NOISY CERAMIC-ON-CERAMIC HIPS.  
OVERVIEW ON THE SQUEAKING PHENOMENON

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Noisy ceramics bearing surfaces are recently recognized as problems in total hip arthroplasty. It appears that exact etiology of squeaking of COC prosthesis still remains unknown, but clinically significant squeaking appears to occur uniquely with hard-on-hard bearing surfaces. Although etiology of squeaking ceramic total hip arthroplasty remains elusive, component malposition, stripe wear and metal transfer to ceramic components has been proposed as potential causes.

1. INTRODUCTION

The total hip arthroplasty have an important tradition in biomechanical study. The English orthopedic John Charnley pioneered the hip replacement on November 1962 when he implanted the first acetabular cup manufactured from polyethylene, combining the metal implant with that from plastic. Using the polyethylene with high density (UHMWPE) in the acetabular cup, he changed the concept of arthroplasty having low friction coefficient with the concept of arthroplasty having low friction moment, at twist. So, declining the head of femur from 41.6mm to 22.25mm, we have in forefront the depression of moment of rotation from all system.

The used total hip bearings are manufacturing by metal-on-polyethylene, ceramic-on-polyethylene, metal-on-metal, metal-on-metal polyethylene sandwich, and ceramic-on-ceramic. The ceramic-on-ceramic bearings for total hip arthroplasty were begun by Pierre Boutin in France during the 1970s, by introducing Alumina ceramic components for articulation. First reports of its combination with UHMWPE cups date back to 1972. One of these ceramic-on-ceramic bearings are from alumina ceramic that was the first generation of ceramic prosthesis, after, was development alumina components of higher density and smaller grain size.

The acetabular component consists of a preassembled polyethylene-alumina compsite liner that is held in a titanium-alloy shell by means of a Morse taper system (JB_JS,2006,88_A, 780-
A Morse taper system showing the metal sleeve within the ceramic head. ([17] J. Arth., 1231-, 2009)

Cross-sectional image of the monoblock ceramic bearing cup with direct-compression-molded UHMWPE interposed between the outer trabecular metal layer and a press-fit alumina ceramic liner (J. Bone Joint Surg 2007; 89-A, 367-375)

Postoperative audible squeaking of a hip replacement is a complication that is almost as old as hip replacements themselves, Charnley noted in vitro squeaking when he tested one of the ceramic-on-ceramic bearings of Boutin in his “pendulum friction comparator”. In the modern era of total hip arthroplasty, it is more commonly a complication of hard-on-hard bearing surfaces.

The squeaking in hip replacement results from a forced vibration that comprises a driving force and a dynamic response [5]. The driving force is a frictional driving force and results from the high friction met in hard-on-hard bearings when is a loss of fluid film lubrication. The dynamic response is resonance of a part of the device at a frequency that is influenced by the natural frequency of the part.

It appears that exact etiology of squeaking of COC bearings still remains unknown, but the factors that have been proposed in the development of squeaking are related to: patient factors, surgical factors, and component factors.

Numerous mechanisms have been proposed to explain the etiology of noisy COC bearings. Mismatch of the bearing surface, which has been previously reported, was once thought to be the main etiology. An interesting study analyzing the joint aspirate of patients with squeaking COC bearing surface, demonstrated numerous ceramic particles in the fluid and proposed microfracture of the bearing surface as the culprit. Other investigators have suggested that impingement between the femoral neck and the metal acetabular rim leads to generation of metal debris that gains access to the bearing surface acting as third body and results in generation of noise. Lack of appropriate lubrication or so-called slip stick was offered as another potential etiological factor in generation of noise with hard on hard bearing surfaces. Over the last few years, attention of orthopedic surgeons had turned to studies by Walter et al. that proposed component malpositioning as the major etiological problem in generating squeaking in COC hips.

Although most of the acetabular components were positioned in “excessive” anteversion, there did not appear to be a direct correlation between acetabular component positioning and squeaking. There was no statistically significant difference in abduction and version angles of the acetabular component between the squeaking hips and those without squeaking. Finally, the femoral head size and the type of femoral stem did
not appear to influence the incidence of squeaking. There were squeaky hips with various femoral head sizes and two different designs of femoral stem.

RETRIEVAL ANALYSIS

In order to further explain the relationship between acetabular component malposition and squeaking, bearings retrieved from squeaking hips are studied, in particular looking for evidence of edge loading. The reason behind edge loading and stripe wear is not exactly obvious. Previous studies have identified steep cup angle, young age, and revision surgery as potential predisposing factors for edge loading and consequent aseptic loosening.

![Picture of the retrieved acetabular component from a patient with squeaking hip with evidence of impingement. Note the indentation of the metal rim generated by the femoral neck. ([15]-J. Arth., 5, pp. 643-649, 2009)](image)

Although impingement was present in a majority of the squeaking retrievals, it does not appear to be necessary for squeaking to occur. The common factor is edge-loading wear, which may well be a critical mechanism. Furthermore, the backside evidence of liner tilting in the shell prompted further questions. To evaluate edge loading further, finite element analysis was conducted. The results of the analysis show that there is a stiffness incompatibility between the acetabular shell and the liner. The shell tends to deform, uncoupling the shell-liner taper system.

![Picture of the retrieved components from a patient with squeaking hip that shows stripe wear on the femoral head and the acetabular component. ([15]-J. Arth., 5, pp. 643-649, 2009)](image)

The ceramic head and ceramic insert were colored with a surgical marking pen, indicating the area of edge loading wear. The pencil indicates the superior aspect of the insert (A) and the posterior aspect of the head (B). The retrieved bearing shows evidence of edge loading of the ceramic head against the posterior rim of the ceramic insert. ([23]- J. Arth., 22 (4), pp. 496–503, 2007)
Schematic of a wear stripe and its orientation within the articulating interface at the time of squeaking. Bearing noise occurred near a loading peak when relative motion was along the long axis of the wear stripe. ([9]-J. Arth., 22, 7, S3, 47-51, 2007)

- All squeaking retrievals showed evidence of edge loading wear,
- Some implants also had evidence of impingement of the femoral neck against the elevated metallic rim, or the ceramic insert, or both.
- Closer inspection of the backside of the ceramic inserts revealed evidence of movement of the ceramic inserts within the titanium shell in several squeaking retrievals.

DEMOGRAPHIC AND RADIOGRAPHIC ANALYSES

The demographic data demonstrated that squeaking hips are more likely in taller, heavier, and younger patients. Walter et al [1], [22], [23] reported a squeaking incidence of 0.66% in an Australian series of 2397 ceramic-on-ceramic THAs, and patients with squeaking hips were younger, heavier, and taller than those without squeaking hips. Such a finding, inversely, might explain the rarity of squeaking in the Asian population, which tends to be smaller, shorter, and less heavy than many other populations. While the issues of squeaking might be unavoidable in a small percentage of patients, this issue may get better, or is a reasonable trade-off for a long term service life and painless and excellent function. Because noise from ceramic-on-ceramic hip bearings has been reported during specific patient activities, squeaking hips were divided into groups depending on the activities that produce the squeak:
- The “bending group”; these hips squeak in flexion, usually when the patient bends to pick an object up off the floor, rises from a seated position, or bends to tie their shoe laces. For example, a patient whose left hip squeaks when they bend over with the left foot forward can usually prevent the squeak by placing the right foot forward when bending.
- The “walking group”; these hips squeak immediately upon commencement of walking and the squeaking does not go away. Video analysis revealed that the squeak occurred at the end of stance phase on the affected side.
- The “prolonged walking group”; squeaking appears only after prolonged periods of walking. Typically, these patients are keen golfers or avid walkers, and the hip begins squeaking on the ninth hole of a golf course or after 2 hours of walking outdoors. These patients were unable to reproduce the squeaking in the office.

A CT scan of bilateral ABG II ceramic-on-ceramic hip replacements. In this patient, the right hip squeaks with walking and the left hip does not squeak. ([1]- J Arthroplasty, 22, 4, pp. 496-503, 2007)
The mean acetabular anteversion was greater in the walking group (40°) than in both the bending group (19°) \((P = .001)\) and the prolonged walking group (18°) \((P = .020)\). There was no statistically significant difference in the inclination between the 3 groups, nor was there a difference in the anteversion between the bending and prolonged walking groups.

**MODAL AND ACOUSTIC ANALYSIS**

Squeaking noises in hip replacements result from a forced vibration that comprises a driving force and a dynamic response. The driving force is a frictional driving force and results from the high friction seen in hard-on-hard bearings when there is a loss of fluid film lubrication. Fluid film lubrication requires a rather delicate balance of a number of factors, including sliding speed, lubricating fluid viscosity, bearing roughness clearance and contact pressure.

A breakdown of fluid film lubrication may result from edge loading (a reduction in contact area), third bodies (such as ceramic debris) in the articulation, damage to the articular surface (increased roughness), mismatched bearing diameters, or perhaps other causes. Finite element analysis demonstrated that, with edge loading, the shell deforms and the shell-liner system uncouples, with the liner tilting in the shell. The friction of the movement between the liner and the shell is another potential driving force. The dynamic response is resonance of a part of the device (the oscillator) at a frequency that is influenced by the natural frequency of the part. By measuring the frequency of squeaking hip replacements and comparing it with the natural frequency of the component's parts, we can determine which part or parts could potentially be the oscillator.

The harmonic series seen on the acoustic analysis is evidence that squeaking sounds are produced by resonance. In order to improve our understanding of how the parts resonate, a modal analysis was performed. Generic three-dimensional models of a titanium-alloy anatomic femoral stem with a 12-mm diaphyseal diameter and a 28-mm ceramic femoral head were generated in Patran, and several different acetabular component models were used. The femoral stem was meshed with use of ten-noded tetrahedral elements and eight-noded hexahedral elements with use of the material properties. Boundary conditions were applied to the components to replicate the in vivo environment as closely as possible. A modal analysis was performed for the femoral stem with the femoral head attached. A modal analysis was performed for the acetabular shell and liner combined with contact boundary conditions to simulate a fully matched taper junction, contact occurring only at the mouth of the acetabular shell. The acetabular shell and ceramic liner were also analyzed as separate pieces.

The results of the modal analysis showed multiple possible modes of resonance for the femoral stem and head. These were different combinations of bending and twisting in different planes. There were no relevant modes seen with the combined acetabular shell and ceramic liner because the ceramic liner effectively locked the rim of the shell, preventing resonance except at very high frequencies well above the audible range. The acetabular shell as a separate piece resonated in an elliptical configuration known as the \((2,0)\) mode, which is typical of wine glasses and bells. The ceramic liner as a separate piece also resonated in the \((2,0)\) mode but at a substantially higher frequency because of the material and geometric differences. Alumina ceramic and titanium alloy have similar densities (3.9 g/cm³ and 4.4 g/cm³, respectively) but very different elastic moduli (390 GPa and 115 GPa, respectively). Furthermore, the ceramic inserts have a similar thickness but a smaller diameter than the titanium shells, resulting in higher natural frequencies.
The squeaking cannot be explained by the components individually – none of the components is responsible alone, although the stem exhibited a first mode close to the frequencies observed in vivo. The different eigenfrequencies for the fixed case can be explained by the different system mass and stiffness by assembling the components [7]. Mode coupling is presently the most likely mechanism responsible for squeaking. This will be further investigated numerically and experimentally. Additionally an explicit simulation will reveal whether surface waves are involved in the excitation.

**IN VIVO ACOUSTIC ANALYSIS**

In order to determine the frequency and nature of the sound emitted from squeaking hips, an in vivo acoustic analysis was performed. Once a squeak was identified, one performed a fast Fourier transform, which allowed the major frequency components of the squeaking to be easily measured. In this way one determines the frequency range of the recording device by observing the frequency range of the background noise on the recording. Was found that if a squeak was audible on the recording, one had no difficulty determining its frequency, regardless of the quality of the device used to make the recording or the amount of background noise. Modal analysis suggested that resonance of the ceramic components would occur only at frequencies above the human audible range and that resonance of the metal parts would occur at frequencies within the audible range. Furthermore, it suggested that resonance of the combined ceramic insert and titanium shell would not be within the audible range. No resonance was detected in the audible range in any of the modular ceramic and titanium acetabular components when they were correctly assembled. No resonance was detected in the audible range in any of the ceramic liners or ceramic heads when they were tested unassembled. Audible resonance was detected in all of the titanium shells when they were tested unassembled. The fundamental frequency of the titanium shell ranged from 4300 Hz to 9800 Hz, with higher modes extending into the higher frequencies.
CONCLUSIONS

Friction, resulting from the sliding contact of solids, often gives rise to diverse forms of waves and oscillations within solids which frequently lead to radiation of sound to the surrounding media. Always acting as a resistance to relative motion, friction fulfills a dual role by transmitting energy from one surface to the other and by dissipating energy of relative motion. In practice, at longer length scales, the dual roles of friction, both transmitting and dissipating energy, almost always coexist. The conditions under which friction provides more energy to a system than that system can dissipate constitute the basis for most of the instabilities observed in friction-excited vibrations and a prime source of resulting sound radiation. Examples of sounds that result from friction-excited vibrations and waves appear frequently: aircraft and automotive brake squeals, the squeak of snow when walking on it, door hinges, chalk on a blackboard, the squeak of some total hip prostheses (THP ceramic-on-ceramic, metal-on-ceramic). The squeaking of THP cannot be explained by the components individually – none of the components is responsible alone, although some of them (the stem) exhibited a first mode close to the frequencies observed in vivo. Coordination of the visualization of joint movement with the measurement of acoustic emissions can help to properly localize the exact sound center and the causes for its occurrence.

Audible squeaking of a hip replacement remains a still unexplained phenomenon. The sliding motion within the acetabular cup, causing a total hip prosthesis to resemble a ball-and-socket joint, could lead to the induction of vibrational propagation across the interface of the femoral head and acetabular cup, possibly leading to audible interactions.

REFERENCES