EFFECT OF ACETABULAR CUP DESIGN ON THE TRIBOLOGY OF METAL-ON-METAL HIP RESURFACING REPLACEMENTS: A CONTACT MECHANICS AND ELASTOHYDRODYNAMIC LUBRICATION STUDY

I. Udofia/University of Leeds, Leeds, UK
F. Liu/University of Leeds, Leeds, UK
Z. Jin/University of Leeds, Leeds, UK
P. Roberts/Royal Gwent Hospital, Newport, UK
P. Grigoris/University of Bradford, Bradford, UK

ABSTRACT

The tribology of metal-on-metal (MOM) hip resurfacing prostheses has been investigated in this study, with particular consideration of the effect of prosthesis design (cup wall thickness and clearance) on the contact mechanics and elastohydrodynamic lubrication (EHL) of these man-made bearings. Two commercially available MOM hip resurfacing designs, which differ mainly in cup-wall thickness and diametral clearance, were investigated.

Finite element contact mechanics and lubrication analyses were carried out on the two MOM hip resurfacing designs. It was found that the thinner acetabular cup with a relatively smaller clearance resulted in lower contact and hydrodynamic pressure predictions, and a significant increase in the predicted lubricant film thickness at the bearing surfaces. This was attributed to the increase in contact area, conformity between the cup and ball and to the increased influence of the underlying non-metallic structures such as bone and cement, which enhanced the elasticity of the thin acetabular cup. It was shown that full fluid-film lubrication was possible in MOM hip resurfacings during the walking cycle with the small clearance and thin cup-wall thickness model. The importance of the design and manufacturing parameters on the tribological performance of MOM hip resurfacings is highlighted in this study, particularly in promoting fluid film lubrication as a means to further reduce wear at the bearing surfaces.

INTRODUCTION

Hip resurfacing prostheses are an increasingly popular choice for young and active patients. Optimising the design parameters of these devices will enhancing the tribological properties at the bearing surfaces and improve the overall clinical performance. Design parameters such as reduced diametral clearance, large bearing diameters and thin-wall components have been shown to promote lubrication experienced at the bearing surfaces, which is crucial to the reduction of wear of the bearing [1-5]. Addressing the tribology concerns of conventional MOM total hip replacements, through research and design optimisation has been crucial to the success of these prosthesis [2, 6]. However, little has been reported in the literature regarding the tribology of the MOM hip resurfacing prosthesis. The aim of this study was primarily to show the effect of the acetabular cup-wall thickness on the contact mechanics and EHL of MOM hip resurfacing prostheses.

METHOD AND MODELS

Two medium sized (50mm) cobalt chromium MOM hip resurfacing designs from two major manufacturers were considered. The differences in material properties were not considered. Three-dimensional finite element models (Figure 1) of both prostheses were created and implanted into pelvic and femoral bone models (45º inclination, 10º anteversion). Model-1 had a uniform cup-wall thickness of 3.9mm and a diametral clearance of 0.145mm. Model-2 had a non-uniform cup-wall thickness (average thickness of 4.8mm), being thicker at the pole than at the equator.

Frictionless contact elements were used in the finite element models to simulate a well lubricated condition at the bearing surfaces. Hip joint contact loads and muscle forces were applied to the finite element model (Figure 1). The cupbone interface was modelled with a friction coefficient of 0.5.
For the EHL analysis, a simple ball-in-socket configuration was used to represent the contact between the femoral head and acetabular cup (Figure 2). A vertical load was applied through the pole of the cup and ball, which were assumed to rotate under steady-state entraining conditions, with an angular velocity of 2 rad/s. The lubricant was assumed to be an isoviscous fluid with a relatively high viscosity of 2.5 mPas, representing pseudo-synovial fluid.

Figure 1: Finite element model showing boundary and loading conditions

Figure 2: The ball-in-socket geometry in the transformed simplified spherical coordinates used for the lubrication analysis.

For the EHL analysis, a simple ball-in-socket configuration was used to represent the contact between the femoral head and acetabular cup (Figure 2). A vertical load was applied through the pole of the cup and ball, which were assumed to rotate under steady-state entraining conditions, with an angular velocity of 2 rad/s. The lubricant was assumed to be an isoviscous fluid with a relatively high viscosity of 2.5 mPas, representing pseudo-synovial fluid.

For the lubrication analysis, both the Reynolds and the elasticity equations were coupled and solved numerically by the finite difference method. The elastic deformation was determined by means of the fast Fourier transform (FFT) technique using the displacement coefficients obtained from the finite element method, which were then used to calculate the elastic deformation of the bearing surfaces [7, 8].

RESULTS AND DISCUSSION
The results of the present study on the effect of acetabular cup design on the contact mechanics and EHL of MOM hip resurfacings showed that the thin acetabular cup-wall model (Model-1) exhibited better tribological properties at the bearing surfaces in comparison to the thicker cup-wall model (Model-2). This was noted in the thin cup-wall model by the following:

- An increase in the predicted lubricating film thickness.
- A reduction in the predicted hydrodynamic pressure.
- A reduction in the predicted contact pressure.
- An increase in the predicted contact area.
- Increased elastic deformation.

The enhanced contact mechanics and lubrication properties of the thin cup-wall model could be attributed to the increased elasticity brought about by the increased influence of the underlying non-metallic structures [5]. However, the most significant factor in contributing to the reduced pressures and increased film thickness was the smaller clearance of the thin cup-wall model (Model-1). The thin cup-wall model had a nominal diametral clearance of 0.145 mm, while clearance of the thicker cup-wall model (Model-2) was 0.3 mm. The smaller clearance led to the increased conformity between the ball and head, thereby enhancing the tribology at the bearing surfaces in terms of increased contact area, reduced pressure, and promoting full fluid film lubrication. In addition to the design considerations required for optimum tribological performance in MOM hip resurfacing replacements, consideration of manufacturing parameters such as, ultra-fine surface finishing, sphericity, and tolerances as well as surgical factors could also contribute to the improved performance of these devices.

ACKNOWLEDGMENTS

Financial support was partially provided by the Arthritis Research Campaign (ARC), UK and Zimmer GmbH, Switzerland.

REFERENCES