Institute of Medical & Biological Engineering

Edge Loading in Modular Metal-on-Polyethylene Total Hip Replacement during Daily Activities

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Background

- Edge loading is an adverse factor that can negatively affect the biomechanics and long-term performance of total hip replacement (THR).
- The occurrence of edge loading in THR has been associated with many factors such as prosthetic design, component malposition, impingement, dislocation, and activities of daily living [1-3].
- The aims of the present study were, firstly, to determine whether edge loading occurred, the duration of edge loading occurrence and specific instances over which edge loading occurred during different daily activities, and secondly, to investigate the effect of daily activities and edge loading on the contact mechanics of a modular metal-on-polyethylene (MoP) THR.

Materials and Methods

- A three-dimensional finite element (FE) model, consisting of a hemi-pelvic bone and a modular total hip system, was developed (Fig. 1).
- The total hip system was composed of metal shell, polyethylene liner and metallic femoral head, with diameters of 36.6 mm and 36 mm for the polyethylene liner and femoral head respectively.
- All the materials in the model were modelled as homogeneous, isotropic and linear elastic except the polyethylene liner which was modelled as non-linear elastic-plastic. The elastic modulus and Poisson's ratio were assumed to be 1 GPa and 0.4 for polyethylene, 116 GPa and 0.25 for metal shell, 0.8 GPa and 0.2 for cancellous bone, 17 GPa and 0.3 for cortical bone.
- Contact was modelled on the bearing surface and at the liner/metal shell interface, with friction coefficients of 0.083 and 0.15 respectively [4].
- Nodes at the sacro-iliac joint and about the pubic symphysis were fully constrained and the bone-implant interface was assumed to be fully bonded.
- The physiological loadings of six different activities including normal walking (NW), ascending stairs (AS), descending stairs (DS), standing up (SU), sitting down (SD) and knee bending (KB) were applied to the FE model.
- A total of 20 orientations of cup angles were considered, with inclination angle varying between 35º and 75º and anteversion varying between 0º and 30º.

Results

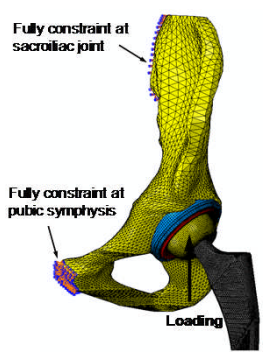

Fig. 1 The FE model of the modeular THR. The loading was applied to the center of the femoral head.

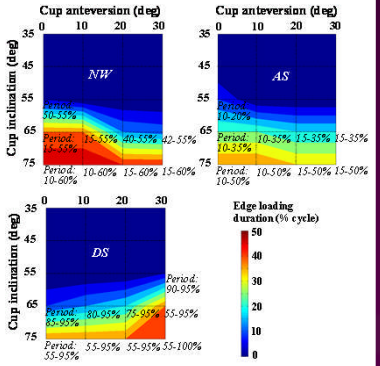

Fig. 2 The duration of edge loading and specific instances at which edge loading occurred for different activities.

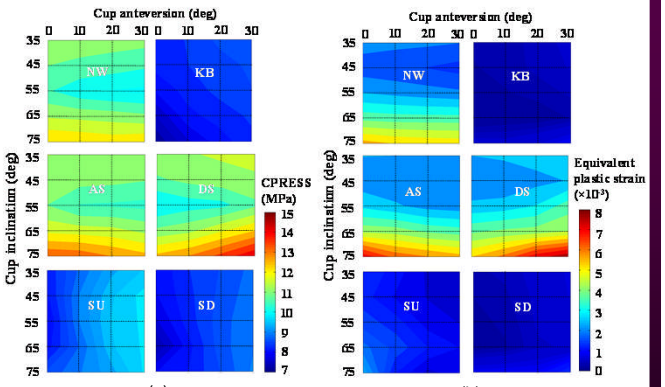

Fig. 3 The peak contact pressure (MPa) at the articulating surface (a) and peak equivalent plastic strain in the polyethylene liner (b) during different activities.

Results

- Edge loading was predicted at some instances of cycle during normal walking, ascending and descending stairs activities under steep cup inclination angle conditions (≥ 55°).
- No edge loading was predicted for standing up, sitting down and knee bending cases for all cup angles considered.
- For NW and AS cases, the combination of steep cup inclination and low anteversion was more inclined to cause edge loading. In contrast, for DS activity, the combination of steep cup inclination and high anteversion tended to induce edge loading (Fig. 2).
- Edge loading caused elevated peak contact pressure at the articulating surface and substantial increase of peak equivalent plastic strain of the polyethylene liner (Fig. 3).

Discussion

- The present study showed that an individual's activity patterns played an important role on the occurrence of edge loading in MoP THR.
- The FE simulations suggested that edge loading would occur during some of the functional daily activities such as normal walking, ascending and descending stairs under steep cup inclination conditions.
- Edge loading induced by these daily activities and steep cup inclination can result in elevated contact pressures at the articulating surface and particularly substantial increase of equivalent plastic strain in the component for the modular MoP THR.
- Therefore, it is suggested that clinically it is important to optimize the orientation of the components in hip joint replacements to avoid edge loading that may occur during activities of daily living.

References

[1] Wang L et al. Proc Inst Mech Eng H. 2012.

[2] Hua X et al. J Biomech. 2014.

[3] Brown TD et al. Iowa Orthop J. 2014.

[4] Amirouche F. J Biomech Eng 2008.

Acknowledgements

The authors thank to the Wellcome Trust and EPSRC (Grant no: WT088908/Z/09/Z) and the EPSRC Centre for Innovative Manufacturing in Medical Devices.