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From Macroscopic to Microscopic: Experimental and Computational Methods to investigate Bio-Tribology

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Abstract. Tribology is an important factor (among other factors) during biological interactions of devices and tissues. The paper discusses how new computational and experimental methods can be used to understand and improve the design and development of medical devices at macro and micro scales to sustain life beyond 50 years.

We have used pre-clinical experiments and computational methods to understand interactions between orthopaedic implants at the macro scale. The computational model has been validated with experiments. Now this computational model can predict damage in implants for different patients. One such application was successfully tried and tested in collaboration with University National Autonomous Mexico. This methodology can be used in future to design patient specific, affordable (using 3D printing) and robust implants which will be useful for developing countries like Vietnam, India and Mexico.

Improvement of catheter designs is important to reduce damage to the internal tissues while being used for cardiovascular problems. We are developing new experimental techniques (in micro scale) that can be used to understand the interaction of cells with the catheter material. These will help reduce the hospital costs incurred during longer stay of the patients admitted for cardiovascular related problems.

Keywords: Friction, Wear, Patella femoral joint, Endothelial Cells, Catheter

1 Introduction

Experimental work is robust, however, it is time consuming and costly [1, 2]. The experimental investigations of kinematics for artificial patella femoral joint replacements for new samples and samples after 15 million cycles took more than 15 months to complete [3]. On the other hand, computational modelling is not costly and explains quasi-static conditions of any interactions, however, requires validation with the experiments [3]. The same kinematics generated using multi-body dynamic simulations took 2 hours. The kinematics generated using the multi-body dynamic simulations were validated with experimental methods [3]. This paper outlines the two methods (namely computational and experimental) for understanding surface to surface interactions at macro and micro scales. These methods are useful in conditions where great in-depth knowledge is required for design and development of medical devices. The paper is divided into two studies. The first study compares the damage/contact maps generated by experimental, computational and retrieval studies of artificial patella femoral joint replacements at the macro scale. The second study highlights a frictional study between a glass bead (representing a catheter tip) against a fibronectin layer on a glass plate (representing tissues without the endothelial cells). Computational studies have been planned in future. However, the micro cellular interactions will be beneficial to understand tribology at the micro level.

2 Materials and Methods

2.1 Experimental and Computational Tribological Studies at the Macroscopic Scale

For the studies at the macroscopic scale, artificial patella femoral joint components (38 mm dome moderately linked ultra-high molecular weight polyethylene patella and Cobalt Chrome Molybdenum size 3 right femoral) were acquired from DePuy International. Experimental tests were carried out in Knee Sim I (Leeds) at gait cycle [1, 2] for 12 million cycles. The damage maps generated due the tribological interactions were compared with retrievals [4]. More details on the kinematics associated with the gait cycle, lubrication used during the pre-clinical testing are reported elsewhere [1]

A computational study was carried out using Multi-body Dynamic Simulations (MBDS) platform namely, MSC ADAMS (Siemens Inc, USA). The model was generated by importing the computer aided design (in STL formats). More details on the design and development of the model is reported elsewhere [3]. The tracks generated by any elements of femoral component were mapped on the patella component. Joining the highest superior and lowest inferior points of the tracks resulted in generation of a contact map. The contact map generated was validated against experimental and retrieval studies.

2.2 Experimental and Computational Tribological Studies at the Microscopic Scale

The experimental studies were carried out using a Universal Material tester (UMT-2). An interaction of engineered tissue with endothelial cells and a catheter tip. Hence, the first step to understand the complete tribological interaction between catheter and engineered tissue was to investigate the effect on fibronectin. A glass bead of 1000 µm diameter was slid (0.20 mm/s) against HiLyte FluorTM 488 Fibronectin (Cytoskeleton Inc., USA) coated on a glass petri dish to generate a contact pressure of 350 kPa. The tribological interaction was submerged in PBS solution. Images of the fibronectin layer before and after the interaction with the glass bead were captured using inverted microscopy (Nikon Eclipse Ti, Amsterdam). Due to the complexity in the tissue being poroelastic and viscoelastic, a computational model will be developed in the future.

3 Results and Discussion

3.1 Experimental and Computational Tribological Studies at the Macroscopic Scale

Good correlation between the experimental damage and MBDS contact maps were achieved (see **Fig. 1**). The damage and contact maps were covering 40% of the total surface area. However, the contact map was stretched towards the inferior side and the damage map was stretched towards the medial lateral side. This is due to the presence of limited medial lateral patellar motion (<1mm) in the MBDS.

Further studies to include medial lateral motion (up to 6mm) will be conducted in future. The sensitivity analysis show that the medial lateral motion and flexion extension angles are important parameters influencing the size of contact maps generated by the MBDS computational model. These studies will help be helpful to design right implant for right patients for developing countries like Vietnam, India and Mexico.

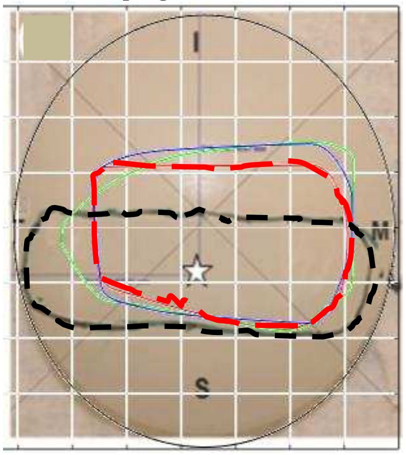

Fig. 1. Comparison of experimental damage map (in black short dash) and computational contact map (in red long dash). Sensitivity analysis of the contact maps with change in kinematics are presented in solid green and solid blue. The star represents the centroid of the damage map. S: Superior, I: Inferior, M: Medial and L: Lateral side of the patella component.

3.2 Experimental Tribological Studies in Microscopic Scale

The tribological interaction of a glass bead on a fibronectin layer generated a frictional graph as shown in Fig 2a. The coefficient of friction is constant at 0.2 for most of the interaction. After a certain point, there is a drop in coefficient friction. This is due to the accumulation of fibronectin between the contacts resulting in lubrication and decrease in the coefficient friction as shown in Figures 2b and 2c. Due to the presence of PBS and buffer solution, the scratch boundaries can be easily located at 40x scale.

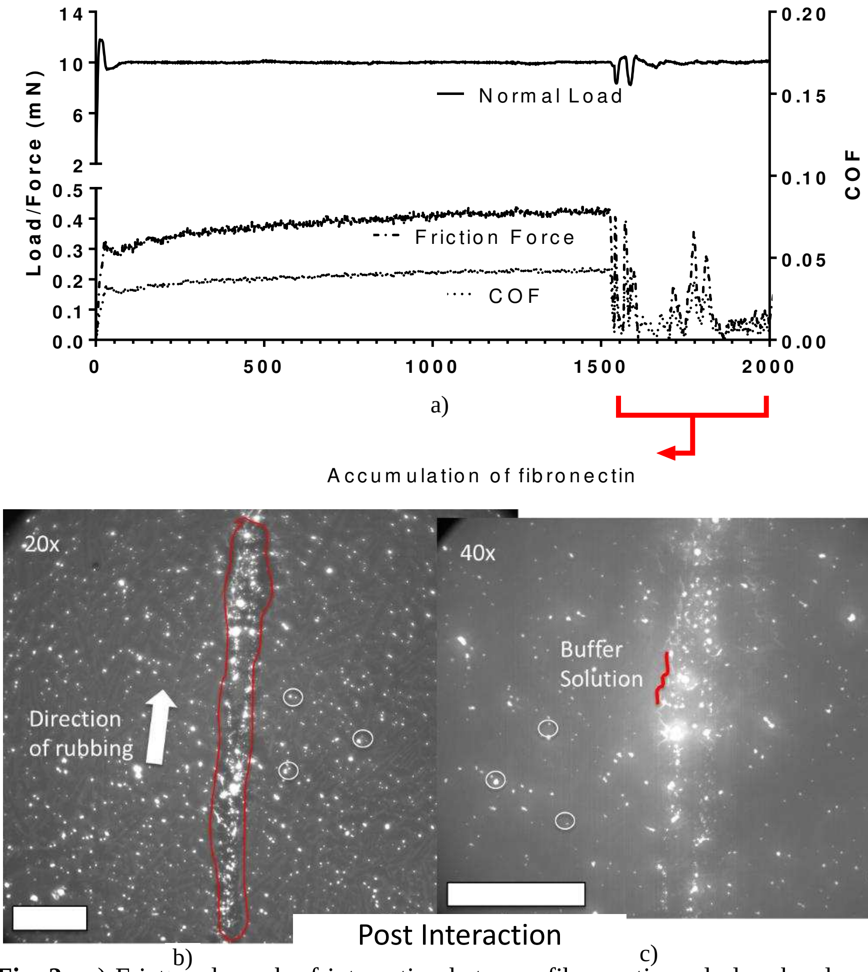

Fig. 2. a) Frictional graph of interaction between fibronectin and glass bead, microscopic image of fibronectin layer post interaction at b) 20x and c) 40x. The arrow represents the direction of sliding and red line represents the boundary of the scratch. The circle represents the fibronectin on the glass petri dish.

Frictional studies with hydrogel will be conducted in future to assess the effect of hydrogel on the tribological properties. The computational studies will be conducted and validated in parallel to understand the catheter tissue interaction. We predict the changes in catheter design in future based on the studies which will save a lot of money for developing countries in terms of number of days a patient takes to recover after the surgery in a hospital.

4 Conclusion

Experimental and computational methods are useful for understanding the interaction between two interacting surfaces in macro and micro scales. The paper describes two such studies: artificial patella femoral joint replacements and catheter tissue interactions. These studies will generate substantial knowledge to improve design and development of medical devices in future.

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References

1. Maiti, R., Fisher, J., Jennings, L.M.: The influence of kinematic conditions and design on the wear of patella-femoral replacements. Proc. Inst. Mech. Eng. H 228(2),175-81 (2014).
2. Maiti, R., Cowie, R.M., Fisher, J., Jennings, L.M.: The influence of malalignment and ageing following sterilisation by gamma irradiation in an inert atmosphere on the wear of ultra-high-molecular-weight polyethylene in patellofemoral replacements. Proc. Inst. Mech. Eng. H 1(7), 634-642 (2017).
3. Maiti, R.: Computational modelling of patella femoral kinematics during gait cycle and experimental validation. J. Inst. Eng. India Ser. C 99(3), 271–276 (2018).
4. Ellison, P., Fisher, J.: Assessment of the damage in retrieved patellar components. J. Long Term Eff. Med. Implants 20(1), 57-72 (2010).