Can a “pre-worn” bearing surface geometry reduce the wear of total hip replacements?

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INTRODUCTION

Total Hip Replacement (THR) is generally a highly successful treatment for joint diseases. However, the demanding wear rate and the implants’ lifetime is not completely satisfied (Figure 1). Wear continuous to be one of the major causes of THR’s failure, thus to minimise wear is one of the most critical strategies to improve the service time of joint replacements.

Typically a two-stage wear has been observed for majority of cases in both metal-on-metal joints as well as where one or both surfaces are ceramic or plastic (Figure 2); a higher initial wear rate in the beginning followed by a lower steady-state one with the surface profile changed. This alludes to the potential use of a cup with a non-spherical interior cavity with an initial geometry similar to a worn surface which may benefit from lower wear rate.

OBJECTIVES

In this paper wear of hip joints is numerically simulated with a cup having a non-spherical geometry inspired by that generated by the initial stage of wear. The transient walking cycles of human beings are investigated. The Elastohydrodynamic Lubrication (EHL) is accounted for in the wear model.

METHOD

A metal-on-metal (CoCrMo alloy) total hip replacement is studied with the diameter of 28 mm and diametrical clearance of 40 µm. A transient mixed EHL model is used to obtain the gap between the lubricated surfaces. The wear model is based on an adapted Archard wear formula in which the wear factor is a function of the gap[3, 4]. Firstly, wear of spherical joint profile is simulated until a steady-state wear is achieved. Then, the obtained worn profile on the cup surface is used to numerically obtain a general manufacturable “pre-worn” profile. The wear of the “pre-worn” joint is simulated and compared to the spherical joint.

The transient EHL problem is solved in spherical coordinates to allow three-dimensional loading and motions of the hip joint[5] (Figure 3). The wear factor was introduced as a function of the load and gap between the lubricated surfaces.

This wear is described by \( k_w \) (Load)\(^{n/3}\) and is used to increment the level of wear and corresponding film thickness on both the head and cup of the artificial joint. The surface profile was updated every 0.1 million cycles and the resulting wear was found to be independent of the wear update rate. The wear coefficient \( (k_w) \) of \( 1 \times 10^{-9} \text{mm}^3/(N \cdot m) \) was used. The power term \( n \) in the wear equation describes the abruptness of the onset of wear as the film thickness reduced below the surface roughness, a value of 2.24 was found to reasonably capture surface wear[3].

RESULTS AND DISCUSSION

- Wear of a spherical joint was simulated for 8 million gait cycles, based on which a non-spherical cup profile was numerically generated (Figure 4).
- The reduced wear rate is attributable to the change in the surface profile as a result of the surface wear, effectively increasing the gap between the bearing surfaces and distributing the pressure more evenly (Figure 5).
- The predicted total wear volume were compared between the spherical cup and the “pre-worn” cup (Figure 6). Approximately 25% reduction in the steady-state wear rate was observed in the non-spherical cup inspired by the worn surface.

CONCLUSIONS

- The resulting model is able to capture how experimentally obtained wear rates vary with time using a linear wear model (Archard law) and an EHL simulation of the lubrication in the joint.
- This study provides an evidence that the joint profile can be designed to eliminate the initially higher wear rates seen at the beginning of the cycles and reduce the total wear.

REFERENCES


ACKNOWLEDGMENTS

The research leading to these results has received funding from the European Union’s Seventh Framework Programme (FP7/2007-2013) under the LifeLongJoints Project, Grant Agreement no. GA-310477, and the Imperial College London Junior Research Fellowship (2015-2018).