Squeaking: Current knowledge and how to avoid it

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Abstract This review aims to update the reader with current thinking and research related to the well documented phenomenon of squeaking hip arthroplasties. The etiology of squeaking is multifactorial and still not well understood. We aim to share our own experience and views on the combination of factors we believe increases the likelihood of squeaking, along with mechanisms by which the sound may be generated. Recent published findings from other groups are summarized along with an appropriate management algorithm we recommend for this cohort of patients.

Keywords Squeaking · Ceramic · Metal · Hip · Arthroplasty · Review

Introduction

Squeaking total hip replacements are not a new phenomenon; the first in vivo reports were of Judet's acrylic hemiarthroplasty in the 1950s [1]. Sir John Charnley noted in vitro squeaking whilst testing Boutin's ceramic on ceramic bearings in his 'pendulum friction comparator' [2]. Squeaking is well documented in medical literature following a total hip replacement. Other noises are grinding, snapping, and clicking. Typically, squeaking occurs within the first 2 years postoperatively and is not associated with pain or loss of function [3].

Though a well-documented phenomenon, the etiology of squeaking is still under debate. In an attempt to identify reasons why it happens, this review article focuses on current

literature concerning the topic along with our own observations and advice on managing affected patients.

What is a squeak?

A squeak is defined as a vibration within an audible range. It requires an impulse which can then be amplified or dampened. The impulse at the bearing surface of a hip replacement is friction and this is amplified by vibration of the components.

Squeaking and bearing surfaces

Squeaking is generally a problem of hard on hard bearings. Excellent clinical and radiological results have been observed with these bearings, though more recently there has been concern over metal-on-metal large diameter hip replacements and resurfacings with regard to metal ion levels, ALVAL, and pseudotumor formation.

The incidence of squeaking in ceramic on ceramic hip replacements varies in previous reports and ranges from <1%–20.9% [4–8]. The incidence of revision of these hips is substantially lower, however, as clinically squeaking is rarely troublesome enough for the patient to warrant further surgery.

With metal on metal bearings, squeaking is less frequently reported. The incidence is between 4% and 10% [9, 10] and appears to occur transiently or is more short term in duration. This may be due to a 'running in' phase with flattening of surface asperities. We believe impingement can create a sharp ridge adjacent to a wear patch, which causes increased friction. Over time this is subsequently worn away and the friction diminishes. We do not know if metal on metal squeaking is an underreported phenomenon, or if it actually

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has a lower incidence than squeaking between ceramic bearings.

Squeaking has also been reported in isolated cases of patients with hard on soft bearings where failure of the polyethylene liner has led the ceramic or metal head to articulate directly with the metal acetabular shell [11, 12], and with ceramic liner fractures [13] or in the presence of ceramic debris [14].

Causes of squeaking

The causes of hip squeaking appear to be multifactorial requiring a certain combination of interaction between patient, implant, and surgical factors.

We looked at a group of patients with squeaking ceramic hip replacements, and when comparing with a control group, found associations including younger age, increased weight, height, hip range of motion, and activity levels [7].

Squeaking is associated with certain activities, such as walking, bending, and rising from a low sitting position. This indicates that noise is produced with either cyclical movement during the gait cycle or during extreme flexion of the hip in bending.

Increased patient weight is thought to predispose to squeaking through increased mechanical loading of the joint, though obesity alone is not associated [7].

Implant position factors such as high or low anteversion and increased inclination have been shown to have a higher association. We believe that these cup positions lead to impingement and edge loading.

Implant design factors have also been implicated with squeaking. The elevated rim of the Trident (Stryker Orthopaedics, Mahwah, NJ) device has been associated with higher than normal rates of squeaking [15•], possibly due to the reduced range of motion it allows which in turn increases the risk of edge loading and rim impingement.

Increased rates of squeaking have also been reported with certain pairs of implants such as with the Trident acetabular component and Accolade stem (Stryker Orthopaedics, Mahwah, NJ). The rate is significantly lower when the Trident device is paired with an Omnifit (Stryker Orthopaedics, Mahwah, NJ) stem, all 3 implants are manufactured by Stryker [16].

The Accolade stem is manufactured from a titanium metallic composite containing higher amounts of Zr, Mo, and Fe. The differing incidence of squeak between may be related to amount of wear debris, stems shape, or stiffness. Material composition is also believed to be important as squeaking has been reported with mismatched bearings where a zirconium ceramic head was coupled with an alumina ceramic liner [17].

Mechanisms of squeaking

Stick slip

The vibrations that initiate squeaking are caused by stick slip friction. This was initially described in metal on metal hip replacements [18] and can also occur between ceramic bearings. Under ideal conditions, hard on hard bearings are assumed to operate under conditions of fluid film lubrication with very low friction [19]. If this fluid film breaks down, there is a substantial increase in friction as a result of sliding contact. With motion, a rotational force overcomes the static frictional force causing acceleration and deceleration of 1 surface with respect to the other, manifesting in vibrations and sound radiation [20, 21•].

Edge loading and stripe wear

The frictional force of a ceramic-on ceramic (CoC) bearing under optimal lubrication conditions is too low to initiate stick-slip. During the manufacturing process, ceramic liners are ground and polished to specification after sintering to obtain the finest surface possible. This creates a hard, sharp edge a few millimeters in from the rim of the component. Edge loading occurs when the hip contact force vector moves over this hard edge, causing both surfaces to damage secondary to increased contact stress. This manifests as a long, narrow roughened pattern of damage on the head termed stripe wear.

Measurement of the location and orientation of stripe wear suggests edge loading occurs with subluxation of the head over the hard posterior edge with the hip in deep flexion [22].

Edge loading wear is common in CoC bearings, however, the clinical consequences are minimal. Posterior edge loading can occur with well positioned acetabular components, in particular in patients who are active with a good range of motion. Squeaking has been associated with posterior edge loading and we have seen this occur in patients who had high levels of edge wear in retrieved alumina ceramic bearings [23•].

Anterosuperior edge loading occurs less commonly but may be more clinically significant. The volume of wear particles is higher compared with posterior edge loading in CoC hips and if squeaking is associated, it is more persistent as it occurs during walking and when the hip is in full extension.

The lack of lubrication during edge loading combined with the damaged bearing surface may be sufficient to generate stick-slip conditions but other mechanisms have also been proposed, such as metal transfer to a ceramic head [24], starvation of lubricant [25], and debris between bearing surfaces [26].

Rim impingement

Certain implants have an elevated metal backing to prevent the ceramic liner from impinging or chipping and fracturing during insertion. This may be a contributing factor to impingement between the neck of the femoral implant and the elevated rim of the socket, causing metallosis. This will be exacerbated if there is excessive socket anteversion or retroversion when the implants are seated along with increased ligamentous laxity or hip range of motion [27].

Liner seating

A well seated ceramic liner in a titanium shell appears to take on the resonant characteristics of ceramic which is above the audible range when we have subjected ceramic bearing couples to acoustic analysis. A series by Langdown et al. [28] demonstrated 19% incidence of incomplete seating of ceramic liners within the Trident shell. It is possible that incomplete seating of the ceramic liner, results in the titanium shell resonating at its normal frequency, which is 4300 to 9800Hz and within the audible range for a squeak.

In addition to this, Jarrett et al. [29] demonstrated that for the same liner size in CoC hips, thinner sockets were more likely to squeak, possibly due to deformation on insertion, predisposing the incomplete liner seating.

Acetabular component orientation

We have found that high acetabular component anteversion has been associated with squeaking [30•]. Patients in our retrieval study demonstrating high-wear anterosuperior edge-loading and squeaking hips all had anteversion $> 22^\circ$ and an increased cup inclination angle $> 55^\circ$ [30•]. The optimum acetabular position appears to be highly dependent on patient range of motion and so in general may be different for each patient.

Another retrieval analysis from our group [23•] suggests the classic square ‘safe zone’ [31] of acetabular implant position does not apply to CoC bearing surfaces. Closed and retroverted cups had a higher association of posterior edge loading, impingement, and squeaking, also found in the recent Delta Motion (De Puy, Warsaw, Indiana) study by McDonnell et al. [32].

Fourth generation CoC bearings and squeaking

New implant designs, in particular those involving ceramic bearings, need to consider edge loading. This is particularly the case with larger diameter devices that are also associated with an increased frictional torque. Frictional torque has been used as an explanation for the damage observed at the

modular junctions of large diameter devices with support from studies involving hard on soft [32], and hard on hard bearings [33].

The Delta Motion (De Puy, Warsaw, Indiana) device is the first pre-assembled, monoblock, large diameter, fourth generation CoC bearing. Its design features have the potential to reduce the incidence of squeaking, yet a recent study reporting on 208 consecutive cases with a mean follow-up of 21 months revealed reproducible squeaking in 12.5% [34••]. This is comparable with previous reports of other CoC total hip replacements but higher than the authors expected.

Our own experience of this implant, which is yet to be published includes 206 consecutive cases with a 7.3% rate of hips that squeaked, all reproducible in deep flexion only whilst the patients were weight bearing. All the squeaking hips occurred with head sizes of 44 mm and above or where the liner was 54 mm or above. Ein-Bild-Roentgen-Analysis (EBRA) of cup inclination and anteversion showed no difference between the squeaking and silent hips.

In the recent study by McDonnell et al. [34••] a selection of 4 different cementless femoral stems were used, Finsbury Type C (Finsbury Orthopaedics, Leatherhead, United Kingdom), Corail (DePuy, Warsaw, IN), SL Plus MIA (Smith & Nephew, Memphis, TN) and Tri-Lock (DePuy, Warsaw, IN). Only 1 stem, the Securit (Stryker Orthopaedics, Mahwah, NJ) was used for all our patients and this may explain the lower rate of squeaking as it is a relatively more rigid stem. Increased rigidity can result in a reduced ability to resonate or amplify the vibrations occurring at the articular interface into an audible squeak.

We previously published a series of 2406 patients where 74 squeaking hips (73 patients) were identified, giving an incidence of 3.1% at a mean follow-up of 9.5 years (4.1 to 13.3) [30•]. A third generation ceramic BioloX forte (CeramTec, Plochingen, Germany) was used in the majority of cases and though the largest available head size was always used, they were still smaller than those used with the Delta Motion component.

In this series, taller, heavier, and younger patients were significantly more likely to have hips that squeaked. Squeaking hips had a significantly higher range of postoperative internal and external rotation compared with silent hips. Patients with squeaking hips had significantly higher activity levels. A squeaking hip was not associated with a significant difference in patient satisfaction or Harris hip score. Four implant position factors enabled good prediction of squeaking. These were high acetabular component inclination, high femoral offset, lateralization of the hip center and either high or low acetabular component anteversion.

The difference in squeaking rate between this study and the more recent published Delta motion study [34••], and indeed our own unpublished work could be due to 3 different

factors: head size, type of ceramic and acetabular component morphology.

Choi et al. [35] have also shown that squeaking is more common in large ceramic heads. Interestingly though McDonnell et al. [34••] found a smaller head size increased the risk of squeaking. They believe a smaller head neck ratio exacerbates edge loading and impingement, but agree ligamentous laxity and increased range of motion were associated with higher rates of squeaking.

The Delta Motion implant is a fourth generation ceramic and to date we are unaware of any studies comparing rates of squeaking between third and fourth generation ceramics.

Finally, the Delta Motion cup is a thinner component (2mm titanium shell with a 3mm ceramic liner giving a 5mm wall thickness) compared with standard ceramic liners and this less rigid construct may result in an increased ability to resonate or amplify the vibrations occurring at the articular interface into an audible squeak. This explanation can be supported by acoustic and finite element analyses [36] revealing stiffness mismatch between shell and liner, which may allow the shell to oscillate producing an audible squeak. Acoustic and modal analysis show that the natural frequencies of the ceramic components are above the audible range, suggesting that resonance occurs in the metallic part.

Metal on metal hips and squeaking

Squeaking has become a more clinically relevant topic over the last 8 years in the literature and in general has primarily revolved around ceramic on ceramic bearings.

Squeaking is less reported with metal-on-metal hips whether large or small diameter bearings and it is unclear why this may be.

A prospective series of 230 hip resurfacings included 3.9% squeaking hips at a mean follow-up of 3 years and 5.3% squeaking hips at a mean follow-up of 5 years [9].

Our own study [37] looked at 290 metal on metal hip resurfacing patients and found 3.4% reported audible squeaking postoperatively. Of these 10 patients, 8 had the Birmingham Hip Resurfacing System (Smith & Nephew, Memphis, TN) and 2 MITCH TRH (Stryker, Orthopaedics, Mahwah, NJ) resurfacings. None of the cases were revised for noise alone as per the patient's wishes. 8 of the 10 patients had well positioned components according to AP radiographs though we were unable to measure anteversion at the time. It would be useful to revisit these cases to remeasure inclination and anteversion with the latest validated software such as EBRA [38].

In vitro friction stimulator tests have demonstrated the incidence of squeaking in metal on metal bearings is highest with larger diameter bearings [39]. Higher friction was associated with these larger bearings suggesting the squeaking is

associated with a less effective lubrication model. Ultrasound was used in this study to demonstrate thinner lubricating films were associated with larger clearance bearings.

However, in 2008, the Australian Orthopaedic Association National Joint Registry identified an increased risk of revision in resurfacings as the size of the components decreased, irrespective of gender [40]. Resurfacing acetabular components have an articular arc of coverage, which is less than a hemisphere (180°). Smaller components have a more lateralized center of rotation and a reduced articular arc [41]. It is believed that this can increase the risk of edge loading, which may in turn be associated with increased wear, failure, and possibly squeaking. Smaller components in theory may also provide a less favorable environment for fluid film lubrication as they generate a reduced sliding velocity when compared with larger diameter components [42]. We are currently investigating the relationship between component size and risk of squeaking in metal on metal hip resurfacings.

Managing the patient with a squeaking hip

There is currently no recognized classification for squeaking or sound generation in hip replacements or hip resurfacings that we are aware of. The sounds can be recorded and classified according to the characteristics of the signal they emit but in clinical practice this may be difficult. We suggest a more clinical approach based on frequency of patient symptoms, associated hip movement, and bearing combination used.

Ceramic on ceramic bearings

Benign squeaking

This is the most common form of squeaking encountered and is most likely associated with posterior edge loading. The patient usually experiences no pain, and hip function is not affected. They do notice intermittent squeaking, which is usually brought on with a specific activity (bending while weight bearing) and well tolerated. The components are well positioned in these cases and there is little or no wear. This can usually be avoided by counseling the patient to externally rotate the foot while weight bearing.

Problematic squeaking

This form is very rare. Patients may experience pain and describe the noise as being 'intrusive' with every step and may affect hip function. The components are usually malpositioned and associated with high wear secondary to anterosuperior edge loading.

Metal on metal bearings

We have found that squeaking in metal on metal hip replacements and resurfacings is generally intermittent [37]. It is often associated with loading the hip in an extreme position that the patient does not often perform. Typical activities are squatting or bending forwards to pick a heavy object.

Often the squeaking will settle after a period of time and we believe that this coincides with flattening of a raised ridge adjacent to the wear patch on the component. Squeaking can return when the patient attempts the same activity again, but it does not appear to be as reproducible as seen with ceramic on ceramic squeaking.

Rare squeakers

These patients report a single event that lasts up to a day and is not reproducible with the same activity.

Episodic squeakers

These patients have episodes of squeaking that last longer, typically up to a few days before settling and are often difficult to reproduce with activity.

Persistent squeakers

Patients in this subgroup can demonstrate regular squeaking after certain activities such as bending forwards to reach for an object, or even after long walks.

Other noises

Theoretically all bearings couples can be involved with noise generation in hip replacements. Practically, however, noises are observed nearly exclusively in hard-on-hard articulations with no studies found reporting the incidence of squeaking in hard-on-soft bearings.

During the normal gait cycle, the bearing surfaces of a total hip replacement can separate and with hard on hard bearings, a hard-landing can occur at heel strike manifesting itself to the patient as a pop or a snap. One study has, however, shown a clear correlation between separation of the bearings and squeaking [43]. Soft tissue impingement or sliding such as a snapping iliotibial band can also generate noise other than squeaks. Clunks, clicks, or knocks can be defined by the dominant frequency of the sound wavelets generated. Certain noises such as grating are believed to be compound sounds made up from a combination of different sounds.

Fig. 1 Algorithm for managing a patient presenting with a squeaking total hip replacement

History and clinical examination

A thorough history and examination should be performed looking to see if the patient can reproduce squeaking and what position this is in. Examination should focus on range of movement of the hip with any signs of impingement.

Imaging

All patients require radiographs of the hip to exclude any obvious malpositioning, implant failure or fracture. We recommend that all patients with ‘problematic’ squeaking also have a CT scan of the pelvis to exclude ceramic liner fracture, which may not be obvious on plain radiographs. The orientation of the components can also be assessed more accurately for both inclination and anteversion.

Treatment

A squeaking hip is not associated with a significant difference in patient satisfaction or Harris Hip Score. When squeaking is infrequent and function is not impaired, patients can be reassured and counseled on activity modification and monitored closely during follow-up. In the great majority of patients with squeaking hips, surgical intervention is not required. Most squeaking can be reduced by modifying the foot into an externally rotated position on bending while load bearing.

Very rarely surgery is recommended for persistent or troublesome squeaking, severe malpositioning of components, failure of the implants (including fracture), impingement and subluxation, and pain. At the time of surgery, component malposition and soft tissue or bony impingement can be corrected and soft tissue tension can be optimized. If necessary the bearing can be changed during surgery to another CoC or to a ceramic-on-polyethylene bearing with a titanium sleeve to go over the trunnion of a well fixed femoral stem which protects it and offers neck length modularity. We have found excellent rates of survival, function, and high levels of patient satisfaction in 165 such cases at a mean of 4.8 years [44•]. We recommend using the fourth generation Delta ceramic wherever possible as it has a lower reported rate of fracture than Alumina ceramic [45]. Our recommended treatment algorithm is summarized below in Figure 1.

Conclusions

The precise mechanics behind the production of sound by a squeaking hip replacement remains unknown. Though squeaking is a multifactorial phenomenon, certain factors such as component position are within the surgeon’s control.

In general it is believed there is a breakdown of fluid film lubrication by a combination of the above described mechanisms, though abnormal edge loading seems the most likely explanation. However, the majority of implants where edge loading occurs do not squeak and the reasons behind this are still unclear.

Squeaking in MoM hips is still poorly understood. It also appears to be multifactorial just as in CoC hips though bearing clearance and bearing size appear to play a more prominent role than component orientation.

In general it appears squeaking is related to adverse tribological conditions caused by suboptimal lubrication and elevated friction. The role of head size with larger diameter MoM and CoC bearings needs to be further evaluated.

The long term consequence if any, of squeaking in hard on hard bearing hip replacements also needs to be investigated. However, after analysing alumina components retrieved from squeaking hips [46•], it is our belief that squeaking CoC bearings are associated with increased wear rates.

Catastrophic anterosuperior edge loading of the early generations of ceramic associated with squeaking has not yet been seen with the latest generation of BioloX Delta, but these newer bearing surfaces need to be further evaluated, along with the role implant design has with regard to squeaking.

At present, all patients undergoing total hip replacement should be counseled about the risk of squeaking, but ceramic-on-ceramic bearing surfaces in particular remain an attractive option because of the extremely low wear rates and low prevalence of osteolysis [47].

Compliance with Ethics Guidelines

Conflict of Interest Arjuna M. Imbuldeniya declares that he has no conflict of interest. Simon J. Pearce declares that he has no conflict of interest. William L. Walter declares that he has no conflict of interest. Bernard A. Zicat declares that he has no conflict of interest. William K. Walter declares that he has no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Papers of particular interest, published recently, have been highlighted as:

- Of importance
- Of major importance

1. Amstutz HC, Clarke IC. Evolution of hip arthroplasty. In: Amstutz HC, editor. Hip arthroplasty. New York: Churchill Livingstone; 1991.
2. Charnley J. Low friction arthroplasty of the hip: theory and practice. New York: Springer-Verlag; 1979. p. 10.

3. Restrepo C, Matar WY, Parvizi J, et al. Natural history of squeaking after total hip arthroplasty. *Clin Orthop Relat Res*. 2010;468:2340–5.
4. Rothman RH. Noisy ceramic hip: is component malpositioning the problem? Dallas: AAHKS. Dallas; 2006.
5. Jarrett C, Ranawat AS, Bruzzone M, et al. The squeaking hip: an under-reported phenomenon of ceramic-on-ceramic THA. AAOS. Vol. Paper 198, San Diego, 2007.
6. Walter WK, Zicat B, O'Sullivan M, Walter WL. Modern ceramic-on-ceramic bearings in total hip arthroplasty - minimum five year follow-up. *J Bone Joint Surg Br*. 2004;87-B(Suppl III):361–2.
7. Walter WL, O'Toole GC, Walter WK, et al. Squeaking in ceramic-on-ceramic hips: the importance of acetabular component orientation. *J Arthroplasty*. 2007;22–4:496–503.
8. Keurentjes JC, Kuipers RM, Wever DJ, Schreurs BW. High incidence of squeaking in THAs with alumina ceramic on ceramic bearings. *Clin Orthop*. 2008;466:1438–43.
9. Back DL, Dalziel R, Young D, Shimmin A. Early results of primary Birmingham hip resurfacings. An independent prospective study of the first 230 hips. *J Bone Joint Surg Br*. 2005;87:324–9.
10. Ebied E, Journeaux S. Metal-on-metal hip resurfacing. *Curr Orthop*. 2002;16:420–5.
11. Bono JV, Sanford L, Toussaint JT. Severe polyethylene wear in total hip arthroplasty. Observations from retrieved AML PLUS hip implants with an ACS polyethylene liner. *J Arthroplasty*. 1994;9:119–25.
12. Mihalko WM, Papademetriou T. Polyethylene liner dissociation with the Harris-Galante II acetabular component. *Clin Orthop Relat Res*. 2001;386:166–72.
13. Suzuki K, Matsubara M, Morita S, et al. Fracture of a ceramic acetabular insert after ceramic-on-ceramic THA-A case report. *Acta Orthop Scand*. 2003;74:101–3.
14. Toni A, Traina F, Stea S, et al. Early diagnosis of ceramic liner fracture: Guidelines based on a 12-year clinical experience with 3710 modern ceramic prostheses. Exhibited at the Annual Meeting of the American Academy of Orthopaedic Surgeons, March 22–24, 2006, Chicago, IL. Scientific Exhibit No. 14.
15. • Parvizi J, Bahar A, Wong JC, et al. A squeaky reputation: the problem may be design dependant. *Clin Orthop Relat Res*. 2011;469:1589–605. *Retrospective review of 1507 CoC patients, all 92 cases of squeaking had an elevated acetabular titanium rim.*
16. Riecker CB, Kottig P, Schon R, et al. Clinical wear performance of metal on metal hip arthroplasties alternative bearing surfaces in total hip replacement. In: Jacobs JJ, Craigs TL, editors. *Alternative bearing surfaces in total joint replacement*: STP 1346. West Conshohocken, PA: ASTM International; 1998. p. 144–7.
17. Morlock M, Nassutt R, Janssen R, et al. Mismatched wear couple zirconium oxide and aluminium oxide in total hip arthroplasty. *J Arthroplasty*. 2001;16:1071–4.
18. 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*. 2010;92:550–7.
19. Smith SL, Dowson D, Goldsmith AA. The lubrication of metal-on-metal total hip joints: a slide down the Stribeck curve. *Proc Inst Mech Eng*. 2001;215:483–93.
20. Walter WL, Waters TS, Gillies M, et al. Squeaking hips. *J Bone Joint Surg Am*. 2008;90 Suppl 4:102–11.
21. • Jeffers JRT, Walter WL. Ceramic-on-ceramic bearings in hip arthroplasty. *J Bone Joint Surgery Br*. 2012;94:735–45. *Recent comprehensive systematic review on the literature concerning CoC hip bearings, including problems encountered and new design concepts.*
22. Walter WL, Insley GM, Walter WK, Tuke MA. Edge loading in third generation alumina ceramic on ceramic bearings: stripe wear. *J Arthroplasty*. 2004;19:402–13.
23. • Esposito CI, Walter WL, Roques A, et al. Wear in alumina-on-alumina ceramic total hip replacements. *J Bone Joint Surg Br*. 2012;94:901–7. *Largest CoC retrieval study examining wear with respect to the 2 main types of edge loading, both implicated in squeaking.*
24. Chevillotte C, Trousdale RT, Chen Q, et al. The 2009 Frank Stinchfield Award “hip squeaking”: a biomechanical study of ceramic-on-ceramic bearing surfaces. *Clin Orthop Relat Res*. 2010;468:345–50.
25. Currier JH, Anderson DE, Van Citters DW. A proposed mechanism for squeaking of ceramic-on-ceramic hips. *Wear*. 2010;269:782–9.
26. Sariali E, Stewart T, Jin ZM, Fisher J. In vitro investigation of friction under edge-loading conditions for ceramic-on-ceramic total hip prosthesis. *J Orthop Res*. 2010;28:979–85.
27. Swanson TV, Peterson DJ, Seethala R, et al. Influence of prosthetic design on squeaking after ceramic-on-ceramic total hip arthroplasty. *J Arthroplasty*. 2010;25:36–42.
28. Langdown AJ, Pickard RJ, Hobbs CM, et al. Incomplete seating of the liner with the Trident-acetabular system: a cause for concern? *J Bone Joint Surg Br*. 2007;89:291–5.
29. Jarrett CA, Ranawat AS, Bruzzone M, et al. The squeaking hip: a phenomenon of ceramic-on-ceramic total hip arthroplasty. *J Bone Joint Surg Am*. 2009;91:1344–9.
30. • 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*. 2011;93:439–42. *One of the largest studies to examine patient and implant position factors in determining a predisposition to squeaking.*
31. Biedermann R, Tonnin A, Krismer M, et al. Reducing the risk of dislocation after total hip arthroplasty: the effect of orientation of the acetabular component. *J Bone Joint Surg Br*. 2005;87:762–9.
32. Burroughs BR, Muratoglu OK, Bragdon, et al. In vitro comparison of frictional torque and torsional resistance of aged conventional gamma-in-nitrogen sterilized polyethylene articulating against head sizes larger than 32 mm. *Acta Orthop*. 2006;77:710–8.
33. Bolland BJRF, Culliford DJ, Langton DJ, Millington JPS, Arden NK, Latham JM. High failure rates with a large diameter hybrid metal-on-metal total hip replacement: clinical radiological and retrieval analysis. *J Bone Joint Surg Br*. 2011;93:608–15.
34. •• McDonnell SM, Boyce G, Bare J, et al. The incidence of noise generation arising from the large-diameter Delta Motion ceramic total hip bearing. *Bone Joint J*. 2013;95:160–5. *Squeaking in fourth generation CoC bearings was more likely where patients had a greater range of motion, ligamentous laxity, and reduced inclination and anteversion.*
35. Choi IY, Kim YS, Hwang KT, Kim YH. Incidence and factors associated with squeaking in alumina-on-alumina THA. *Clin Orthop Relat Res*. 2010;468:3234–9.
36. Walter WL, Waters TS, Gillies M, et al. The squeaking ceramic hip retrieval, radiographic, acoustic, and finite element analyses. *J Bone Joint Surg Br*. 2010;92(Suppl):168.
37. Esposito C, Walter WL, Campbell P, Roques A. Squeaking in metal-on-metal hip resurfacing arthroplasties. *Clin Orthop Relat Res*. 2010;468:2333–9.
38. Grammatopoulos G, Pandit H, Glyn-Jones S, et al. Optical acetabular orientation for hip resurfacing. *J Bone Joint Surg Br*. 2010;92:1072–8.
39. Brockett CL, Harper P, Williams S, et al. The influence of clearance on friction, lubrication and squeaking in large diameter metal-on-metal hip replacements. *J Mater Sci:Mater Med*. 2008;19:1575–9.
40. No authors listed. Australian Orthopaedic Association National Joint Replacement Registry, Hip and Knee Arthroplasty Annual Report, 2008. Available at: www.aoa.org.au/jointregistry-pub.asp. Accessed February, 2009.
41. Jeffers JR, Roques A, Taylor A, Tuke MA. The problem with large diameter metal-on-metal acetabular cup inclination. *Bull NYU Hosp Jt Dis*. 2009;67:189–92.
42. Leslie I, Williams S, Brown C, et al. Effect of bearing size on the long-term wear, wear debris, and ion levels of large diameter metal-

- on-metal hip replacements: an in vitro study. *J Biomed Mater Res B Appl Biomater*. 2008;87:163–72.
43. Glaser D, Komistek RD, Cates HE, Mahfouz MR. Clicking and squeaking: in vivo correlation of sound and separation for different bearing surfaces. *J Bone Joint Surg Am*. 2008;90 Suppl 4:112–20.
 44. • Jack CM, Molloy DO, Walter WL, et al. The use of ceramic-on-ceramic bearings in isolated revision of the acetabular component. *Bone Joint J*. 2013;95-B:333–8. *Results of leaving well fixed femoral stems alone in revision hip surgery, and using ceramic heads with titanium trunnion sleeves coupled with ceramic or polyethylene liners. This method can be used in the rare instance of revising a squeaking hip.*
 45. Koo KH, Ha YC, Jung WH, et al. Isolated fracture of the ceramic head after third generation alumina-on-alumina total hip arthroplasty. *J Bone Joint Surg Am*. 2008;90:329–36.
 46. • Walter WL, Kurtz SM, Esposito C, et al. Retrieval analysis of squeaking alumina ceramic-on-ceramic bearings. *J Bone Joint Surg Br*. 2011;93:1597–601. *Multicenter retrieval analysis of squeaking alumina CoC components, revealing increased wear and edge loading as a common factor.*
 47. Lusty PJ, Watson A, Tuke MA, et al. Orientation and wear of the acetabular component in third generation alumina-on-alumina ceramic bearings: an analysis of 33 retrievals. *J Bone Joint Surg Br*. 2007;89:1158–64.