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THE INFLUENCE OF CLEARANCE ON FRICTION, LUBRICATION AND SQUEAKING IN LARGE DIAMETER METAL-ON-METAL HIP REPLACEMENTS

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The Influence of Clearance upon the Friction, Lubrication and Squeaking of Large Diameter Metal-on-Metal Hip Replacements

Abstract

Large diameter metal-on-metal bearings are becoming increasingly popular, addressing the needs of young and more active patients. Clinical data has shown excellent short to mid-term results, though incidences of transient squeaking have been noted between implantation and 2 years post-operative. Material choice and geometric design features, such as clearance, have been significant in influencing the performance of the bearings. Three different clearance bearings were investigated in this study using a hip friction simulator to examine the influence of clearance on friction, lubrication and squeaking.

The friction factor was found to be highest in the large clearance bearings under all test conditions. The incidence of squeaking was also highest in the large clearance bearings, with all bearings squeaking throughout the study. A very low incidence of squeaking was observed within the other two clearance groups. The lubricating film was measured using an ultrasound reflection method and was found to be lowest in the large clearance bearings. This study suggests that increasing the bearing clearance results in reduced lubricant film thickness, increased friction and an increased incidence of squeaking.

Introduction

Total hip replacement is a very successful surgical intervention. However, it has long been considered an inadequate solution for the needs of younger, more active patients, due to higher dislocation rates and reduced longevity (Charnley 1982; Kobayashi 1997). Surface replacements were developed to preserve bone stock and increase joint stability, whilst yielding more natural biomechanics. Early designs, employed a metal-on-polyethylene (MOP) bearing failed due to high wear, resultant from the increased sliding distance (Tanaka 1978; Wagner 1978; Bell *et al.* 1985). More recent designs have used a metal-on-metal (MOM) bearing with encouraging short-to-mid-term clinical performance, with high survival rate and swift rehabilitation of patients (McMinn 1996; Daniel *et al.* 2004; Treacy *et al.* 2005). However, as early generation conventional MOM total hip replacements were often noted to fail due to high frictional torque, concerns exist that the larger bearing may generate torques sufficient to cause frictional loosening.

The choice of material, size and clearance have all been important factors governing the performance of MOM bearings. Many theoretical and experimental studies have determined that MOM bearings operated within a mixed lubricating regime (Jin 2002; Scholes and Unsworth 2006). Theoretical analysis, using the Hamrock and Dowson equation, suggests that a reduction in clearance would enhance the lubrication of the bearing, and hence reduce friction. *In-vitro* wear studies have shown reduced bedding-in wear with reducing clearance (Chan *et al.* 1999).

Clinical cases of transient squeaking in patients with resurfacing bearings have been noted in recent years, with some reporting an incidence of up to 10% between 6 months and 2 years post-implantation (Ebied et al. 2002). Back *et al* identified 3.9% of their study group (230 patients) had exhibited squeaking, in isolated occurrences within 6 months of implantation. They proposed that the squeaking was due to disrupted fluid film in the bearing (Back *et al.* 2005).

The aim of this study was to compare the lubrication and friction of surface replacements with three different clearances, whilst noting the incidence of 'squeaking' and assessing the sound generated.

Materials and Methodology

Metal-on-metal surface replacements (ASR, DePuy International, Leeds, UK) with a nominal diameter of 54.6mm and mean diametric clearances of 94µm and custom-made replacements with mean diametric clearances of 53µm and 194µm (n=4 for each clearance) were tested with a friction simulator (SimSol, UK). Components were inverted with a flexion-extension of ±25^{o} applied to the head and lubricated with 25% (v/v) and 100% newborn bovine serum. A peak load of 2kN, with swing phase loads of 25N, 100N or 300N were applied (Brockett *et al.* 2007). Tests were performed in a forward and reverse direction, and a mean taken, to eliminate potential errors due to misalignment of the components. The frictional torque generated between the head and cup was measured, and the friction factor was calculated during the high-load, high-velocity phase of the test cycle. Tests were performed for a minimum of 120 cycles.

Sound data was recorded during each friction test using a MP3 recorder and pre-amplifier (Cirrus Research, UK). A microphone was set up at a distance of 50mm from the implant, and data recorded over a minimum of 10 seconds where sound was generated. Sound data was assessed through narrow band analysis on Frequency Master software (Cirrus Research, UK).

Lubrication was assessed by directly measuring the separation between the head and cup during the test cycle by ultrasonic methods developed at the University of Sheffield (Tribosonics, UK) on one sample of each clearance. A 7mm diameter piezoelectric sensor was bonded to the back of the cup and ultrasonic reflection measurements were taken during the friction tests at a sampling rate of 100Hz. Using equations which related reflection coefficient to lubricant properties and film thickness, values for the film thickness were calculated (Dwyer-Joyce *et al.* 2003).

Results

A comparative study examining the influence of clearance on friction, lubrication and squeaking was performed. The surface replacement with the largest clearance yielded the highest friction factor (Figure 1), with a mean friction factor of 0.196 (±0.027) in 25% serum. The difference between the large clearance bearing and the smaller clearance samples was statistically significant in 25% bovine serum, the more clinically relevant lubricant (ANOVA, $p<0.05$). No statistically significant difference was observed between the 53μm and the 94μm clearance groups

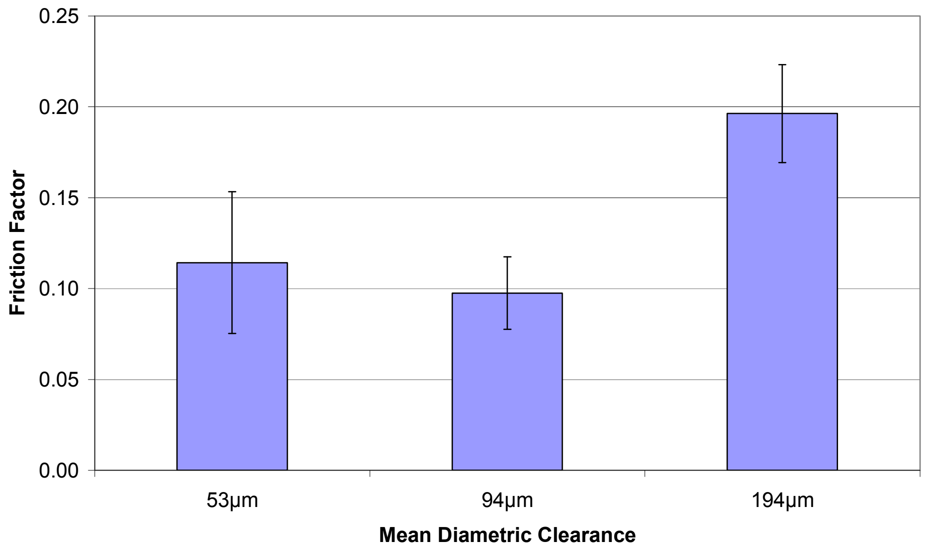

Figure 1 Influence of clearance on friction (in 25% serum, 95% confidence limits indicated)

The protein concentration of the serum was shown to influence the friction of all three clearance groups, with lower friction in the higher serum concentration (Figure 2). Furthermore, a different trend was observed when comparing the influence of clearance on friction. The 100% serum tests demonstrated increasing friction with increasing clearance, though there was no statistically significant difference between the mean friction factors of the three clearances (ANOVA, $p>0.05$).

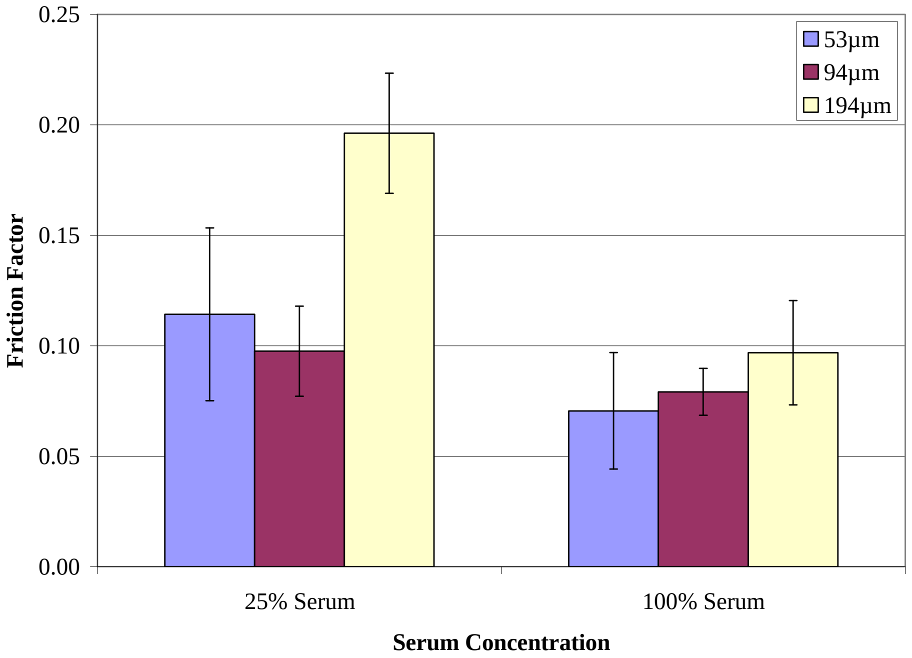

Figure 2 Influence of serum concentration upon friction

The peak frictional torques measured in each group, under 100N swing phase load, 25% lubricant test conditions, are shown in Table 1. The highest frictional torque was measured in the largest clearance bearing.

Table 1 Influence of clearance on peak frictional torque

Mean Diametral Clearance/µm	Peak Frictional Torque/Nm
53	6.55
94	5.33
194	10.51

Sound measurements were recorded from each bearing where squeaking occurred, and the incidence of squeaking under each test condition was noted. 'Squeaking' was observed for all samples in the 194µm clearance sample group, in 25% and 100% serum. There was a lower incidence of squeaking in the smaller clearance groups (Figure 3). Analysis of the sounds generated demonstrated a slight negative association between sound frequency and the friction factor.

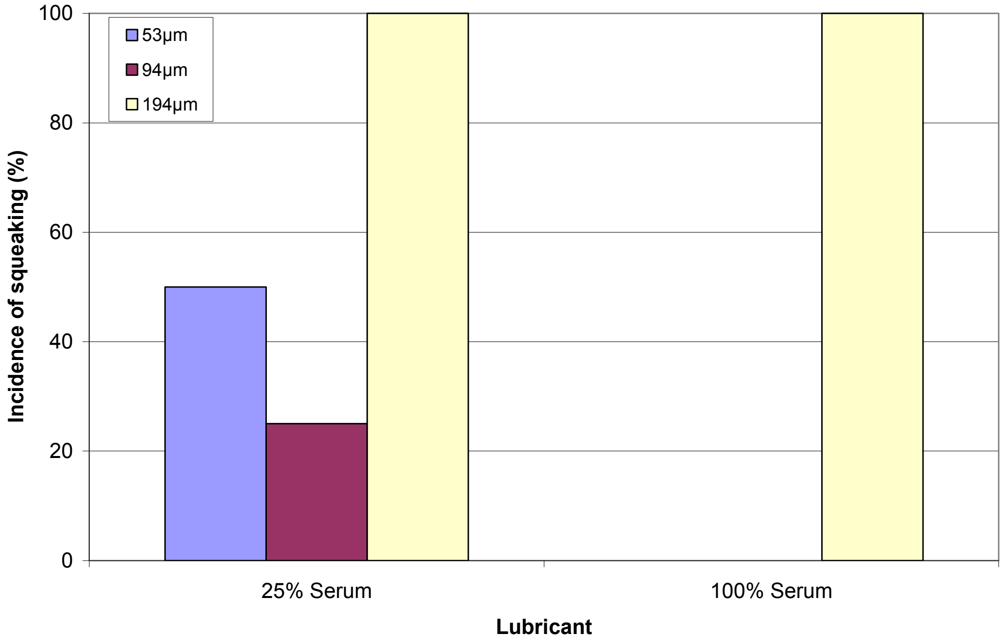

Figure 3 Incidence of squeaking

Ultrasonic measurement of the lubricant film thickness showed the large clearance bearing to have the thinnest film, although the 53µm clearance bearing exhibited similar film thickness. The best lubrication condition was shown to be the 94µm bearing, also exhibiting the lowest friction, as shown in Figure 4. A negative trend of increasing friction factor with reducing film thickness, as the swing phase load increased, was observed.

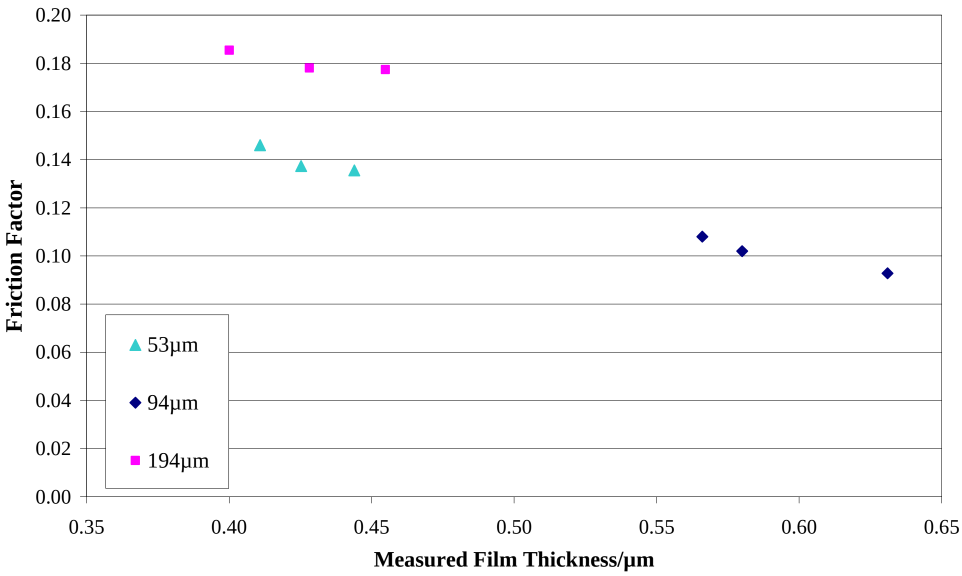

Figure 4 Influence of diametric clearance upon film thickness (data points for 25N, 100N and 300N swing phase loads)

Discussion

This study has examined the influence of diametric bearing clearance upon the friction, lubrication and squeaking of large diameter metal-on-metal implants through a friction simulator study. Friction studies have often been used to indirectly assess the lubrication of a hip replacement, this study introduces a novel method to directly assess lubrication within the bearing.

The friction study employed a uni-directional flexion-extension motion, and the loading cycle is a simplified model of the gait cycle, with one peak. The bearings are arranged in an inverted position, with respect to *in-vivo* and the cup is not angled.

Diametric clearance was shown to have a significant influence upon the friction of the metal-on-metal bearing. An increase in diametric clearance from 53μm or 94μm to 194μm resulted in a significant increase in friction under 25% serum conditions. The small and mid-range clearance bearings were shown to have similar friction factors throughout all test conditions. The friction trends indirectly indicate the smaller clearance bearings have increased lubrication compared with the large clearance bearing. This influence is supported by a number of experimental studies examining the influence of clearance on the wear performance of metal-on-metal bearings. In an experimental study of wear, McKellop *et al* (1996) saw increasing wear occur as the clearance was increased from approximately 120 microns to 390 microns. Several other studies, including Chan *et al* (1999) have identified a reduction in diametric clearance as beneficial to the wear performance of a metal-on-metal implant. Electrical resistance measurements during a wear study, assessing the separation of the head and cup by lubricant, indicated that a reduction in diametric clearance resulted in longer periods of complete separation of the head and cup during each walking cycle (Dowson *et al.* 2000).

It was noted that the effect of clearance upon friction was not so marked when tested in 100% serum, compared with 25% serum. It is proposed that proteins adhere to the surface of the metal bearings, acting as solid phase lubricants to reduce the adhesive forces between the metal-metal contact. The increased concentration of proteins acting in this role may have partially concealed the effect of the depleting fluid film at the large clearance.

Frictional torque was cited as a reason for failure of early generation bearings, therefore it is still of clinical interest to establish whether the frictional torque generated within a large diameter metal-on-metal bearing might be sufficient to cause acetabular loosening. A clinical study by Mai *et al* established that frictional torque was not a primary influence in the loosening of large diameter metal-on-metal acetabular components, however, no frictional measurements were recorded (Mai *et al.* 1996). Cadaveric assessment of the frictional torque to loosening have been performed by a number of authors, examining both cemented and uncemented acetabular cups, however, none appear to have been performed upon large diameter metal-on-metal bearings. Thus it is difficult to contrast the findings of the present study with the findings of dissimilar cup designs.

The sound generated by the bearing was investigated due to the clinical incidence of squeaking in hip replacement patients, with up to 10% of patients reporting transient squeaking in one study (Ebied *et al.* 2002). In this experimental study, sounds were recorded during friction simulator tests, and the incidence of squeaking noted for each bearing combination. The incidence of 'squeaking' was highest in the large clearance bearing group, with squeaking occurring under all lubricant conditions, and in most tests. This group also exhibited the highest friction factors during the, suggesting the bearings were lubricated less effectively than the other bearing groups, potentially causing the squeaking. The smaller clearance groups exhibited little squeaking during the study, with only one 94μm clearance bearing squeaking under 25% bovine serum lubricant conditions.

The influence of clearance upon lubricating film thickness was directly assessed using a novel ultrasound technique, previously used to successfully examine the film thickness in machine elements (Dwyer-Joyce *et al.* 2003; Dwyer-Joyce *et al.* 2004). The largest clearance bearings exhibited the thinnest lubricating films, whilst generating the highest friction. However, it must also be noted that the film thickness for the smallest clearance was also reduced, yet this did not have the same impact upon the friction. The ultrasound study employed only one sample per clearance, and as there appears to be variation between samples in each clearance group for friction, it may be assumed that similar variability may occur in the film thickness. Therefore further test development and a bigger sample size may generate a more notable trend.

This study appears to indicate some correlation between friction, lubrication and squeaking. Ultrasonic measurement of lubrication demonstrated reduced film thickness in the large clearance bearing, correlating with increased friction factor. The incidence of squeaking was also greatest in the large clearance bearings, which generated the highest friction. Lubrication theory predicts that an increase in diametric clearance would result in depleted film thickness. It may be concluded that an increase of diametric clearance may result in a reduction of film thickness, increasing asperity contact and therefore increasing friction. It is proposed that the depleted lubrication in the large clearance bearings allowed more bearing surface contact, generating the squeaking observed within this study.

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