Institute of Medical and Biological Engineering

Stress analysis of the proximal femur used in the assessment of AVN

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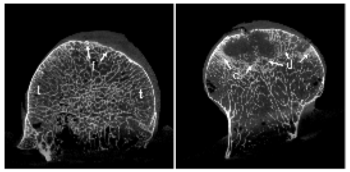
Introduction

Avascular necrosis (AVN)

- AVN is a bone disease that most commonly affects the hip.
- Young patients, average age 38 (30-50) [1]
- Prevalent among the Asian population
- Most common risk factors for non-traumatic AVN are corticosteroid therapy, alcohol abuse.

Progression of the disease

- Interruption of the blood supply (ischemia) prevents normal bone turnover that normal fatigue lesions cannot be healed anymore.
- Poorly connected trabeculae and the decalcification of bone tissue leads to a reduction of the Young's modulus of 72% [2]



CT-scan of femoral head (a) Collapsed subchondral bone. (b) Thinned trabecular regions. (c) Dense trabecular regions around necrotic tissue. [3]

Rational

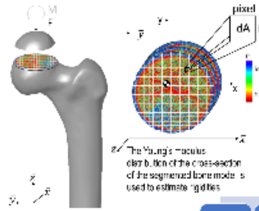
To prevent fractures and to reduce associated morbidity an early diagnosis is desirable

- No sufficient diagnostic method currently available
- Allows a broader spectrum of different therapies including joint preserving procedures.
- Better for young patients because joint preserving treatments might be more durable.

Aim

- Development of a non-invasive fracture prediction tool which can be used in the clinical practice.

Methodology Fracture Prediction



Biomechanical model

- Loading was simplified and merged to a single static joint contact force (10° adduct. for stance).

Material Model

- Material properties were retrieved from non-invasive QCT-scans using a material model.
- Power law: HU~E

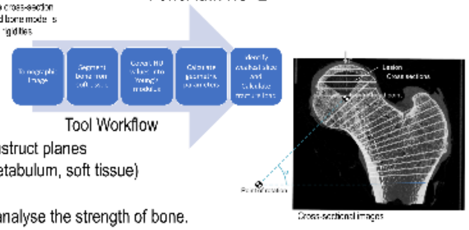


Image Processing

- Load image data and reconstruct planes
- Segment femoral bone (acetabulum, soft tissue)

Tool Workflow

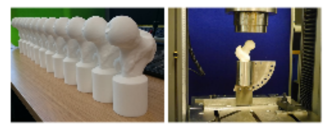
Structural mechanics

- Beam theory was used to analyse the strength of bone.
- A straight beam follows the loading vector from the bone surface to the centre of the femoral head. A curved beam runs from the centre of the femoral head to the shaft.
- The yield force, at which the bone is likely to fracture, is calculated for each cross-section perpendicular to the beam.

Stress distribution at a cross section in the femoral neck. Stress inside the bone is calculated in three dimensions.

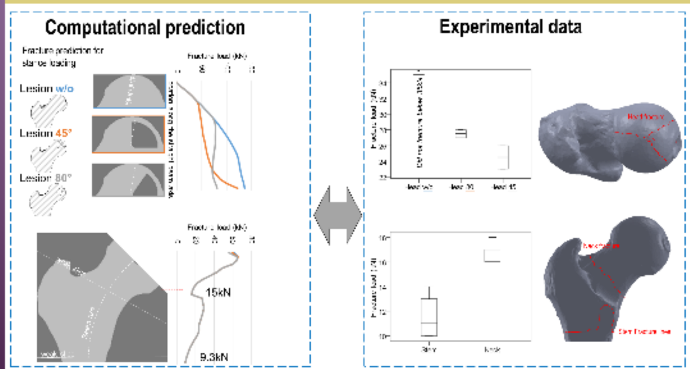
Verification of the fracture prediction method

- The results from the computational fracture prediction were verified against in-vitro tests on 3D-printed femurs (n=12).
- Three different lesion types were simulated with cone-shaped voids placed at different positions and angles, namely 45° and 80°.



3D-printed proximal femur mounted in an holder for compression testing

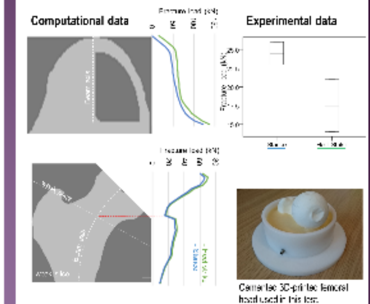
Results



Results: Heel Strike Loading

Loading condition: Heel strike

- Tested on a 3D-printed femur with a lesion angled at 45°. Heel strike is at 20° flexion.



Discussion

- The computational tool is capable of predicting sites of increased fracture risk within the analysed bone.
- Lesion position and loading of the bone play an important role in analysing the fracture risk.
- Predicting an accurate fracture load is difficult and dependant on the material model used, however, the loads correlate with expected values.
- The higher predicted load for heel strike was not reflected within the experimental results. The loading vector is parallel to the surface of the void which can induce an unfavourable shear stress causing the lower fracture load.

Beam theory necessitates simplifications

- Stress was assumed to be uniformly distributed over the cross section in accordance to the Saint-Venant's principle.
- Centroid was identical to the neutral axis.

Limitations of 3D-printed bone models

- 3D-printed material is different to natural tissue though it has better repeatability.
- Complex geometry (Shape of femur and hole in surface)

Outlook

- Further tests on 3D-printed femur models as well as a Validation against in-vitro tests on porcine femurs are necessary and should confirm these initial findings and results.

References

[1] Mont & Hungerford, 1995, The Journal of Bone & Joint Surgery

[2] Brown et al., 1981, Clinical Orthopaedics and Related Research

[3] Mahsa Avadi, 2015

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