Taiho Kogyo Tribology Research Foundation

Main report

Name: Dr Philippa Cann and Professor Daniele Dini

Theme: Tribology Properties of β-Sheet Protein Hydrogels as Artificial Cartilage for Osteoarthritis Repair

1. Progress and result of the research

One of the most debilitating health problems facing our aging population is Osteoarthritis (OA), which affects 80% of people over the age of 65, it is the most frequent cause of disability affecting the elderly population and the primary cause of artificial joint replacements. OA is a degenerative disease of the load bearing joint resulting in degradation and damage of articular cartilage (AC) bringing two articulating bones into contact causing pain. AC is a soft tissue which covers the articulating surfaces of human diarthrodial joints; its purpose is to support load arising from body weight and physiological activities and reduce the stresses in the joints through deformation. AC is a superbly engineered tribological material: it allows joint movement whilst at the same time reducing friction and surface wear for many millions of loading cycles often over a lifetime of use. However abnormal or excessive stresses cause the AC tissue to change structure and composition which results in surface damage and joint degeneration. Current research in the Tribology Group addresses two aspects of AC damage and repair: mechanical degradation and the effect on lubrication and the tribological function of artificial materials for AC repair. A detailed understanding of the effect of OA on mechanical and tribology properties will contribute to the development of optimised biomaterials for AC repair. Studies into both of these aspects was carried out supported in part by TTRF funds. Progress in each of these areas is summarised below.

1.1 Mechanical and frictional behaviour of OA degraded porcine articular cartilage

This work was a continuation of studies supported by the earlier TTRF grant "A Novel Tribometer to Test Articular Cartilage under Physiological Loading and Shear Conditions". The MCSTR (Multiaxial Compression and Shear Testing Rig) test machine developed for the TTRF grant was used to measure the mechanical properties of OA cartilage under unconfined compression. Friction behaviour of AC was measured using a High Frequency Reciprocating Rig (HFRR) which was also used to characterize the silk hydrogels described in the next section.

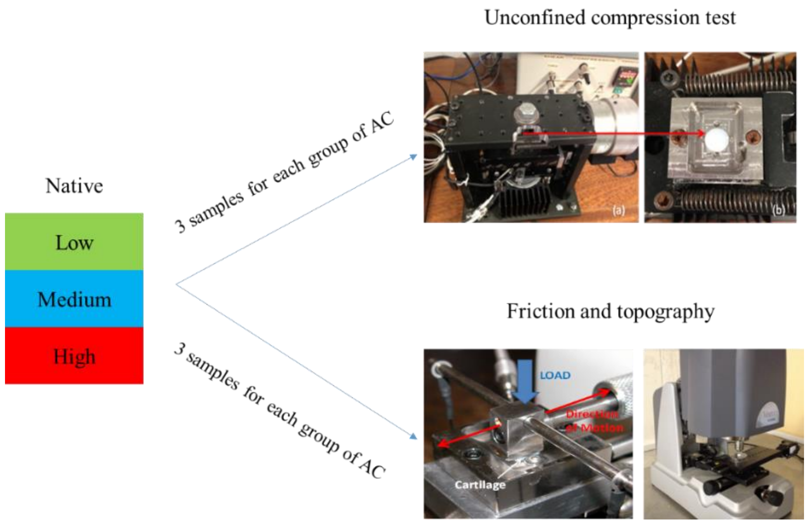

Figure 1 Schematic of mechanical and tribological evaluation of mechanically damaged AC

In this study, porcine AC has been used to prepare OA-like samples; the AC was subject to mechanically induced damage due to shear in the HFRR in an attempt to investigate any variation in mechanical properties and the resulting frictional response. A steel ball was loaded and reciprocated against an AC disc to mechanically degrade the surface of the AC and friction was measured throughout the test. The HFRR allowed testing under different configurations and conditions and higher testing frequencies, meaning that the sample could be subjected to more cycles and more mechanical damage in a given amount of time comparing to the MCSTR rig. Three different levels of damage were prepared; low, medium and high depending on the length of shearing time (2, 6, 10 hours). The different tests are shown in Figure 1. The results of the HFRR friction tests for the mechanically damaged AC samples are shown in Figure 2.

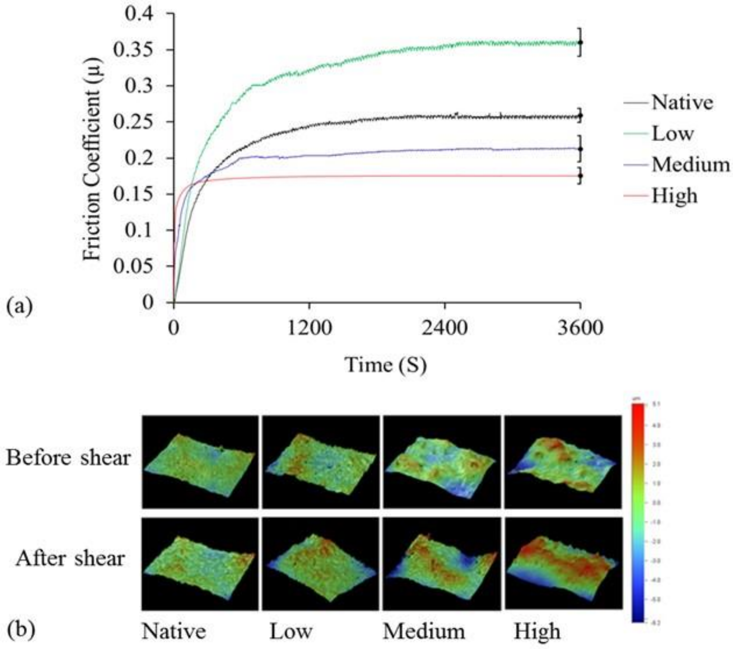

Figure 2 Representative (a) frictional response curves of native and mechanically induced OA-like porcine cartilage, (b) WLI images of native and mechanically induced OA-like cartilage before and after shear.

The mechanical quality of the tissue declined as a result of induced mechanical damage. Stiffness was shown to decrease and permeability and relaxation rates were shown to increase as compared to the native sample. It is thought that, since AC is a strongly inhomogeneous material, damage to the surface structure, which is in part responsible for the global mechanical response of the tissue, can cause significant variation in mechanical properties. Structures in the superficial zone are thought to strongly influence the mechanical response of the tissue. This suggests that mechanically induced damage, as well as degradation due to enzymes, could also play a role in the degradation of AC in vivo.

1.2 The tribology function of artificial materials for AC repair

In a companion study porous hydrogels were made from silk fibre as potential materials for AC repair. SEM images of these constructs are shown in Figure 3.

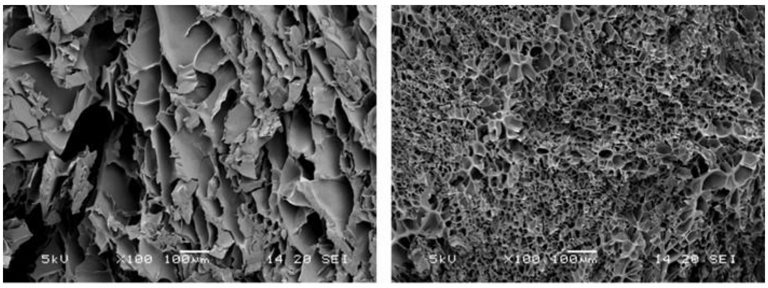

Figure 3. Silk fibroin hydrogels as imaged by SEM at 100 x magnification. Left: sheet like structure; Right: interconnected pore structure.

The aim was to develop materials which mimicked the tribological behaviour of cartilage, with controlled pore-sizes and optimised mechanical properties. Mechanical and friction/wear tests were carried out on the hydrogel materials and compared to porcine AC. Mechanical tests showed hydrogels had a comparable compressive modulus to cartilage, with stiffness improved by decreasing pore size. Under static loading and during shear hydrogels demonstrated significant interstitial fluid support. Friction testing showed the hydrogels had a cartilage-like frictional response, dominated by this interstitial fluid support. The tested silk hydrogels showed little wear, early signs of which were changes in surface morphology that did not correlate with the equilibrium friction coefficient. Consequently both wear and friction should be monitored when assessing the tribological performance of hydrogels

2. Subjects remain to be solved in future/Subjects required further investigation

Research is continuing into two aspects of this work:

(a) *AC mechanical degradation mechanisms*

Continuing research into OA degradation mechanisms in AC with specific application to human samples and the effect of artificial materials used in hemiarthroplasty on AC damage.

(b) *Artificial materials as bio-mimics for tribology research*

The development of suitable bio-mimics for tribology testing; including hydrogels as phantoms for brain tissue research, further development of AC materials and skin mimics.

In both these areas the test methods and protocols developed through the TTRF Grant will contribute significantly to the research.

3. Plan and past presentation or publication of your research results

The research has contributed the following:

1. Niloofar Ajdari "*A study of the mechanical and tribological behaviour of articular cartilage affected by osteoarthritis with particular application to hemiarthroplasty*", Thesis submitted for the degree of Doctor of Philosophy of Imperial College London and the Diploma of Imperial College, November 2016
2. Maria Parkes *"Lubrication mechanisms of lipids and proteins in model synovial fluids'* Thesis submitted for the degree of Doctor of Philosophy of Imperial College London and the Diploma of Imperial College, 2014

The work was also presented at the following meetings:

3. Parkes, M. "Optimising the tribology of silk hydrogels for use as articular cartilage scaffolds" ICoBT May 2014 Toronto, Canada
4. Dini, D., Invited talk: "Soft Materials and Tissues for Tribological Applications", presented at the Soft Matter Symposium: Friction, Rheology and Tribology - 21-22 October 2015, University of Florida, USA.
5. Dini, D., Invited talk: "Physically-based Modelling of Soft Materials and Tissues for Biotribology", ICoBT 2016 -September 2016, London, UK.

Publications Submitted:

6. Forte, A.E., Galvan, S., and Dini, D., (2017) "Models and tissue mimics for brain shift simulations", Submitted to Biomechanics and Modeling in Mechanobiology (BMMB), Springer – Revision Required.

In preparation:

7. Ajdari, N., Accardi, M.A., Cann, P., Dini, D., et al., (2017), "Investigating osteoarthritis using mechanical properties: a comparison between enzymatically and mechanically simulated osteoarthritis cartilage", *in preparation*
8. Parkes, M. Forte, A., Dini, D., Cann, P. (2017) "Bio-mimics for tribology research and tissue repair", *in preparation*