Institute of Medical & Biological Engineering

The Influence Of Cartilage Disorganisation on the Contact Mechanics of a Biphasic Finite Element Hip Model

UNIVERSITY OF LEEDS

Junyan Li [1], Alison Jones [2], Sophie Williams [2], Zhongmin Jin [2,3], John Fisher [2], Ruth K. Wilcox [2]

[1] School of Science and Technology, Middlesex University, UK. [2] Institute of Medical and Biological Engineering, School of Mechanical Engineering, University of Leeds, UK

[3] School of Mechanical Engineering, Xi'an Jiaotong University, China

ljyjerry@gmail.com

INTRODUCTION

- Function and degeneration of articular joints closely linked to biphasic fibre-reinforced cartilage.
- Different fibre organisation through thickness of cartilage & specific fibre orientation across surface of cartilage [1].
- Disorganised fibre patterns in osteoarthritis (OA) affected cartilage.
- Effect of disorganised fibre pattern on biomechanical function of hip joint is unknown.
- Finite element (FE) models of articular joints with biphasic cartilage-on-cartilage contact under prolonged physiological loads are difficult to solve [2].
- Contact mechanics of hip is greatly subject to joint geometry [3].
- Biphasic properties have yet to be incorporated into 3D whole hip models with subject-specific geometry under physiological loading.

AIMS

- To develop a FE model of the hip with subject-specific geometry incorporating biphasic fibre-reinforced cartilage properties.
- To investigate the influence of fibre disorganisation at different stages of OA on the contact mechanics of the model.

METHODS

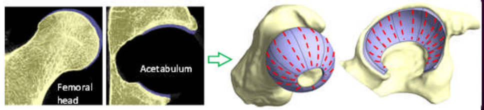
- FE model of a cadaveric hip with subject-specific geometry and biphasic fibre-reinforced cartilage properties was constructed using a validated modelling process [4] (Fig 1).
- Three models (randomly oriented fibre replicated by incorporating fibre material along three orthogonally directions):

  Model 1 – healthy joint (surface zone with natural fibre orientation [5]; middle zone with randomly orientated fibre; deep zone fibre perpendicular to subchondral bone)

  Model 2 – early stage OA (surface and middle zones with randomly orientated fibre; deep zone fibre perpendicular to subchondral bone)

  Model 3 – late-stage OA (randomly orientaed fibre)
- Material properties from literature [6, 7] – aggregate modulus = 1.2 Mpa; Poisson's ratio = 0.045; permeability = 0.0009 mm^4/Ns; fibre (space-orthogonally reinforced) modulus = 12 MPa. Same fibre density for all zones of cartilage and all models.
- Loading [8]: heel-strike (2820N), mid-stance (1773 N) and toe-off (2126N) during walking; one leg stance (2600 N) over 600 s.
- Contact-dependent fluid flow considered and FE models simulated in FEBio (v 2.0).

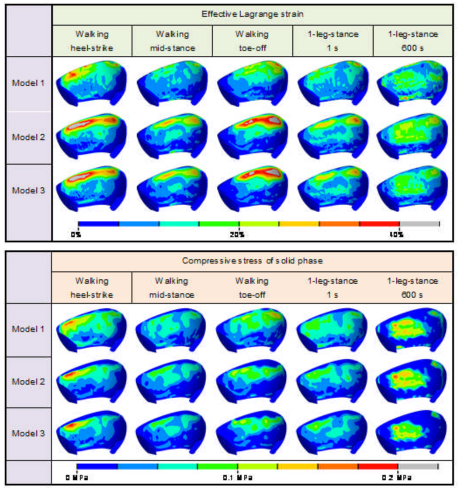
Figure 1: FE model of healthy hip with specific fibre orientation on surface of cartilage [5].



RESULTS

- Magnitude and distribution of fluid pressure and contact stress and compressive stress of the solid matrix were similar for three models.
- Compressive stress of solid phase was much lower (max = 0.22 MPa), than contact stress (max = 6.5 MPa) (Fig 2).
- Models with disorganised fibre pattern had markedly higher strain than healthy model, particularly when contact occurs around edge region of the acetabular cartilage (e.g. 40% - 50% higher strains at heel-strike and toe-off).
- Model 2 and 3 had similar results.

Figure 2: Contour of effective Lagrange strain and compressive stress of the solid matrix of acetabular cartilage.



Discussion

- Very low compressive stress of the solid phase demonstrates excellent function of hip joint.
- Higher strains in the model with disorganised fibre pattern than healthy model demonstrated
  (1) excellent biomechanical function of healthy hip that is contributed by specific fibre pattern;
  (2) adverse biomechanical situation in hip with disorganised fibre that may lead to further degeneration.
- Peak contact stress and strain of healthy model is 3.5 MPa - 6.5 MPa and 20% - 60% respectively, which are consistent with previous experimental measurements [9, 10].
- Limitations of this study include material properties adopted from literature and omission of solid phase viscoelasticity, but these are appropriate for parametric purpose of this study.

Significance

- This is the first study to
  (1) develop a specimen-specific biphasic full hip model under physiological loading
  (2) evaluate influence of disorganised fibre pattern, which is commonly seen in OA affected joints, on hip biomechanics.
- This study provides important information for function, degeneration and potential interventions of hip joint.

References: *[1] Buckwalter et al., J Am Acad Orthop Surg, 2:192-201, 1994. [2] Li et al., J Biomech, 46: 1641-1647, 2013. [3] Anderson et al., J Biomech. 43:1351-1357, 2010. [4] Li et al., Proc Inst Mech Eng H, 228: 547-555. [5] Mital and Millington, Micron, 2: 236-249, 1970. [6] Soltz, M. A, and Ateshian, G. A J Biomech Eng, 122: 576-86, 2000. [7] Athanasiou et al., J Orthop Res, 12: 340-349, 1994. [8] Bergmann, G., et al., J Biomech, 2001. 34(7): p. 859-871. [9] Brown T.D. and Shaw D.T. J Biomech. 1983;16:373–384. [10] Halonen, K.S., et al., J Biomech, 2014. 47(10): p. 2467-2474*

Acknowledgement: *The research was supported by the EPSRC, the Centre of Excellence in Medical Engineering funded by the Wellcome Trust and EPSRC WT 088908/z/09/z and by the NIHR LMBRU Leeds Musculoskeletal Biomedical Research Unit. JF is an NIHR senior investigator.*