An estimation of the incidence of squeaking and revision surgery for squeaking in ceramic-on-ceramic total hip replacement

A META-ANALYSIS AND REPORT FROM THE AUSTRALIAN ORTHOPAEDIC ASSOCIATION NATIONAL JOINT REGISTRY

Squeaking arising from a ceramic-on-ceramic (CoC) total hip replacement (THR) may cause patient concern and in some cases causes patients to seek revision surgery. We performed a meta-analysis to determine the incidence of squeaking and the incidence of revision surgery for squeaking. A total of 43 studies including 16 828 CoC THR that reported squeaking, or revision for squeaking, were entered into the analysis. The incidence of squeaking was 4.2% and the incidence of revision for squeaking was 0.2%. The incidence of squeaking in patients receiving the Accolade femoral stem was 8.3%, and the incidence of revision for squeaking in these patients was 1.3%.

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In ceramic-on-ceramic (CoC) total hip replacements (THR) squeak is an unusual phenomenon that has attracted the interest of the orthopaedic community, as it represents an unanticipated complication of THR that has multiple contributing factors.

Wear-related failure is the most common reason for revision in many published series and joint arthroplasty registries, and is significant for young patients who have long life expectancies and place high physical demands on their THRs.

Currently available bearing materials include moderate to highly cross-linked polyethylene with metal, metal-on-ceramic, metal-on-metal or CoC. A number of laboratory and clinical studies have demonstrated superior wear rates for CoC couplings, although there is a need for long-term clinical studies to confirm these observations. Limitations of such bearings include the risk of fracture of the head and liner, and squeaking. Squeaking in CoC bearings was first reported by Charnley in 1979 and has been sporadically reported in cases of mismatched ceramic bearing surfaces and bearing failure. However, it was not until the late 2000s that squeaking from THR attracted widespread attention from the media and the orthopaedic community. This gave rise to a number of clinical and laboratory studies aimed at investigating the incidence and mechanisms of noise generation in THR. It has been reported that a squeaking THR may affect the patient's quality of life, and in few cases cause them to undergo revision surgery.

We have explored published series by meta-analysis to determine the incidence of squeaking and the frequency of revision surgery for squeaking. In addition, data from the Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR) are presented and the proposed mechanisms of squeaking in CoC THR are reviewed.

Materials and Methods

We used the guidelines for the construction of a meta-analysis. On 5 January 2013 we searched the PubMed database with combinations of the terms ‘hip and squeak’, ‘hip and squeaking’, ‘hip and ceramic’, ‘hip and noise’, ‘squeak and arthroplasty’, ‘squeaking and arthroplasty’, ‘arthroplasty and ceramic’, and finally ‘noise and arthroplasty’. The search was confined to the English language and human studies. Citation and internet searches were performed to include all published series. In all, 1403 articles were identified for assessment by title and abstract for further evaluation by two of the authors (DHO, NCR). During this process duplicates, case reports and review articles were removed. Posters and conference presentations were not considered.

A total of 116 articles were subsequently identified which were searched in their entirety for documentation of noise, squeaking or sound originating from a CoC THR. Studies were...
eligible for analysis if either or both the incidence of squeaking and the incidence of revision for squeaking could be determined. Studies were excluded if both of these numbers were missing or could not be calculated. Where there were multiple publications using the same dataset, only the most recent publication was considered.

In all, 43 studies met the inclusion criteria with a total of 17 409 THRs of which 16 828 were CoC (Table I). These studies were then assessed to identify the incidence of squeaking and of revision for squeaking and any patient awaiting revision, which was taken to represent the upper incidence of revision for squeaking. The incidence of squeaking and noise as defined by each study at the most recent follow-up left a total of 16 828 CoC hips. Squeaking was not reported by Porat et al,\textsuperscript{79} thus this study was excluded from the calculation estimating the incidence of squeak; similarly revision for squeak was not reported by Nikolaou et al,\textsuperscript{54} thus this study was excluded in the revision for squeak calculation.

Whether the squeak was self-reported or identified following specific questioning was also recorded. The AOANJRR was consulted with regard to the incidence of revision surgery for squeaking.

**Table I. Studies included in the analysis of squeaking ceramic-on-ceramic (CoC) total hip replacement (THR)**

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Total THR</th>
<th>CoC THR followed up</th>
<th>Mean follow-up (months)</th>
<th>Method</th>
<th>Squeaking (%)</th>
<th>Revision for squeak (%)</th>
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<td>Restrepo</td>
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<td>1056</td>
<td>1056</td>
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<td>Keurentjes</td>
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<td>Jarrett</td>
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<td>102</td>
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<td>Petasatodis</td>
<td>2010</td>
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<td>Amanatullah</td>
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<td>125</td>
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<td>Cogan</td>
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<td>284</td>
<td>265</td>
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<td>2011</td>
<td>115</td>
<td>78</td>
<td>60 (Minimum Follow-up)</td>
<td>Self-reported</td>
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<td>Byun</td>
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<td>56</td>
<td>55</td>
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<td>Finkbone</td>
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<td>175.2</td>
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<td>Yeung</td>
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<td>244</td>
<td>130.8</td>
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</tbody>
</table>

Total 17 409 16 828

*Not recorded; HHS, Harris hip score; UCLA, University of California, Los Angeles; BMI, Body Mass Index; SF-36, Short Form 36.*

eligible for analysis if either or both the incidence of squeaking and the incidence of revision for squeaking could be determined. Studies were excluded if both of these numbers were missing or could not be calculated. Where there were multiple publications using the same dataset, only the most recent publication was considered.

In all, 43 studies met the inclusion criteria with a total of 17 409 THRs of which 16 828 were CoC (Table I). These studies were then assessed to identify the incidence of squeaking and of revision for squeaking and any patient awaiting revision, which was taken to represent the upper incidence of revision for squeaking. The incidence of squeaking and noise as defined by each study at the most recent follow-up left a total of 16 828 CoC hips. Squeaking was not reported by Porat et al,\textsuperscript{79} thus this study was excluded from the calculation estimating the incidence of squeak; similarly revision for squeak was not reported by Nikolaou et al,\textsuperscript{54} thus this study was excluded in the revision for squeak calculation. Whether the squeak was self-reported or identified following specific questioning was also recorded. The AOANJRR was consulted with regard to the incidence of revision surgery for squeaking.

**Statistical analysis.** Incidence rates were modelled using a $\beta$-binomial distribution to account for an over-dispersed binomial distribution. These estimates were calculated with R statistical analysis software version 3.0.0 (The
Results

Reported incidence of THR squeaking. Of the 15,131 CoC hips included in studies that reported squeak, 545 squeaked, giving an incidence of 4.2% (95% confidence interval (CI) 2.7 to 6.4). A funnel plot of the incidence of squeaking in THR against the number of hips studied is shown in Figure 1. This demonstrates a significantly lower incidence of squeaking of 1.2% (95% CI 3.5 to 5.8) (p = 0.002). No difference in incidence of squeaking in THR was found between large series (>500 hips) (3.4%) (95% CI 2.4 to 4.8) and smaller series (3.9%) (95% CI 2.5 to 6.2) (p = 0.59). There is a lower incidence of THR squeaking in studies with a follow-up of > 100 months (2.4%) (95% CI 1.3 to 4.6) than in studies with <100 months’ follow-up, with an incidence of 4.6% (95% CI 3.5 to 6.1), but this difference was not statistically significant (p = 0.82). Figure 2 demonstrates the relationship between squeak and duration of follow-up in self-reported studies and in patients questioned about THR squeaking.

We found a significantly higher incidence of squeaking of 8.3% in CoC THRs with the non-cemented Stryker Accolade femoral (Stryker Orthopaedics, Mahwah, New Jersey) component (95% CI 5.9 to 11.3, n = 242/2924) than with other femoral components (cemented and non-cemented) (1.9%) (95% CI 1.3 to 2.8, n = 193/9973) (p < 0.001). These numbers were derived from studies or groups of hips within the included studies, where the incidence of squeak could be calculated. The incidence of squeak for other designs of femoral component is not given due to the small amount of available data.

The presence of other noises, not defined as squeak (which included pops, clicks, grating and grinding), was reported in 25 studies. The incidence of these noises was 7.5% (95% CI 4.4 to 12.4, n = 309/4073).

Reported incidence of revision THR for squeaking. The incidence of revision for THR squeaking has been reported to range between 0% and 4.7%.

Using the data obtained from the studies included in our analysis that reported on revision surgery for squeak (Nikolaou et al excluded), we estimated the incidence of revision for squeak to be 0.2% (95% CI 0.08 to 0.57, n = 41/16,794). The AOANJRR reports a revision rate for squeaking of 0.03% for all CoC THRs (n = 55,417).

The AOANJRR includes 2955 CoC THR with the Accolade stem of which five were revised for squeaking (0.17%). The overall rate of revision for this stem is equivalent to that for other types of non-cemented CoC THR. To be recorded as revision for squeak, squeak must be specifically recorded in the ‘other diagnosis’ section of the revision hip reporting form. According to our analysis the revision rate for the Accolade stem is 1.3% (95% CI 0.6 to 2.6 n = 7/556), which was significantly higher (p < 0.001) than other femoral components (0.02%) (95% CI 0.0050 to 0.079, n = 2/9939).

Although revision THR for squeaking is a rare occurrence, a number of studies report patients with a high-grade frequent squeak considering or waiting for revision. If this is taken as an upper boundary of revision for squeaking, the incidence becomes 0.30% (95% CI 0.16 to 0.72, n = 47/12,530).

Discussion

Definition and assessment of squeaking. Squeaking in THR is defined as an audible sound that emanates from the hip with
movement.\(^{39}\) It has been further defined by some authors to include grinding, clicking or grating that is reproducible,\(^\text{30}\) or which can be heard by other people.\(^{31,39}\) In a study recording noise from a number of different THR bearing types, a variety of sounds including pops, snaps and thuds, knocking, crunching, grating, cracking and squeaking were reported, with the notable distinction that the CoC bearing couples produced sound throughout the gait cycle.\(^{35}\)

Some authors have attempted to grade the squeak based on loudness, perceptibility to others and frequency of occurrence.\(^{35,39,56}\) Others have classified squeaking as ‘problematic’ or ‘concerning’ in terms of social impairment, and investigated when patients would want revision surgery for squeaking.\(^{31}\) Unfortunately, there is no universally accepted classification system. Similarly, there is no validated assessment standard by which to determine the presence of squeaking in THR, which may have influenced the reported incidence.\(^{1,38,57}\) It is possible to speculate that squeaking in THR is under-reported in studies that rely on patients to volunteer this information whereas it appears that a specific THR is under-reported in studies that rely on patients to volunteer this information whereas it appears that a specific THR is under-reported.\(^{1}\)

**Reported incidence of squeak.** This study estimates an incidence of CoC THR squeaking of 4.2%, which is higher than the 2.4% reported in a recent meta-analysis.\(^{56}\) The recent meta-analysis by Stanat and Capozzi\(^{56}\) used 12 studies, including two series that were re-reported in later publications.\(^{1,38}\) The incidence of squeaking in CoC THR has been variably reported, ranging from 0% to 37.5% in a subset of Korean patients,\(^{58}\) and as high as 35.6% in patients receiving Acoclate femoral components.\(^{39}\) Squeaking in THR has been observed to be variable, with a small proportion of patients in some studies describing a change in frequency and even cessation of the squeak over time.\(^{24,31}\) Others, however, have not reported any change,\(^{36}\) and some have reported an increase in squeaking with extended follow-up.\(^{31}\) Squeaking is recognized to take some time to manifest itself, with no reports of squeaking immediately post-operatively and some reports demonstrating late-onset squeaking.\(^{39,59}\)

**Incidence of revision for squeaking.** Our estimate of revision for CoC THR squeak is 0.2%. Although few studies report revision surgery for squeaking, a high rate of revision of 4.65% was reported in a series of 43 hips.\(^{30}\) Elsewhere, six squeaking THRs in a series of 304 were revised (1.97%).\(^{57}\) Based on studies reporting on patients contemplating or waiting for revision surgery,\(^{1,38,39,58}\) a worst case revision rate for squeak is recalculated as 0.3%.

**Mechanism of squeaking.** There are essentially two mechanisms described. The first involves sound that is generated by extra-articular impingement of the femoral neck on the acetabular component.\(^{59,60}\) A second process is said to be dependent on increased friction of the bearing couple, causing resonance and the production of audible noise.\(^{61}\) (Fig. 3).

Factors linked to squeaking in a CoC THR are shown in Table II. Squeaking was first linked to rim impingement in a case report in 2003,\(^{39}\) and has been proposed again more recently.\(^{18}\) Rim impingement is noted to be common in conventional THR\(^{52}\) and is associated with short neck length.\(^{30,59}\) It is also associated with elevated metal rims of acetabular components.\(^{39,60,63}\)

A number of studies have considered acetabular orientation and its role in the production of squeaking.\(^{1,18,21,24,25,39}\) In addition to an increased probability of neck–rim impingement, the proposed mechanism is edge loading. This leads to localized stress and wear on the head, termed stripe wear.\(^{39}\) Using finite element analysis, eccentric loading of the femoral head has been modelled and investigated in the laboratory, with high inclination and anteversion shown to increase edge loading, wear and squeaking.\(^{63,64}\) In contrast to these findings, some retrieval studies have reported evidence of rim impingement with normal acetabular orientation,\(^{22}\) and some have shown no relationship between squeaking and acetabular orientation.\(^{30,37-39}\)

The ‘increased friction hypothesis’ contends that squeak is a result of reduced lubrication. This was proposed by Reiker et al.\(^{65}\) in metal-on-metal articulations, where it was postulated that a slip-and-stick mechanism leads to noise by generating vibration. This is easily reproduced in the laboratory with a dry joint.\(^{20}\) Alteration of the bearing surface\(^{65}\) by roughening or by metal deposition can also produce squeaking.\(^{29,66}\) Disruption of fluid film lubrication...
Squeaking has been related to edge loading and stripe wear.\textsuperscript{18,67,68} In contrast to these observations, stripe wear has been observed on a large number of femoral heads that do not squeak.\textsuperscript{68}

Micro-separation, which describes micro-subluxation of the femoral head,\textsuperscript{69} occurs during the gait cycle, where the femoral head is eccentrically loaded causing localised stress and stripe wear. Experiments incorporating micro-separation produce stripe patterns similar to that seen in retrieval analysis.\textsuperscript{68} Squeaking has been linked to a patient’s predisposition to micro-separation, including those with ligamentous laxity and leg-length shortening.\textsuperscript{38,69}

Femoral stem design has been linked to squeak production by laboratory, clinical studies and meta-analysis. Stanat and Capozzi\textsuperscript{56} showed a significant association with the implantation of the Accolade stem. Walter et al\textsuperscript{70} noted that the acetabular component construct resonates above the audible range of human hearing. Hothen et al\textsuperscript{13} conducted laboratory experiments examining the natural frequency of THR components and concluded that the design of the femoral, and not the acetabular component, was responsible for generating audible sound. Of the designs examined, the Accolade stem was shown to be particularly prone to this phenomenon.

There is controversy over which patient factors are associated with squeaking in CoC THR. In a recent meta-analysis Stanat and Capozzi\textsuperscript{56} found that elevated body mass index alone was linked to squeaking. Sexton et al\textsuperscript{24} found squeaking to be associated with heavier, taller, younger people. Other series have found a relationship with male gender and higher activity scores.

In conclusion, the incidences of squeaking in CoC THR and of revision for squeaking are estimated to be 4.2% and 0.2%, respectively, but these estimates are considerably higher when the Accolade femoral component is used.

The exact mechanism of squeaking in THR remains a matter of conjecture and is probably multifactorial. This review demonstrates that squeaking in CoC THR, although rare, is not insignificant. Although there is not yet any definitive evidence to suggest that regular squeaking reduces the survival of the THR, there are a number of studies that have related squeaking to increased wear and suboptimal positioning, which may suggest at future problems.

It is important to acknowledge that the vast majority of CoC THRs perform as expected, providing patients with significant relief from pain and return to function. Although some patients are troubled by the squeak, many remain unconcerned and very few seek revision surgery.

\begin{table}[h]
\centering
\begin{tabular}{|l|l|l|}
\hline
\textbf{Study} & \textbf{Significant associations} & \textbf{No association} \\
\hline
Walter\textsuperscript{18} & High anteversion variance, high inclination variance, taller, heavier and younger patients & Pain scores, HHS, inclination, anteversion \\
Ecker\textsuperscript{20} & Stryker Accolade stem and Stryker Trident acetabular component combination & Inclination, anteversion, age, gender, BMI, indication, complications, cup size, head size, stem size \\
Restrepo\textsuperscript{22} & Short femoral neck length & No statistical difference between inclination, anteversion, leg length, head size distribution \\
Keurentjes\textsuperscript{30} & Negative quality of life & Age, gender, weight, BMI, side, unilateral/bilateral, indication, head size, acetabular component \\
Jarrett\textsuperscript{38} & Height, smaller neck geometry, neck-cup combination with combinations other than C-taper/ABC, V40 neck & Age, height, weight, BMI, abduction angle, cup size, neck length \\
Mai\textsuperscript{40} & Male gender, larger head size & Gender, age, height, weight, BMI, follow-up, acetabular components, femoral component, head size, SF-36, anteversion, inclination \\
Choi\textsuperscript{47} & Accolade stem & Gender, height, BMI \\
Restrepo\textsuperscript{57} & Accolade stem/Accolade stem/Trident acetabular component, RA, short femoral neck & Age, gender, height, weight, BMI, side, UCLA score, head size, femoral offset, inclination, anteversion \\
Cogan\textsuperscript{28} & Association between noise and dissatisfaction & Inclination \\
Schröder\textsuperscript{23} & Age, height, weight, adduction, external rotation, internal rotation, activity subgroup of HHS & BMI, hip flexion, abduction, HHS, patient satisfaction, head size \\
Sexton\textsuperscript{24} & Trident cup & TMZF\textsuperscript{®}, stem, operating surgeon \\
Parvizi\textsuperscript{71} & Gender, weight, acetabular component size, femoral component size, UCLA score & Inclination, anteversion \\
Kj\textsuperscript{98} & Squeaking & Age, BMI, HHS, Postel-Merle score, surgical approach, neck length \\
Chevillotte\textsuperscript{36} & BMI inclination, limb length shortening of >5mm & Age, acetabular anteversion, HHS \\
Owen\textsuperscript{21} & BMI inclination, limb length shortening of >5mm & Height, weight, BMI, age, indication \\
\hline
\end{tabular}
\caption{Studies demonstrating factors associated with CoC THR squeak.}
\end{table}

\textbf{BMI}, body mass index; HHS, Harris hip score; UCLA, University of California, Los Angeles; SF-36, Short Form 36; RA, rheumatoid arthritis; TMZF\textsuperscript{®}, titanium, molybdenum, zirconium and iron alloy (Ti-12Mo-6Zr-2Fe); C-taper/ABC, neck and cup combination (arc-deposited hydroxyapatite-coated cup), Stryker, Mahwah, New Jersey; Trident Cup (Stryker, Mahwah, New Jersey.)
References

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