World Journal of Orthopedics

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DOI: 10.5312/wjo.v6.i10.812

World J Orthop 2015 November 18; 6(10): 812-820
ISSN 2218-5836 (online)

MINIREVIEWS

Review on squeaking hips

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Author contributions: Levy YD contributed to literature review and manuscript preparation; Munir S manuscript preparation and editing; Donohoo S contributed to critical review and scientific input; Walter WL contributed to scientific input, critical review and editing.

Conflict-of-interest statement: No potential conflicts of interest relevant to this article were reported.

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Received: May 28, 2015
Peer-review started: July 1, 2015
First decision: August 6, 2015
Revised: August 21, 2015
Accepted: September 25, 2015
Article in press: September 28, 2015
Published online: November 18, 2015

Abstract

Squeaking is a well-recognized complication for hard-on-hard bearings. The nature of squeaking is not yet completely understood however it is considered a multifactorial phenomenon. Patient, implant, and surgical factors play a role in squeaking. It is believed that mechanisms damaging the fluid film lubrication in which these bearings function optimally have a critical role. Such mechanisms include edge loading, stripe wear, impingement, third body particles and ceramic fracture. The resonance of metallic parts can produce noise in the human audible range hence the implant metallurgic composition and design may play a role. Implant positioning can facilitate impingement and edge loading enhancing the occurrence of squeaking. The recent introduction of large heads (> 36 mm) 4th generation ceramic-on-ceramic bearing may accentuate the conditions facilitating noise formation; however the current literature is insufficient. Clinically, squeaking may manifest in extreme hip positions or during normal gait cycle however it is rarely associated with pain. Evaluations of patients with squeaking include clinical and radiographic assessments. Computer tomography is recommended as it can better reveal ceramic breakage and implant malposition. The treatments for most squeaking patients include reassurance and activity modification. However for some, noise can be a problem, requiring further surgical intervention. In the occurrence of ceramic fracture, implant failure, extreme components malposition, instability and impingement, surgery should be advised. This review will aim to discuss the current literature regarding squeaking.

Key words: Squeaking; Total hip arthroplasty; Ceramic-on-ceramic; Lubrication; Edge loading; Metal-on-metal

Core tip: Ceramic-on-ceramic bearings can reduce osteolysis and wear, however they can make noise. Squeaking is multifactorial phenomenon and is associated with patient, implant and surgical factors. Ceramic-on-ceramic bearings function best under well lubricated conditions and hindrance to these conditions such as edge loading and stripe wear may produce vibrations, which resonate through the implants metal component producing an audible noise. Mostly, squeaking is a benign phenomenon however it has a psychological effect on patients. Clinical and radiographic evaluations may reveal pathology that requires further surgery however for most, activity modification and reassurance is the treatment.

Levy YD, Munir S, Donohoo S, Walter WL. Review on squeaking hips. *World J Orthop* 2015; 6(10): 812-820 Available from: URL: http://www.wjgnet.com/2218-5836/full/v6/i10/812.htm DOI: http://dx.doi.org/10.5312/wjo.v6.i10.812

INTRODUCTION

Total hip arthroplasty (THA) is one of the most successful orthopedic procedures available today. It is estimated that more than 300000 procedures are performed annually in the United States[1] and it is projected that by year 2030 the need for primary and revision THA will increase by 174% and 137%, respectively[2]. The worldwide increase in THA demand together with the improvement in instrumentation, surgical techniques and biomaterials has allowed THA become a common surgical option. Data acquired from the Australian National Joint Registry estimated that 13% of the patients undergoing THA are younger than 55 years[3]. The revision rate in this age group was 11.3% at 12 years, which was the highest rate amongst all age groups. According to this registry, loosening and osteolysis are the leading causes for revision THA[3]. In order to improve implant wear, osteolysis and implant longevity the development of alternative bearings to conventional metal on polyethylene (MoP) were encouraged. These include the improvement in polyethylene processing and development of hard-on hard bearings such as metal-on-metal (MoM) and ceramic-on-ceramic (CoC). The clinical utilization of these hard-on hard bearings has led to the formations of new complications such as metallosis, ceramic fracture and squeaking. However, CoC articulations have excellent tribological properties, biocompatibility, and promise of increased longevity[4]. The progressive improvement in the manufacturing and fabrication processes of ceramics has dramatically decreased the wear and the fracture rate however squeaking is still an ongoing concern[5].

Squeaking is an audible phenomenon almost exclusive to hard-on-hard bearings. Other audible sounds such as clicking, snapping, cracking and grinding are also described in the literature and sometime miss interpreted as squeaking[6-10]. The squeaking rate in MoM and CoC articulation has been reported between 2.9% to 16%[11-14] and 0.3% to 24.6%[9,15], respectively. There are less reports of MoM squeaking relative to CoC. The large variation in squeaking reported in the literature is influenced by the investigators query. Meta-analysis estimated that the rate of self-reported squeaking was 1.2% while studies evaluating squeaking with specific questionnaire the rate was 4.2%[16]. The presence of other noises such as pops, clicks, grinding was reported at 7.5%[16]. Squeaking can significantly affect patients' quality of life, and may lead to revision surgery[17-19]. Owen *et al*[16] calculated from 43 studies that the overall revision rate due to squeaking was 0.2% in CoC bearings. According to the United Kingdom National Joint Registry there is a decline in the use of CoC bearings in THA. It is possible that squeaking may have led to this trend[20]. The squeaking phenomenon is not completely understood and thought to be multifactorial. The association between squeaking and patients' characteristics, surgical factors, implant positioning and implant types have been studied. However, there is not always uniformity in the results among different studies. The purpose of this review is to provide a summary of the current literature with respect to the squeaking phenomenon.

Mechanism of squeaking

Squeaking defined as a high pitched, audible sound that occurs during movement of the hip joint. It is produced by a forced vibration generated by a driving force resulting in a dynamic response[18]. The driving force is a result of high friction generated in hard-on-hard bearings from a loss of fluid film lubrication (stick slip)[21-24] which can be facilitated in certain conditions such as; edge loading and stripe wear[24-26], rim impingement[18,27], improper liner sitting[18,28], ceramic fracture and third body debris[29]. The dynamic response is the amplification of this vibration. If the amplified impulse occurs at a frequency of an audible range a squeak can be heard.

Vibrations that initiate squeaking are believed to arise from a stick-slip friction. CoC bearings operate best under well lubricated conditions[30]. Ceramics extreme hardness allows the surface to be highly polished and scratch resistant while their hydrophilic character accounts for the formation of a thin fluid film at the articular interface[4]. Loss of the fluid film lubrication results in direct contact between the articulating surfaces reducing sliding and increasing friction[18,25,31]. During hip movement a rotational force overcomes the static frictional joint force resulting in acceleration and deceleration of one articular surface with respect to the other. This produces vibrations within the implant material. Different materials and implant designs carry inherent ability to resonate these vibrations, which can lead to formation of squeak.

Edge loading and stripe wear

During the manufacturing process of grinding and polishing a ceramic acetabular liner a sharp edge is generated inside the rim[25]. When the hip contact force vector moves, the contact patch is over this hard edge (edge-loading). The delicate balance in the articulation fluid film lubrication is disrupted and there is an increase in the frictional forces between the two moving surfaces which can lead to a squeak.

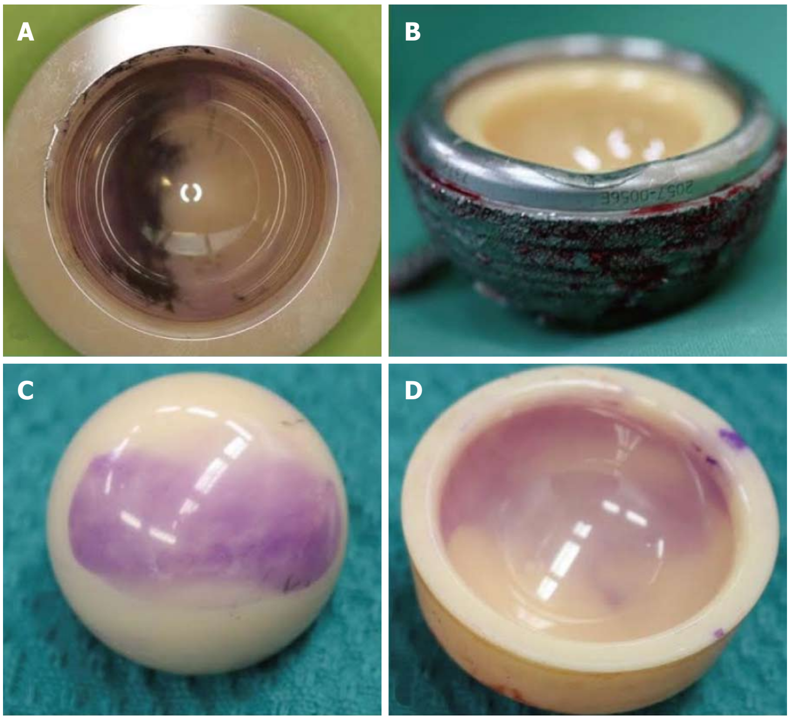

Figure 1 Rim chipping, stripe wear and metallosis. Stripe wear is identified by a purple marking on the ceramic head (A) and liner (B); impingement is identified by a notch created on the acetabular shell (C and D).

Furthermore, both surfaces are damaged secondary to increases in contact stress[32]. This leads to the formation of stripe wear along the femoral head and acetabular cup (Figure 1). Laboratory experiments have demonstrated that edge loading increases friction and leads to squeaking in ceramic bearings[24]. Location of the wear patch may indicate whether the edge loading occurs during deep hip flexion (posterior edge loading) or during walking and hip extension (anterior superior edge lodging)[25]. Another theory describes a micro-separation of the femoral head during swing phase as a possible etiology for stripe wear formation[33]. When this separation occurs, the contact area of the femoral head on the acetabulum liner becomes small leading to the formation of stripe wear. This theory was further demonstrated by 3D modeling and video fluoroscopy[34]. Some patients are clinically pre disposed to micro-separation, such as those with short leg or joint laxity have been shown association to squeaking.

Retrieval analysis of CoC bearings from multiple studies demonstrated the presence of stripe wear[35,36]. A multicenter retrieval study analyzed 12 CoC components from squeaking hips and compared the pattern and wear rate to 33 similar CoC components retrieved from silent hips[35]. All components from the squeaking hips and majority of the components from the silent hips showed edge loading and stripe wear. The retrievals from the squeaking hips had an overall 45 times greater wear rate compared to the retrievals from the control group. The authors suggested that edge loading may represent a normal process in CoC bearing[25,35,37]. Since the majority of the CoC THAs do not squeak, the combination of edge loading and excessive wear rate may produce squeaking[35]. Clinical and retrieval studies report on the appearance of squeaking after more than six months from the index THA surgery[17,19,25,35-37]. A hip stimulator study did not produce squeaking when the bearing surfaces were in their pristine condition but did at the presence of stripe wear[24]. These observations imply a run out phase in clinical setting before the bearing surface is affected by edge loading and possibly representing the time necessary to produce stripe wear.

Rim impingement and third body particles

Rim impingement is suggested as a possible mechanism in producing squeaking either directly or indirectly. Impingement between the femoral component neck and the acetabular component rim can lever the head out of the acetabular socket leading to squeaking secondary to edge loading and stripe wear. Moreover, direct metal impingement may lead to metal-metal squeaking, metallosis, chipping and other third body particles[18,31,35]. The acetabular component design is a suggested contributing factor to squeaking. Some designs have an elevated acetabular rim to protect the ceramic liner from either chipping or fracturing, however impingement can occur at the rim (Figure 1)[31]. A non-elevated acetabular rim design may allow impingement to occur directly between the neck and the ceramic liner leading to metallosis, and chip fractures at the ceramic rim (Figure 1)[31]. With the introduction of the 3rd and 4th generation of ceramics the risk of ceramic chipping is reduced. Toni *et al*[38] showed that aspirates from squeaking CoC THAs have had high levels of ceramic particles suggestive of third-body wear. Abdel *et al*[29] observed squeaking associated with ceramic fractures.

Dynamic response

In the previous section we discussed possible mechanisms producing forced vibrations in CoC bearings. These vibrations represent excessive energy that the system needs to dissipate; this can be done *via* heat generation or motion[18]. The forced vibrations travel along the system components which can act as an amplifier. Vibrations amplified to a level that can be detected by the human ear (between 20 Hz to 20000 Hz), is recorded as a squeak. An *in vivo* acoustic analysis of 31 patients with squeaking CoC hips demonstrated that squeaking replicated a harmonic wavelength series between the frequency range of 400 Hz and 7500 Hz. Therefore the authors concluded that squeaking sounds are produced by resonance[18]. A modal analysis was conducted to better understand how the parts resonate[18]. That study showed that a ceramic liner whether coupled or isolated with a titanium acetabular shell did not show any relevant modes of resonance[18]. A titanium stem attached to ceramic head showed resonance in multiple modes and planes. An isolated titanium acetabular shell will resonate in an elliptical configuration like a bell. Thus, the metal components are the system amplifiers responsible for squeak propagation. Moreover, if the ceramic acetabular liner is perfectly seated in the metal shell it can potentially prevent the metal cup from resonating hence reducing squeaking. Finite element analysis demonstrated stiffness mismatch between the shell and the liner may cause the liner to tilt out of the shell leading to shell oscillation and squeak formation[18]. An *in vitro* acoustic study determined that neither isolated ceramic components nor perfectly assembled acetabular cup and liner resonate within human audible range. However when the metal acetabular shell or titanium stems were evaluated their resonance frequency falls in whole or in part within the human audible range (from 4300 Hz to 9800 Hz and 1500 Hz-20 kHz, respectively). Additionally it was demonstrated that thinner and larger shells produced a lower frequency[18]. The importance of this data is in the core of understanding that the metal components are a fundamental factor in amplifying the vibration to generate an audible sound heard as a squeak. The implant metallic composition and geometry may influence the resonance propagation affecting the rate of squeaking. From a clinical prospective, it is important to verify and properly secure the acetabular liner in the shell, this can potentially reduce the rate of squeaking as well as the chance to develop backside wear[18,31].

Causes of squeaking

Multiple studies have illuminated that various factors play a role in the formation of squeaking[18,39]. Due to the multifactorial nature of squeaking these factors are integrated and probably cannot be separated, however they can be classified in relation to patient characteristics, surgical factors and implant factors.

Patient's factors and squeaking: Several patients factors such as; age, sex, height and weight may contribute to squeaking as determined by the reporting found in the literature. A study conducted by Sexton *et al*[39]. reported a significantly higher rate of squeaking in taller, heavier and younger patients, however obesity was not shown to be associated with squeaking. Contrary to this, a recent meta-analysis showed that the only significant patient factor was the increase in body mass index[40]. Choi *et al*[41] found that gender was a contributing factor were his study reported males to have a higher occurrence of squeaking. Mai *et al*[10] found that patient height was a contributing factor to the squeaking mechanism. They found that taller patients squeak more. In contrast, Keurentjes *et al*[19] and Restrepo *et al*[36] did not find any correlation between squeaking and these mentioned patients factors. Thus, far patients' factors have mixed results with no specific known indicator relating to the occurrence of squeaking.

In addition to patients demographic factors activity types such as walking, bending, and rising from low sitting position was associated with squeaking[17,31]. This suggests that squeaking is either generated during the normal gait cycle or in extreme flexion. Although extreme positions may be associated with squeaking it is not associated with either hip function or pain as no correlation between squeaking and pain could be demonstrated[10,41,42]. It has been observed that patients with hyperlaxity have a higher rate of squeaking[31,43]. This excessive range of motion can lead to impingement, micro-separation and edge loading, hence resulting in squeaking.

Surgical factors and squeaking: Prosthetic component orientation is considered to play a significant role in noise generation. Improper component position may lead to impingement, edge loading and increased wear. It is believed that the positioning of the acetabular cup can be associated with squeaking. A previous study has shown that an acetabular cup placed within a 25 ± 10 degree of anteversion and 45 ± 10 degree of inclination, will significantly reduce the chance of squeaking[42]. This observation was supported by Sariali *et al*[44]. In contrast, others did not find a similar correlation regarding cup positioning[10,19,36,40,41]. Previous findings showed that anterior edge loading is associated with increased cup anteversion and inclination while posterior edge loading associated with insufficient anteversion and inclination[25,42]. In extreme cup positions squeaking can be generated from direct impingement of the femoral component neck and the cup (titanium squeak) or from edge loading of the head and the ceramic liner (ceramic squeak)[42]. A retrieval analysis of squeaking hips can support this mechanism. A squeaking hip demonstrated marks on the rim of the cup representing impingement whilst the bearing demonstrated stripe wear representing edge loading (Figure 1)[35].

Implant factors and squeaking: Implant design and specific implant coupling may to be linked to squeaking. Acetabular component designed with a raised edge can potentially prevent impingement between the acetabular ceramic liner and the femoral component neck, and consequently prevent ceramic fracture. However, it may increase the risk for MoM impingement hence subsequently squeak[40]. Parvizi *et al*[45] noticed squeaking primarily in patients receiving acetabular system designed with elevated titanium rim (Trident, Stryker Orthopaedics, Mahwah, NJ). On the contrary, Stanat *et al*[40] in a meta-analysis, could not demonstrate a significant relationship between squeaking and elevated cup rim.

Previously, femoral stem design and metallurgy were evaluated as a cause of squeaking. Several studies reported a high rate of squeaking utilizing a thin profile stem and thin neck[10,17,19]. Restrepo *et al*[46] reported that the squeaking rate in patients receiving Omnifit stem (Stryker Orthopeadics) was seven times less than in patients who received an accolade stem (Stryker Orthopeadics). The Omnifit stem made of Titanium - Aluminum - Vanadium alloy with hydroxyapatite coating and has a c-taper neck geometry. The Accolade stem is made of Titanium - Molybdenum - Zirconium - Iron alloy with hydroxyapatite coating and has a V-40-taper neck geometry. The different design factors which can potentially be related to the higher incidence of squeaking produced by the Accolade stem are the stem geometry, taper dimension, and the material composition. The accolade stem alloy composite and geometry creates a more flexible stem with a thinner front to back diameter which has a clinical potential to reduce thigh pain[46], however due to its flexibility it may resonate more hence producing a squeak[18,46]. The V-40 neck has a smaller diameter and should lead to less impingement. However the smaller diameter leads to a lower bending stiffness and lower resonant frequency and is more capable of amplifying vibrations generated by the CoC articulation producing audible squeak[46]. Fan *et al*[47] conducted an *in vitro* study evaluating squeak production in 3 different types of stems in compromised lubrication conditions. Their study showed that stiffer (cobalt chrome *vs* titanium) and smaller stems demonstrated higher critical friction factors which correlates clinically with squeaking. The frequencies captured *in vitro* by Fan *et al*[47] are in agreement with the frequencies measured previously *in vivo* (between 0.4 and 0.75 kHz)[18].

Squeaking in large diameter CoC*:* Large diameter femoral heads (> 36 mm) have the potential to reduce instability following THA[48]. They provide greater range of motion[49], decrease the component impingement and increase the jump distance that the head must travel before dislocation occurs[50]. Delta Motion (DePuy, Warsaw, Indiana) is a preassembled, monoblock, large diameter, fourth generation CoC (Biolox - Ceramtec) Acetabular cup. The acetabular cup consists of a titanium alloy with thin ceramic liner which can accommodate a large (> 36 mm) ceramic head, optimizing the head-neck ratio.

Recently, Tai *et al*[5] reported on the short term results of large diameter CoC in patients acquiring Delta Motion bearings with a proximally coated titanium stem (Secure Fit, Stryker orthopeadics, Mahwah, New Jersy). In their series, 7.3% (15 of 206 hips) of the hips were recorded as squeaking. The mean postoperative time to onset of squeaking was 1.4 years (range 0.4-3 years). Squeaking was documented only at deep flexion. Although the median femoral component size was larger in the squeaking hips compared to non-squeaking hips (44 mm *vs* 40 mm, respectively), no statistically significant difference in the incidence of squeaking in various head size could be demonstrated. Radiographic analysis did not show statistical significance with respect to acetabular cup inclination, anteversion and correlation to Lewinnek's acetabular safe zone position. Patient demographic characteristics such as height, weight, BMI or range of motion were also not significant between patients with or without squeaking. McDonnell *et al*[43] reported on 208 THA acquiring Delta Motion cups and heads with four different cementless stem designs. They found 31% of the hips producing noise with a squeaking rate of 20.7%. Squeaking almost exclusively occurs during deep hip flexion. Similarly to Tai *et al*[5] they found no relation between squeaking to patient height and weight. However, they found amongst the squeaking hips a statistically significant lower inclination and anteversion angles, increased ligament laxity, and higher rate of squeaking with smaller heads. A possible explanation of the difference in the squeaking rate in-between these studies may be related to the stem design. The predominant stem (151 of 208) used in the series by McDonnell *et al*[43] was Tri-Lock (DePuy) which is a short and narrow stem composed of Titanium - Aluminum- Vanadium. In spite of the high squeaking rate reported the short term clinical results of the Deltamotion/TriLock combination show a low revision rate in the Australian registry data 0.3% at 3 years. Bishop *et al*[30] measured the friction moments of large ceramic (DeltaMotion) and metal bearings in hip simulator with variable cup angles and in both wet/dry conditions. They showed that friction moments were smaller for CoC bearings in lubricated conditions (optimal conditions) but increased over fivefold for 48 mm diameter ceramic bearings in dry conditions (extreme conditions). The combination of a 48 mm ceramic head and an increase in cup inclination angle was associated with increased friction. They concluded that extreme conditions dramatically increase the friction moments in large diameter ceramic bearings, which can amplify the clinical problem of squeaking[30]. Another theory suggested that larger heads have a greater mass which may decrease the frequency of the resonating waves, bringing them into the audible range for humans[5]. Yet other study suggested that since the Delta Motion cup is relatively thin (5 mm) with only 2 mm titanium shell it is more flexible and can better resonate or amplify vibrations which can produce an audible squeak[51]. In conclusion, a large CoC articulation is a relatively new design, with limited reports in the literature with respect to squeaking. It appears that the rate of squeaking is relatively high however most of the reported series have a benign type of squeaking[5,43]. The biomechanical mechanism which results in larger heads having a higher incidence of squeaking is primarily due to the increase in the total work done at the articular interface, the lowering of the natural frequency of the oscillations, and the increase in the amplitude of oscillations. The work at the bearing surface correlates to the applied normal force, frictional force, and moment arm. Therefore for a given frictional co-efficient and angular rotation the work at the bearing will increase. Therefore, in order to try and reduce the rate of squeaking we can recommend on optimal implant position and implant selection. Currently while implanting DeltaMotion ceramic bearings we use a thick long titanium stem with relatively wide neck (*e.g.*, Secure - Fit, Stryker) which potentially can reduce the vibration propagation and squeaking. Mid and long term outcome studies will be necessary to further understand the possible causes for squeaking in of patients utilizing large CoC bearings.

Clinical assessment and management of patients with squeaking: Patients undergoing hip replacement should be aware of the advantages and the disadvantages of the different bearings for THA. Therefore, the management of patients with squeaking starts with informed consent. We tend to recommend CoC bearings for young active patients as such bearings have shown to have superior wear rate both in laboratory[52-54] and clinical studies[6,55,56]. As squeaking is one of a possible complication utilizing such bearings, patients should understand and agree to the use of ceramic bearings. Owen *et al*[9] reported a squeaking rate of 24.6% in 69 patients undergoing THA with CoC bearing. Only 7.5% of the patients recalled being warned preoperatively of squeak as a possible complication. More than 50% of the squeaking patients were concerned, anxious and embarrassed with their squeak. Therefore, their study further highlights the importance of warning patients from squeaking as a possible surgical complication. This can ultimately better address patient psychological concerns, match patient's postoperative expectation and can prevent litigation against surgeons.

The assessment of patients presenting with a squeaking hip should include clinical and radiographic evaluation. Clinical evaluation should assess whether the squeak is benign or problematic and if it is constant or transitory. Benign squeaking is most likely a result of posterior edge loading and occurs with activities involve deep hip flexion such as squatting or rising from a low chair[25]. This type of squeaking usually related to certain activity or hip movement and can be avoided with activity modification. Problematic squeaking occurs during normal gait cycle and is relatively rare. It is produced with each step, may be associated with pain, jeopardize hip function and generally created a significant concern to the patient. It is believed that this type of squeak involves anterior edge loading usually as a consequence of components malposition[25]. This type of squeaking is reproducible and usually intolerable by the patients requiring further treatment and surgery. Others types of squeaking such as transitory or single occurrence can be found however their significance is not well understood.

Evaluation of patients with squeaking involves a thorough history and examination. Evaluation should include assessment of patients demographics such as height, weight, age, sex[18,31,39,41] and ligament laxity[43] which may be associated with squeaking. Range of motion assessment may differentiate between benign and problematic squeak and may give further input to the nature of the squeak. For example, squeaking may be associated with component impingement[31] or ceramic component fracture which may be painful and can limit range of motion[29]. After clinical assessment plain radiograph should be performed to evaluate component alignment, implant failure and bone or ceramic fracture. The presence of ceramic fracture should be further assessed with CT it does not always seen in plain x-ray. Moreover, CT scan further assesses component anteversion and inclination. If no abnormal radiographic pathology is observed, the squeaking is activity related, and the patient is pain free reassurance is appropriate and the patient should consult to modify his activities. If the squeaking is problematic then a revision surgery may be performed, however prior to surgery all the possible reasons producing the squeak should be attempted to be understood.

Squeaking and the association with implant failure are not clearly understood. Traina *et al*[57] reported that an audible noise had an association with ceramic fracture. Eighty point seven percent (21 hips) which produced a noise resulted in a fracture compared to the non-audible group which had only 6.1% (3 hips) ceramic fractures. A recent case report has also reported on a ceramic femoral head fracture following squeaking[58]. Due to the multifaceted nature of squeaking it is not clearly understood if squeaking itself is a sole reason to implement ceramic fractures.

While the incidence of revision due to squeaking in CoC bearings has been reported between 0 to 4.7%[16] a recent a meta-analysis estimated the revision rate to be 0.2%[9]. During revision surgery component can be revised to CoC or CoP, while optimization of implant position, soft tissue balance or correcting issues such as bone impingement. Jack *et al*[59] reported on the clinical outcome of 165 revision total hip replacement. During revision surgery a polyethylene liner was replaced with ceramic liner while the femoral head revised to ceramic head with titanium sleeve. At 8.3 years of follow up the implant survival rate was 96.6% and none of the patient was diagnosed with squeaking.

Squeaking in metal on metal bearing: Being a hard-on-hard bearing MoM articulation, it carries the inherent is ability to produce noise and squeak. Squeaking in MoM bearing has been reported with incidences ranging from 1.5% to 16%[11-13,60]. Limited reports have been found in the literature therefore it is difficult to conclude which risk factors are associated with squeaking in MoM bearings. Bernasek *et al*[60] reported 1.5% squeaking rate in 539 patients undergoing MoM THA. The average time from surgery to onset of squeaking was 23 mo (range 6-84 mo). The authors also observed increased frequency of squeaking among females and in patients having a cup inclination greater than 45 degree. Imbuldeniya *et al*[14] reported squeaking rate of 2.89% in 380 patients undergoing MoM hip resurfacing. Cases were matched for age, gender, BMI and implant to three controls. The mean time for squeaking to appear was 11.3 mo (range 3-22 mo). No correlation was demonstrated to patient demographic characteristics, radiographic cup position and serum chromium or cobalt levels. They found males with head size smaller than 50 mm was associated with squeaking. The theoretical concept of not having a complete thin fluid formation at the bearing interface due to the smaller diameter head which has a less favorable environment to generate a fluid film[61]. The lack of lubrication correlates with a higher frictional coefficient at the surface which can lead to increase wear which can potentially result in squeaking[61]. In the study by Imbuldeniya *et al*[14] 3 of the 11 patients with squeaking had undergone revision surgery. Interestingly, among the patients who did not undergone revision the squeaking spontaneously resolved at a mean of 19.3 mo (range 4-78 mo). This might be explained by a self polishing mechanism which is generally associated as the "running in" period for this bearing[14]. Thus, the authors suggested that squeaking in MoM resurfacing should not be the sole indication for revision surgery and closer patients follow up is advocated[14].

Other noises: While squeaking is concerning as it may be associate with wear and fracture, other noises are more commonly produced following THA[8,10,62]. Schroder *et al*[8] reported an overall noise rate of 11% in patients undergoing CoC THA. The most common type of noise was clicking or snapping. Squeaking was reported only in 1.9% of the patients. A similar trend was observed following CoC THA by Mai *et al*[10] and Jarrett *et al*[17]. Despite that THA related noise is predominantly reported in hard-on-hard bearings, some describe noise generation in hard-on-soft bearings[62]. Wyatt *et al*[62] found that 37.7% of the patients undergoing THA with CoC bearing report noise, while only 12.7% of the patients undergoing THA with Ceramic-on-Polyethylene will experience noise. Jarrett *et al*[17] compared a matched cohort of patients who had CoC THAs to patient receiving MoP THAs showed noise incidence of 21% and 4% respectively. None of the patients with CoP squeak. It was suggested that the higher incidences of noise, and more specifically click, pop or snap observed in CoC bearing are due to hard on hard bearing loading[17]. Glaser *et al*[63] conducted an *in-vivo* acoustic analysis in combination with fluoroscopic analysis in patients with various THA bearing types. They found distinctive sounds such as popping, snapping, knocking, crunching, granting, cracking and squeaking. The sounds generated were assessed in correlation with the gait cycle and with the bearing surface. They suggested that during the gait cycle there is a separation of the femoral head from the acetabular liner, whilst at heel strike the femoral head returns into position knocking against the acetabular component, which can produce a knocking or popping sound[63]. Other observed sounds are possibly related to soft tissue impingement such as iliotibial band snap, however the etiologies and the consequences of these sounds are poorly understood.

CONCLUSION

Squeaking is a multifactorial, unique phenomenon to hard on hard bearings. Although there is no uniformity in the literature with respect to the etiology of squeaking we believe that there are several factors contributing to its formation. These include patient, surgical and implant factors. Careful patient assessment; particularly the height, weight and hyperlaxity, are important. Meticulous surgical technique which places the components in the right tension and location can potentially reduce the loss of lubrication and pathological edge loading as well as component impingement. Stem design and alloy composite have shown to associate with increased resonance and squeaking. Stem selection is of particular importance when a large ceramic head (> 36 mm) is used as these shown to have relatively high rate of squeaking. While assessing patients with squeaking a differentiation should be made between benign and problematic squeaking. A transitory squeak or squeak that can be reproduced in extreme hip flexion without any radiographic signs of pathology can be managed with patient education and reassurance. Problematic squeaking which occurs during normal gait cycle usually requires further surgical intervention. An important part of patient evaluation is the understanding of the psychological effects of the noise on the life of the patient as this may change the treatment plan significantly. In the recent years due to the clinical failure of the large head MoM bearings in THA, the high reported rate of squeaking in CoC bearings, concerns regarding ceramic fracture and the introduction of highly crossed linked polyethylene, there is a shift from the use of hard-on- hard articulations toward hard on soft bearings. Yet the future is unknown and long term studies will clarify the longevity of such bearings and their ability to reduce the rate of osteolysis and wear in a similar fashion to CoC bearings.

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P- Reviewer: Jeffers JRT, Mica L, Papachristou GC
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