Effect of clearance on friction and cartilage damage in hip hemi-arthroplasty

INTRODUCTION:
Hemi-arthroplasty offers a more conservative option compared to total hip replacement in cases of fractured neck of femur as it replaces only the femoral side. However, the incidence of early hemi-arthroplasty failure is substantial and has been attributed to acetabular cartilage degeneration due to the friction between the metal head and acetabular cartilage [1]. It is hypothesized that an increase in clearance between the head and natural acetabulum and resulting increase in cartilage contact stress will increase cartilage degradation.

This study investigated the biotribology of hemi-arthroplasty in an *in vitro* model to assess cartilage tribology (friction, degradation and wear) as a function of clearance between head and cup under constant and dynamic loading cycles.

METHODS:
Porcine acetabulums were dissected within 36 hours of slaughter from 12 month old animals, mounted at an angle of 45 degrees inclination in PMMA cement and measured in the flexion-extension (FE) and medial-lateral (ML) directions. The diameters of the Cobalt Chrome alloy heads were 32, 34, 35, 36 and 37 mm each having a surface roughness (Ra) of 0.008μm prior to testing (measured using a contact profilometer, TalySurf, Taylor Hobson, Leicester, UK).

The tribological simulation was conducted using a pendulum motion simulator (Simulator Solutions, Stockport, UK; Figure 1). Components were mounted in an inverted configuration compared to the anatomical position (i.e. the head superior to the cup). A FE motion of ±15 degrees was applied to the head. A constant load test with a 400N load regime or a dynamic load test with a 75~800N load regime was applied at a frequency of 1 Hertz. The lubricant was 25% bovine serum.

The radial FE clearance ‘x’ was defined as Small (S: x<0.6mm), Medium (M: 0.6≤x<1.2mm), Large (L: 1.2≤x<1.8mm), and Extra Large (XL: x≥1.8mm). The friction factor (f, Equation 1) was calculated using R (the bearing radius [meters]), Lp (peak load [N]) and T (friction torque [Nm]). Friction factor magnitude is similar to the coefficient of friction (μeff), but varies with the finite contact area. The coefficient of friction (μeff) was calculated when the head was passing the lowest position of the acetabulum (i.e. at 0 degree FE).

\[
f = \frac{T}{RL_p} \quad \text{(Equation 1)}
\]

Porcine acetabulum specimens (8 variables studied, n=6 per group) were tested with different clearances under constant load or dynamic load for two hours and coefficient of friction was measured over time.

RESULTS:
The coefficient of friction was significantly lower with increased clearance (ANOVA single factor, 0.005; be tested at 10, 20, 120 minutes time points), contrary to the hypothesis. The coefficient of friction decreased as the clearance was increased under both dynamic loading (Figure 2) and constant loading. The coefficient of friction was higher under constant load and showed a trend of decreasing with increasing clearance.

\[\text{Figure 2 - Mean (n=6) coefficient of friction of different clearances under dynamic loading, ±15 degrees FE, 25% bovine serum}\]

Under constant loading with XL clearance, cartilage was damaged/remodeled from bone and cartilage friction was reduced. It is postulated that this was when the cartilage damage occurred (Figure 3).

\[\text{Figure 3 - Coefficient of friction under 400N constant loading with XL clearance (reduced friction due to cartilage damage relating to circled points)}\]

DISCUSSION:
Friction coefficient under constant load was higher than under dynamic load due to the biphasic properties of cartilage. The coefficient of friction did not, however, increase with clearance as hypothesized but instead reduced as the clearance increased (over the range of <0.6 to >2mm). This was due to an increase in translation of the contact point over the surface of the cartilage in the cup allowing for fluid to re-inbine into the cartilage when unloaded, such that the fluid phase supported the load when reapplied. For extra large clearances under constant load this was not the case and cartilage was disrupted and damaged. This was due to contact pressures and frictional shear stress exceeding the durability limit for articular cartilage (as reported for in the knee following meniscectomy [2]). This study indicates that low levels of friction and short term durability is achievable for a range of clearances in hemi-arthroplasty of the hip (up to 1.8mm), whereas extra large clearances (>1.8mm) should be avoided.

REFERENCE

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