Density-Adapted Tetrahedral Mesh for the Human Proximal Femur

Background Osteoporosis (OP) is a silent metabolic bone disease reducing bone mass and leading to increased rates of bone fractures. OP is a major challenge for quality of life and health care of our ageing populations. Homogenised finite element (FE) models of the proximal femur based on quantitative computer tomography (QCT) were shown to better predict *ex vivo* strength of the hip than densitometric measures such as dual energy x-ray absorptiometry (DXA) [1]. Recent clinical studies suggest that QCT-based FE analysis offers an equivalent or better hip fracture risk prediction than DXA. The QCT-based FE method currently approved by the food and drug administration of the United States of America (FDA) is based on voxel meshes of mm size that neglects the subtle mechanics of the cortical shell [2]. Moreover, homogenisation of material properties is based on local bone mineral density distribution and delivers a poor approximation in the presence of important gradients within a voxel.

Aim The objective of this master thesis is to develop an automated procedure to produce a smooth, density-adapted mesh of the human proximal femur based on high resolution CT images. The outcome of the procedure will be controlled with the FE analysis of a former set of HR-pQCT scans and experimental results in stance and fall loading configurations. Robustness of the procedure will also be verified with scans of different resolutions.

Materials and Methods An existing dataset consisting of 36 pairs of HR-pQCT scans of the proximal femur and the corresponding mechanical tests in stance and fall conditions will be exploited [3]. After masking, filtering the images and creating a fine, smooth surface mesh of the proximal femur, different open-source meshing tools (Gmsh, CGAL) will be investigated to account properly for the bone mineral density distribution. A finer mesh (< 1mm) is aimed in regions of high bone mineral density gradients, while a coarser mesh (<5mm) is aimed in homogeneous regions. A script to generate the embedding pads will then be written to produce FE models with quadratic elements, the in-house non-linear/non-softening material model for bone tissue and the boundary conditions of the two loading conditions. The resulting models will be run on the available dataset for comparison with the experimental data. Eventually, a test of the developed methodology will be conducted with scans of the proximal femur of lower and higher resolution.

Nature of the Thesis:
Literature review: 10%
Implementation / programming: 60%
Analysis: 30%

Requirements:
Competence in Python
Knowledge in image processing
Knowledge in FE analysis

Supervisors:
Gabriela Gerber
Yvan Gugler
Philippe Zysset

Institutes:
ARTORG Center for Biomedical Engineering Research, Bern, Switzerland

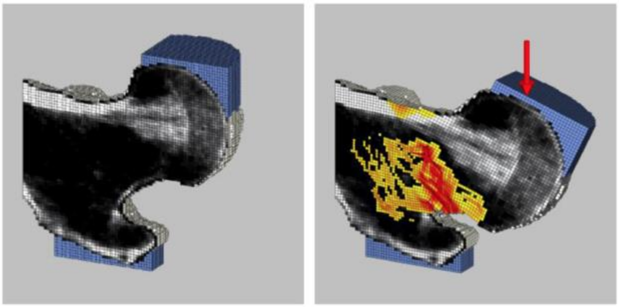

Fig. Finite element model of the human proximal femur loaded in a sideway fall configuration. The mesh consists of cubic voxels and integrates embedding pads in PMMA to avoid local stress concentrations. The colors designate the failed bone tissue for instance in tension for the medial cortex [2].

References:
[1] Bouxsein et al., "Perspectives on the non-invasive evaluation of femoral strength in the assessment of hip fracture risk", Osteoporos Int 31:393-408, 2020.
[2] Keaveny et al., "Biomechanical Computed Tomography analysis (BCT) for clinical assessment of osteoporosis", Osteoporos Int 31:1025-1048, 2020.
[3] Dall'Ara Enrico et al., "A non-linear QCT-based finite element model validation study for the human femur tested in two configurations in vitro", Bone 52(1):27-38, 2013.

Contact:
Prof. Philippe Zysset, philippe.zysset@unibe.ch, Freiburgstrasse 3, 3010 Bern.