An *In-Vitro* Investigation of Sliding Friction between Biomaterials for Cartilage Substitution and Articular Cartilage

E. Northwood 1, R. Kowalski 2, and J. Fisher 1
1 Institute of Medical and Biological Engineering, University of Leeds, Leeds, UK
2 DePuy CMW, Cornford Rd, Blackpool, England

**ABSTRACT**

Understanding friction and wear of biomaterials when in contact with articular cartilage is vital within the development of future hemi-arthroplasty and cartilage substitution. This study aimed to compare the frictional properties of single phase and biphasic polymeric materials against articular cartilage. Continuous sliding friction was applied by means of a simple geometry wear simulator.

The single-phase polymers produced peak frictional values of 0.37(±0.02). The biphasic hydrogel produced a peak frictional coefficient of 0.17(±0.05). It is postulated that this reduction in friction can be attributed to its biphasic properties, which instigates the fluid phase load carriage within the articular cartilage/hydrogel interface to be maintained for longer, reducing the frictional coefficient. This study illustrates the importance of biphasic properties within the tribology of future cartilage substitution materials.

**INTRODUCTION**

Natural articular cartilage has a unique biphasic lubrication regime, (Mow et al., 1980; Mow et al., 1984; Lai et al., 1991). Internal interstitial fluid pressure (Forster and Fisher, 1996; Krishnan et al., 2004) leads to low levels of friction, under extended periods of loading, independent of any elastic-hydrodynamic effects. This intrinsic biphasic lubrication is the fundamental element within the lubrication of natural joints.

In contrast, the majority of total joint replacements are composed of single phasic metallic, ceramic or polymeric materials, which do not benefit from the intrinsic biphasic lubrication found in natural articular cartilage. While theoretically lower modulus single phasic materials such as polyurethanes can promote fluid film lubrication (Walker and Gold, 1971; Medley, 1980; Bigsby et al., 1998) as a cushioned bearing, these essentially only produce low friction under periods of continuous motion and dynamic loading. However, for 95% of the time our joints experience little or no motion.

In contrast, biphasic hydrophilic polymers, such as water swollen polyhydroxyalkacrylic (McCutchens, 1969), PVA-hydrogel (Oka et al., 1990; Oka et al., 2000) and semi-interpenetrating network methacrylate hydrogel (Corkhill et al., 1990; Caravia et al., 1993) all showed reduced friction under adverse loading conditions. When considering hemi-arthroplasty or cartilage substitution solutions these biphasic properties of the materials can be important.

The aim of this study was to compare the frictional properties of biphasic and single phasic materials when sliding against natural articular cartilage under a constant load and reciprocating motion. It was predicted that the intrinsic fluid pressurization within the biphasic hydrogel will reduce the frictional results compared to the single phasic materials.

**METHOD**

A methacrylate based full inter-penetrating network hydrogel with equilibrium water content (EWC) of 13%, was compared against medical grade silicone and polyetherurethane. Articular cartilage was chosen as the negative and stainless steel as the positive controls. Six specimens of each material were mounted and the surface roughness quantified using a TalySurf 5 (Rank-Taylor-Hobson, Leicester, UK) and a laser micro-focus system, (USB Messtechnik, GMBH, Germany).

Each test specimen was tested against a 9mm diameter bovine articular cartilage pin extracted from Patella-femoral canals of healthy appearance, less than 24hrs after slaughter. Immediately after extraction each pin was stored in 100% Ringer’s Solution at -20°C until being defrosted 12hrs before testing.

Sliding friction was applied by means of a simple geometry wear simulator. A constant force of 30N was applied through the 9mm diameter pin, producing a contact stress of 0.5MPa, over a sliding distance of 10mm/cycle at a cyclic frequency of 0.4Hz. All tests were completed within 100% Ringer’s solution at 20°C. The frictional coefficient was calculated from the calibrated voltage output of a linear piezolectric sensor.

The loading protocol consisted of 60 seconds of static loading, then the reciprocating motion was engaged. The friction reading was recorded over 2hrs. Once a final reading was taken, the rig was stopped, the contact surfaces separated by 1mm and held in this position for a further 2hrs to allow unloaded re-hydration. The data acquisition process was then repeated for a further 2hrs. Once completed, the surface roughness of each test specimen was measured.

**RESULTS**

The frictional response of the single phasic stainless steel plate against a cartilage pin (positive control) shown in Figures 1A, 1B and 1C, demonstrates the effects of fluid pressurisation and a reduction in the fluid load phase (Forster and Fisher, 1996). The initially low frictional value progressively increases over each 120 minutes of testing as the fluid within the permanently loaded articular cartilage pin exudates from the contact area reducing the proportion of the fluid load phase and increasing the surface to surface contact.

The optimum performance of a biphasic material is shown by the frictional response of a cartilage pin against a cartilage plate (negative control), shown in Figures 1A, 1B and 1C. Interstitial fluid pressure at the contact area maintains at constant frictional coefficient of 0.03 (±0.01), over the 6 hour test. The fluid load support element of the cartilage plate maintains the fluid pressure at the contact area overcoming any fluid exudation. The reciprocating nature of the test allows the un-loaded area of the cartilage plate to re-hydrate so when loaded, it can maintain the fluid load support.

Each single phasic polymer shown in Figure 1A and 1B produced very similar frictional traces to the positive control. Both the medical grade silicone and medical grade polyetherurethane produced a progressive rise in the frictional...
coefficient value over each 2 hour period of reciprocating motion. Each test material produced a peak frictional coefficient of 0.37(±0.06). This progressive rise in friction is a result of fluid exudation from the cartilage pin away from the contact area and an increase in surface to surface contact. The differences in fundamental mechanical properties of each test material and yet the similar frictional response also indicates that the frictional response is dominated by alterations within the fluid load support at the contact area.

In contrast, the bi-phasic hydrogel specimen shown in Figure 1C produced a statistically significant reduction in the frictional coefficient when compared to all single phasic materials. Following an initial steady rise in friction over the first 80 minutes of each loading cycle, a peak value of 0.17(±0.05) was maintained for the remainder of the test. It is postulated that this reduction in friction of the hydrogel can be attributed to its biphasic properties. The fluid phase load carriage within the articular cartilage/hydrogel interface is maintained for longer, preserving a higher proportion of load carriage by the pressurised interstitial fluid, which results in a lower frictional coefficient.

The surface roughness measurements of all polymeric materials, biphasic or single phasic showed no statistically significant change in surface roughness indicating no surface wear occurred during 6 hours of testing.

**DISCUSSION**

The biphasic polymer did not achieve the frictional coefficient or characteristics of articular cartilage. The cartilage/cartilage interface with the internal electro-chemical reactions, higher water content and biphasic surface amorphous layer results in an extremely low constant friction coefficient. The study illustrated the importance of biphasic properties within the tribology of cartilage substitution materials and future work will focus on the optimisation of biphasic properties, such that materials will more closely mimic the biotribology of natural articular cartilage.

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**REFERENCES**


