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Predicting the friction of Metal-on-UHMWPE hip joint replacements

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This work produced a framework for the prediction of friction for a range of typical motion cycles which can be represented in a (2D) pendulum friction simulator. A transient non-Newtonian elastohydrodynamic lubrication (EHL) computational model was developed to analyze and predict the frictional properties of metal-on-metal and metal-on-polymer hip prosthesis. A range of clearances between the acetabular cup and femoral head were investigated. Different frequency values of the pendulum simulator were also considered. Film thickness and friction values were comparatively analyzed with the applied load and speed profiles. The results show that the maximum friction force occurs at the extreme positions of the swing phase. The cycle frequency of the swing also had a significant influence on the lubrication performance.

Keywords: Biotribology, hip replacement, friction simulation, pendulum simulator

1. Introduction

The wear of total hip replacements has been the focus of many clinical and pre-clinical studies, both experimental and in-silico. However, as orthopaedic technologies progress, there is a need to better understand and predict friction at these interfaces and its systemic effects at other interfaces[1]. Despite five decades of pre-clinical simulation of total hip replacements, a framework for the accurate prediction of friction when subjected to established pre-clinical testing methodologies does not exist. The current work produced a framework for predicting friction for a range of typical motion cycles, which can be represented in a (2D) pendulum friction simulator.

2. Methods

The transient non-Newtonian Reynolds equation used in this study is shown below:

$$\frac{\partial}{\partial x}\left(\frac{\rho h^3}{12\eta}\frac{\partial p}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{\rho h^3}{12\eta}\frac{\partial p}{\partial y}\right)=u_s\frac{\partial(\rho h)}{\partial x}+\frac{\partial(\rho h)}{\partial t} \quad (1)$$

Where the viscosity of lubricating fluid was based on an equation:

$$\eta=\eta_\infty+\frac{\eta_0-\eta_\infty}{1+\alpha\left(\dot{\gamma}\right)^\beta} \quad (2)$$

Where exercise the limiting shear rate values of viscosity adopted were η_0 = 40,000 mPas and η_∞ = 0.9 mPas. The friction force within the EHL domain was calculated by the summation of asperity friction and lubricant film friction. The asperity friction was calculated by:

$$F_c = f_c \times w_c \quad (3)$$

The lubricant film friction was calculated by:

$$F_h = \iint_{\Omega_h} \tau dxdy \quad (4)$$

Where:

$$\tau = \tau_L\left(1-e^{-\eta\dot{\gamma}/\tau_L}\right), \quad \tau_L = \tau_{L0}+\gamma_L p_h \quad (5)$$

Then, the total friction force and COF was calculated:

$$F = F_c + F_h \quad (6)$$

$$f = F/w \quad (7)$$

The mechanical properties and rough surfaces used in the simulation were numerically simulated with roughness parameters of the measured surfaces (Metal head: $S_q \sim 20$ nm & UHMWPE liner: $S_q \sim 860$ nm).

3. Results and Discussions

Figure 1 shows the transient load and speed profiles and the corresponding and transient average film thickness, contact ratio, and COF values for a Metal-on-UHMWPE (MoP) hip prosthesis. Highest predicted COF corresponds to the minimum average film thickness, where the contact ratio is also the largest. A good agreement with simulated and measured data was observed. Results from this study align with steady-state lubrication theories[2-3] and progress the current understanding by considering transient non-Newtonian rheology and topography dependent contact mechanics.

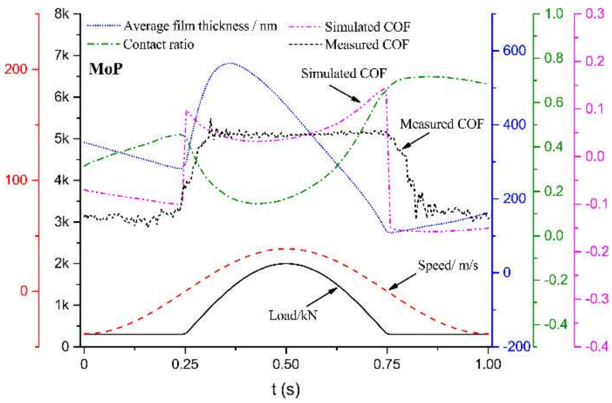

Figure 1: Film thickness, COF, and contact ratio of the MoP configuration.

4. References

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