INTRODUCTION
Total hip replacement is generally a successful surgical intervention but less so for younger, more active patients. This has been attributed to the effects polyethylene wear debris [1]. Large diameter metal-on-metal bearings used with both conventional total hip replacement and surface replacement, have increased stability and reduced level of volumetric wear, and have become increasingly popular in recent years [2].

The choice of material, size and clearance have been important considerations in the design of the resurfacing implant. Theoretical analysis has predicted that a reduced clearance should increase film thickness and hence improve lubrication [3]. In-vitro wear tests have also demonstrated reduced bedding-in wear with lower clearance implants. However, there is presently no clinical data to support these theoretical and experimental findings.

It has been reported clinically that up to 10% of patients have presented with transient ‘squeaking’ arising from the bearing for a short period of time between 6 months and 2 years post-implant [4]. At present there appears to have been no published scientific investigation into these sounds and their causes.

The aim of this in-vitro investigation was to compare the frictional behaviour of surface replacements with three different clearances, whilst noting the incidence of ‘squeaking’ and assessing the sound generated.

METHODS
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). Four samples were tested for each clearance. Initial geometric and surface finish data was measured using a CMM (Kemco, UK) and a Form-Talysurf (Taylor-Hobson, UK).

Implants were tested in an inverted position, with a flexion-extension motion of ±25° applied to the head. Tests were performed at 1Hz, with a simple sinusoidal waveform over 60% of each loading cycle to apply dynamic load, with a peak of 2KN, and swing phase loads of 25N, 100N and 300N. Bovine serum at 25 and 100% concentrations (Harlan Sera-Lab, UK) were used as lubricants. Each test was performed in both forward and reverse directions and the mean taken, to eliminate potential errors due to misalignment. The lubricant was removed and the prostheses cleaned between each test.

The friction factor was calculated from the frictional torque measured during the high load, high velocity phase of the test cycle. Friction factor, defined as; $f = \frac{T}{rL}$, where $T$ is the frictional torque, $r$ is the femoral head radius and $L$ is the load; is similar to the co-efficient of friction but varies with finite contact area.

Sound data was recorded during friction testing 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)

RESULTS
The mean (±95% confidence limits) friction factors for each clearance group are shown in Figure 1. The set of surface replacements with the largest clearances (mean=194µm) yielded the highest friction factor under all test conditions. This was found to be statistically significant for 25% serum (ANOVA, $p<0.05$), but not significant in 100% serum (ANOVA, $p>0.05$). The mean friction factor for the 53µm clearance group was not significantly different to that of the 94µm clearance group.

DISCUSSION
Metal-on-metal bearings operate within a mixed lubricating regime, hence the effects of both boundary and fluid film lubrication need to be considered when examining the tribological behaviour of the bearing. Theoretical predictions suggest increasing the clearance would result in reduced film thickness yielding conditions where boundary lubrication dominates, and the friction is increased. This would appear to be occurring when increasing the clearance from both 53µm and 94µm to 194µm. The effect of clearance appears much less in the 100% serum tests. The effect of the proteins as a boundary lubricant may be concealing the influence of the fluid film under these conditions.

Sound was generated within the bearing for all the large clearance samples. There appeared to be some negative association between the frequency of the sound and the friction measured, with the frequency reducing with increased friction factor.

This study indicates a reduced radial clearance reduces friction and the incidence of squeaking. Other studies have shown a reduced clearance also reduces wear. However it should be noted that in product design terms there is a minimum diametrical clearance that can be tolerated, as the clearance must accommodate the manufacturing tolerance for form and shape, in addition to any deformation of the head and cup. A clearance in the range of 50-60µm represents the minimum recommended diametrical clearance.

ACKNOWLEDGEMENTS
The samples within this study were provided by DePuy International, Leeds, UK.

REFERENCES
1. Ingham, E. and J. Fisher, Biomaterials, 2005. 26(11)

** DePuy International, Leeds, UK