Artificial joint lubrication: Effect of Patient Synovial Fluid Properties on Implant Wear

Introduction: Wear is essentially controlled by the properties of the lubricating film formed between the rubbing interface and the nature of the rubbing surfaces. Whilst our understanding of the mechanical and surface properties of metal artificial hips is good; we lack in-depth knowledge on the synovial films which form during articulation and their implications on the performance of the artificial joints. In part, this is a result of most current experimental research into prostheses tribology being confined to the measurement of wear in joint simulators or friction in pin-on-disc apparatus. Thus we understand very little about the nature of the lubricating film or the effect of joint kinematics on film formation. We also do not understand the effect of different synovial fluid (SF) chemistries on film formation, implant wear or failure.

SF is an aqueous suspension of large and surface active molecules; including proteins (albumin and γ-globulin), phospholipids and hyaluronan. The viscosity, protein content and pH level [1, 2] of SF varies dependent on patient history. Trauma or diseases such as osteoarthritis and rheumatoid arthritis affect its chemical and physical properties. This can result in a significant change in the lubricating and wear performance of SF.

All in-vitro testing of metal-on-metal (MoM) hips uses bovine serum (BS) as the fluid test medium with the addition of other chemicals to control the pH and bacterial growth. However the current composition standard is ill-defined, as the focus is to roughly match the overall protein content and effective viscosity of periprosthetic synovial fluid. The single composition does not capture the range of patient SF properties.

Recently, the researchers presented a new inlet aggregation mechanism for lubricating film formation in artificial hip joints [3]. These films did not obey classical fluid film theory; they are thicker than predicted in the currently accepted Newtonian fluid film models [4].

In this report we present coupled lubricant film thickness, and wear, measurements under carefully controlled speed and load conditions for different model SF composition. The effect of suspension concentration and chemical composition on lubrication performance is discussed, and the implications this may have for MoM hip function.

Measurement method: Film thickness measurements were carried out using a standard optical interferometric technique with a CoCrMo femoral component (38 mm diameter, as-cast) loaded (5N) against a moving glass disc [3]. This provides a simple, steady state simulation of the gait cycle. Film thickness and wear were measured both during and after the test, under various sliding conditions, at physiological temperatures (37 °C). This arrangement also allowed visualisation of the entire contact region, so development of the interfacial film could be observed. After each test the femoral head was cleaned and examined under a microscope and a final wear measurement taken.

Results and Discussion: Visual observations showed that protein-containing fluids formed a high-viscosity gel-like phase in the inlet region of sliding contact, caused by bulk phase-separation rheology. This material is then entrained into the contact forming a thick protective film. The film within the contact is formed by a complex matrix of proteins and exhibits ‘sponge’ like properties; inflation and deflation in water content with changing load. Film thickness was also found to be very sensitive to load (contact pressure); this finding has important implications for edge loading conditions, where much higher pressures occur. A further observation is that the film thickness recovered under repeated loading suggesting it has elastic properties.

It was observed that thicker films produced lower wear rates. The formation of these protective films was sensitive to protein concentration and type, shear rate and the suspension medium chemistry (pH, buffer). Figure 1 shows the effect of albumin concentration on film thickness; an inversion in sliding speed dependency can be observed; this is not predicted by the fluid film model. The wear results (CWr = contact width at the end of the test/contact width at start), Fig 2, show the effect of protein type and, to a lesser extent, the effect of protein concentration. The globulin-containing fluids gave significantly lower wear than the albumin or BS solutions. Wear appeared to reduce with increasing protein content although this effect was less marked. These results suggest that different protein concentrations and composition occurring in periprosthetic SF would significantly influence implant wear.

Conclusions: The work highlights the importance of understanding the role of patient SF properties in determining implant wear and risk of revision. It has been shown that the globulin/albumin content and bovine serum degradation must be considered in the light of periprosthetic synovial fluid properties. This work has important implications for the specification of implant screening fluids in future standards. More importantly it may be used to explain some of the variation in reported in-vitro test results and the difference between in-vivo and in-vitro performance of the current generation of MoM hips.

The results emphasize the importance of not treating these protein-containing solutions as simple continuum fluids with a single representative viscosity. The observations suggest that protein-containing lubricating films are exceptionally sensitive to increased contact pressure and are thus more likely to fail in edge-loaded hips.

Significance: The work may contribute to more relevant screening tests and improved implant design. A better understanding of the effect of SF properties and gait (load/speed) on implant tribology might also lead to improved treatment as this could be tailored to patient needs and SF properties.

References:

Figure 1. Film thickness plotted against mean speed for Albumin and BS solutions.

Figure 2. Wear measurements for test fluids, represented by the effective contact width, CW.