CONTACT MECHANICS AND LUBRICATION ANALYSIS OF MCKEE-FARRAR METAL-ON-METAL HIP IMPLANTS

**Introduction:** One of the approaches to avoid UHMWPE wear particles in current artificial hip joint replacements is to promote lubrication and hence minimize wear through the use of metal-on-metal (MOM) material combinations. This is a resurgence of an old concept developed largely with the McKee-Farrar type MOM hip joint replacement. A number of clinical studies have shown that some of these prostheses can last twenty or thirty years, while other studies of some early designs have shown that dramatic short-term failure can occur within three years [1]. The reason for the long-term success or the short-term failure has not been fully identified, although the intrinsic wear properties of the cobalt chrome alloy, design features such as the radial clearance between the femoral head and the acetabular cup, and manufacturing tolerances have all been shown to be important [2,3]. There are currently an increasing number of orthopedic surgeons using this type of prosthesis available from the majority of orthopedic manufacturers. One of the major differences between the modern MOM total hip joint replacements and the original McKee-Farrar prosthesis is the femoral head size. The majority of the modern MOM total hip replacements have a femoral head diameter of 28 mm, largely copied from UHMWPE hip prostheses, while the original McKee-Farrar prostheses use a larger femoral head, typically 35 mm and 42 mm in diameter. There are a number of tribological advantages of using a large femoral head for a fixed clearance, including large contact area, low contact stress, better lubrication and potentially less wear [4]. However, a larger femoral head also results in a larger sliding distance and potentially more wear if the resultant lubrication regime is in the mixed or boundary, and asperity contacts prevail as in the case of UHMWPE hip prosthesis.

The purpose of this study was to investigate both contact mechanics and elastohydrodynamic lubrication in a typical McKee-Farrar MOM hip prosthesis.

**Materials and Methods:** A typical McKee-Farrar MOM hip implant shown in Figure 1 was considered in this study. The radii of the femoral head and the acetabular cup were measured as 17.5 mm and 17.6 mm respectively, giving a radial clearance of 0.1 mm. The thickness of the acetabular cup was approximately 3 mm. A simple ball-in-pocket model shown in Figure 1 was chosen for both the contact mechanics and lubrication analyses. The cup was placed horizontally and fixed with a cement layer to a simple pelvic bone. A vertical load of 2500 N and a horizontal angular velocity of 1 rad/s (representing flexion/extension) were applied to the femoral head. The viscosity for synovial fluid after total joint replacements was assumed to be 0.005 Pas. The elastic modulus was chosen as 210 GPa for the cobalt chrome alloy; 2.27 GPa for the cement; 17 GPa for the cortical bone and 0.8 GPa for the cancellous bone.

![Figure 1 A typical McKee-Farrar MOM hip implant and the ball-in-pocket model used for contact and lubrication analyses](image)

Both contact mechanics and lubrication were analyzed for the typical McKee-Farrar hip implant shown in Figure 1. The contact pressure was predicted by the finite element method. The lubricating film thickness was analyzed based on the elastohydrodynamic lubrication mechanism. In addition, iso analyzed using the Hertz contact theory and the Hamrock and Dowson’s formulae for estimating the maximum contact pressure and the minimum lubricating film thickness respectively [3].

**Results:** Figure 2 shows the comparison of the predicted contact pressure distribution between the McKee-Farrar and the thick cup considered in this study. The corresponding minimum lubricating film thickness for the McKee-Farrar prosthesis was predicted to be 0.026 µm.

![Figure 2 Prediction of maximum contact pressure](image)

**Discussion:** It is clear that the predicted contact pressure distribution for the McKee-Farrar hip implant considered in this study deviates significantly from the “thick” cup predicted from the classical Hertz contact theory. The maximum contact pressure is decreased by 52% from 87.9 MPa to 42 MPa, as a result of the increased elastic deformation due to both the bone and the cement underneath the McKee-Farrar acetabular cup. An increase in the femoral head radius from 14 mm (modern MOM hip prostheses) to 17.5 mm results in an increase of the minimum film thickness by 63% from 0.012 to 0.019 µm. This clearly demonstrates the importance of the femoral head in promoting fluid film lubrication in MOM hip prostheses. An increase in the femoral head radius from 14 mm to 17.5 mm not only results in an increase in the equivalent radius by 56%, but also the sliding velocity by 25%. For the same radius of 17.5 mm, the additional elasticity due to the cement and the bone increases the predicted minimum film thickness from 0.019 to 0.026 µm. This clearly demonstrates the advantage of the increased elasticity of the acetabular bearing surface in promoting the formation of elastohydrodynamic lubricating film.

The potential problems introduced by the relatively flexible structure of the thin acetabular cup should also be addressed. For example, too much elasticity and flexibility of the acetabular insert may not only increase the micro-motion at the interfaces between the prosthesis/cement/bone, but also extend the contact area towards the edge of the cup, leading to equatorial contact and lubrication starvation. A careful approach is required to balance all these requirements. For example considered in the present study, the contact pressure is located within the polar region of the cup and no equatorial contact can be observed as shown in Figure 2 (half contact angle less than 20°). However, the thickness in some original McKee-Farrar acetabular cups can be as low as 1.5 mm, and this should be investigated in further studies. Furthermore, it should be pointed out that since both the cement and bone have significant influence on the predicted contact mechanics and lubrication, a more realistic three-dimensional pelvic bone model may be required for these further studies.

**References:**


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