which cup orientation and edge-loading were reported as factors contributing to squeaking of ceramic-on-ceramic hips⁴. Our detailed analysis of this failed prosthesis provides a plausible chain of events for why malpositioning may lead to noise: malpositioning induces high local contact stresses, decreasing lubrication, leading to higher frictional forces and stick-slip. If the frictional shear stresses are high enough, grain pullout takes place, which may lead to severe wear, as observed here. Stick-slip caused by inadequate lubrication is consistent with the varied etiology of squeaking because lubrication issues can arise for a variety of reasons, such as high local stresses from malpositioning and impingement and conceivably even from periprosthetic fluid composition.

Our findings support the conclusion that the squeaking sound made by this joint was associated with degradation of the bearing surfaces caused by excessive cup inclination, although the primary cause of the squeaking is probably stick-slip resulting from inadequate lubrication rather than wear. Additional

contributing factors, such as the bearing material and joint fluid composition, are also possible. The substantial volume of wear observed in this case after only thirty-two months of implantation suggests that this degradation process, if left unchecked, could have led to large amounts of debris, which must be deemed undesirable even for alumina. For perspective, the combined head and cup linear wear rate of 77 µm/yr observed here is bracketed by the average linear wear of 30 to 220 µm/yr for conventional ultra-high molecular weight polyethylene (UHMWPE)³⁰⁻³² and is more than the 10 to 20 µm/yr for highly cross-linked UHMWPE, the 5 µm/yr for metal-on-metal hips after running-in³³, and the <5 µm/yr for well-functioning alumina-on-alumina hips²¹. Such a comparison is limited because the biological activity of wear debris depends not only on quantity but also on the material involved and the particle size distribution³⁴⁻³⁷. Our findings suggest that severe squeaking in a malpositioned ceramic-on-ceramic joint may provide an early warning signal of joint degradation. Such a possibility merits an investigation on the specific relationship, if any, between prosthetic design, joint positioning, surface degradation, wear, and noise acoustics. Studies of vibration analysis related to hip conditions³⁸ are just beginning to appear in the literature and should be further monitored. ■

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