Institute of Medical & Biological Engineering

Contact Mechanics of Modular Metal-on-Polyethylene THR: Finite element analysis and Experimental Testing

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Introduction

- Finite element (FE) models are becoming increasingly useful tools to conduct biomechanical analysis for total hip replacement (THR) [1].
- However, the accuracy of the FE predictions should be demonstrated by comparing with either clinical or experimental observations [2, 3].
- The aim of the present study were to develop an FE model for a modular THR and to demonstrate the verification of the model by comparing with the experimental test.

Materials and Methods

Specimens:

- Three specimens of polyethylene liner (DePuy Orthopaedics, Inc.) with three different inner surface radii were tested.
- The radii of the inner surface of the polyethylene liners were measured using Coordinate Measuring Machine (CMM, Legex 322, Mitutoyo, UK).

Experimental measurement

- A station of the Leeds Prosim hip joint simulator (Prosim Limited, UK) was used (Figure 1a).
- Five different loads from 500 N to 2500 N were applied for 2 minutes, which were then moved immediately.
- The contact areas were imaged and calculated using Image-Pro Plus (Media Cybernetics, Inc., MD, USA).

Materials and Methods

Finite element modelling:

- A three-dimensional anatomic modular THR model was created (Figure 1b), which was then simplified to a simple modular THR model (Figure 1c) for purpose of simplifying the experimental set-up.
- The elastic modulus and Poisson's ratio were assumed to be 1 GPa and 0.4 for polyethylene, 116 GPa and 0.25 for titanium, 0.8 GPa and 0.2 for cancellous bone, 17 GPa and 0.3 for cortical bone, 2.5 GPa and 0.254 for cement in both models.
- Contact was modelled on the bearing surface and at the liner/metal shell interface, with friction coefficients of 0.083 and 0.15 respectively.
- For the anatomic model, nodes at the sacro-iliac joint and about the pubic symphysis were fully constrained and the bone/implant interface was fully bonded.
- For the simple model, the nodes at the outside of the cement were fully constrained and the cement/metal shell interface was fully bonded.

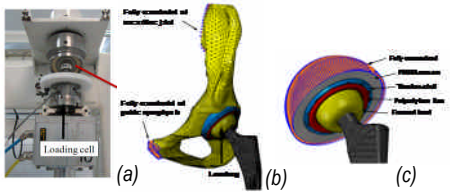

Figure 1: Experimental set-up (a); anatomic modular THR model (b); simplified modular THR model (c).

Results

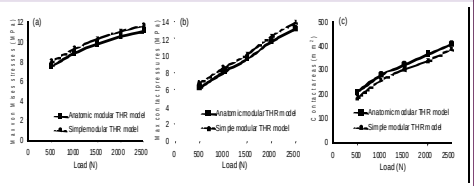

Figure 2: Comparison of parameters between the FE predictions from the anatomic model and simple model for specimen 1: (a) maximum von Mises stress of the liner, (b) maximum contact pressure and (c) contact areas on the articulating surface.

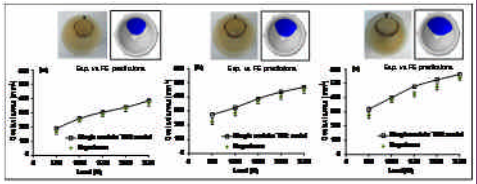

Figure 3: Comparison of the contact areas on the articulating surface between the experimental measurements and FE predictions from simple model: (a) specimen 1, (b) specimen 2, (c) specimen 3. The error bars represent 95% confidence limit.

- For all loading conditions considered, the anatomic model predicted lower maximum von Mises stress, lower maximum contact stress and larger contact areas compared to the simple model, with differences of within 6%, 8% and 12% respectively (Figure 2).

Results

- For the three liners with various radii, similar contact area patterns were observed between the experimental measurements and FE predictions from the simple model (Figure 3).
- The differences of contact areas between the experimental measurements and FE predictions from the simple model were within 2.6%, 7.2% and 12% for the three liners respectively under all loading conditions considered (Figure 3).

Discussion

- For purpose of validation and simplifying experimental process, the anatomic model was simplified to a simple model and such simplification was found not to affect the predictions of the contact mechanics of the modular MoP THR.
- Good agreement of the contact areas were observed between the experimental measurements and FE predictions from the simple model under the same conditions, indicating that the simple model and anatomic FE model was reliable and valid to predict the contact mechanics of modular MoP THR.
- The FE model developed in this study will be used to investigate the contact mechanics of modular MoP THR under different conditions, especially under adverse conditions in the future study.

References

[1] Elkins et al. J Orthop Res. 2012.
[2] Romero et al. J Orthop Surg. 2007.
[3] Plank et al. J Biomed Mater Res B Appl Biomater. 2007.

Acknowledgements

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