The Friction of Metal on Metal Hip Joints with Different Clearances and Viscosities
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Introduction: Lower friction in metal on metal (MOM) hip joints can reduce the wear, production of metal ions and loosening of acetabular cups. Current research has focused on the influence of geometrical factors, such as clearance and surface roughness of the bearings. The effect of the fluid viscosity, especially in the relation to the physiological range, is still not fully investigated. The aim of this paper was, therefore, to study the frictional behaviour of MOM hip joints within the human physiological fluid viscosities.

Materials and Methods: CoCrMo hip prostheses of 50 mm diameter with diametral clearances of 100 and 200 μm were tested. The friction measurement was carried out using a friction simulator (Simulation Solutions, UK) during a wear simulator test. The samples for the friction test were taken from a wear simulator at 1.4, 2.3 and 3.2 million cycles. The femoral head was placed on the top of the acetabular cup and the measurements were carried out on the wear patch. The cup component was held in a low friction carriage which was supported on externally pressurized bearings so that the friction between the head and the cup bearings was the only significant force measured. A dynamic loading cycle was applied to the femoral head. The minimum load during the swing phase and maximum load throughout the stance phase were 100N and 2000N respectively. A simple harmonic motion with a frequency of 1 Hz and amplitude of +/-23 degree was applied to the femoral head in the flexion-extension plane. The friction force was recorded for at least 120 cycles for each measurement. This was repeated in both forward and backward directions to minimize errors. Samples were carefully cleaned between each measurement. The friction factor was calculated from the equation, $f = T/rL$, where $T$ - frictional torque, $r$ - femoral head radius and $L$ - load applied.

Tests were performed using 25% new born calf serum which consisted of different ratios of serum and carboxymethyl cellulose (CMC). The fluids viscosities ranged from 0.0011 to 1.1 Pa s determined by a cone-on-plate viscometer (Physica Rheolab MC100) at a shear rate of 300/s.

Results: In Fig 1, the friction factors of both clearances reduced with the progress of wear. In the lower range of viscosity, the friction factors of the 100 μm clearance joint were lower than that of 200 μm clearance. However, this trend was reversed with the increase of viscosity. When the viscosity reached the range of 0.01-0.06 Pa s, the friction factors of 100 μm clearance surpassed that of 200 μm clearance and this difference became wider with the increase in viscosity.

Fig 2 shows the change of friction factor during a measurement due to the application of loading over 120 cycles. For 100 μm clearance, the curves started from low friction ($\approx 0.05$), but increased rapidly and remained high for the rest of the measurement except the lowest viscosity of 0.001 Pa s, which stayed level throughout the whole measurement. The friction factors were higher with increased viscosity. In the 200 μm clearance, the curves were stabilized when the viscosity was below 0.36 Pa s and low friction factors were observed as the viscosity increased. The friction factor started to increase only from 0.36 Pa s, but the gradient was less stiff compared to that of 100 μm clearance.

Discussion: Normal synovial fluid is non-Newtonian in nature with shear-rate dependent viscosity. Researchers have reported 300/s shear rate viscosities for normal, osteoarthritis, and inflammatory synovial fluids as 0.01-0.4, 0.0025-0.2 and 0.001-0.07 Pa s respectively [1-2]. Other studies have also reported that peri-prosthetic fluids from patients with primary joint replacement displayed decreased viscosities, but were similar to normal synovial fluid [3]. In Fig 1, the 200 μm clearance has lower friction in the upper range of viscosity which has the most relevance to the physiological conditions.

Theoretical studies have suggested that smaller clearance and higher viscosity can benefit the lubrication in MOM bearings. This theory is valid if continuous and complete lubrication film is achieved between the bearings. However, smaller clearance and high viscosity may also prevent the recovery of lubricant between cycles and may cause depletion of lubricant due to the geometrical shape of hip joint. This would lead to direct contact of bearings and increase friction.

The curves’ behaviour in the 100 μm clearance (Fig 2) implied that when the load was applied, the lubrication fluid was squeezed out and could not be recovered due to the small clearance and high viscosity. In contrast the lubrication depletion only started to happen after 0.36 Pa s for the 200 μm clearance and was much less significant compared to the ones in 100 μm clearance. It is therefore concluded that the selection of clearance for MOM components should consider the human physiological fluid viscosities to achieve optimal tribological performance.

![Figure 1. The relation between the friction and fluid viscosity of prostheses with two clearances at different stages of wear.](image1)

![Figure 2. Friction factor behavior with different viscosities over 120 cycles.](image2)


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