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# A CRUSHABLE FOAM MATERIAL MODEL FOR STRENGTH PREDICTIONS OF HUMAN BONES

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## Introduction

Finite element (FE) models allow quantitative predictions of bone strength and fracture location and, thus, became increasingly popular for assessing fracture risk or effectiveness of osteoporosis therapies. However, the predictions crucially depend on the used material models, which are usually complex and rely on a large number of parameters. The goal of this study was twofold as indicated in Figure 1. First, a simple crushable foam (CF) plasticity model was proposed and material parameters were identified. Second, the accuracy of predicted strength and fracture patterns was assessed for a large number of human vertebral bodies and femora subject to two loading scenarios. To achieve this, a comparison was performed with existing experimental data and a highly sophisticated reference material model which is currently one of the best existing in literature.

## Methods

Material parameters of the CF plasticity model were identified based on previously published yield stress data of non-linear micro-FE models analyzed under twenty different loading conditions [1]. In order to assess the accuracy of the CF model predictions, voxel-based FE models of thirty-six femora pairs [2] and thirty-eight vertebral bodies [3] were generated from QCT images. The femora models were analyzed with boundary conditions simulating one-legged stance and side-fall on the greater trochanter. The vertebral body models were subjected to uniaxial compression. Load-displacement curves, ultimate forces and damage distributions obtained with the CF model were compared to the reference material model and to in vitro experiments.

## Results

The result showed that the FE models with CF material provided good quantitative predictions of experimentally measured strength (R2>0.79, SSE<0.860 kN). In case of the vertebral bodies (R2=0.79, SSE=0.57 MPa) and the femora in side-fall configuration (R2=0.85, SSE=0.440 kN), 1:1 predictions of experimental strength were achieved. Fracture locations observed in vitro were reproduced well for the femora in both loading scenarios. Comparison of the FE results obtained with the CF and the reference material model showed very similar outcomes regarding ultimate force, load-displacement behavior and damage patterns for all investigated anatomical sites and loading conditions.

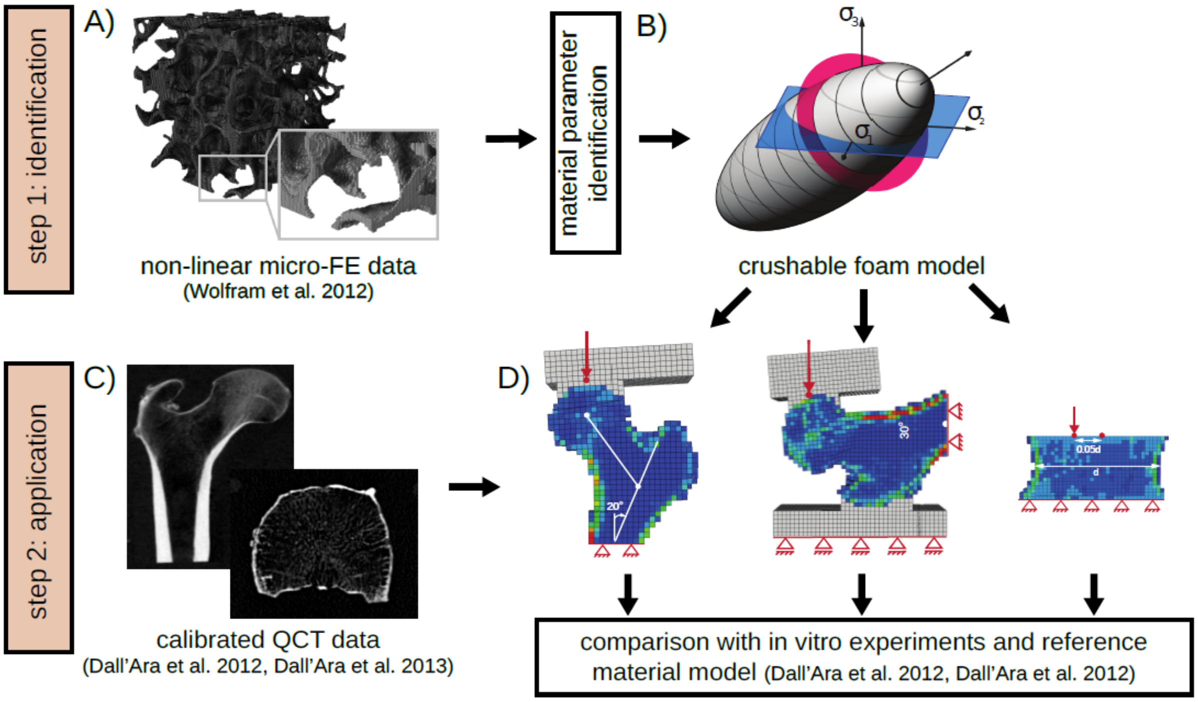

Figure 1: *Overview of the study: based on yield stress data obtained from non-linear micro-FE models (A), the material parameters of the crushable foam material model (B) were identified. Homogenized, voxel-based finite element models of the femur in standing and falling configuration as well as of the vertebral body were generated from QCT images (C). The models were analyzed using the crushable foam plasticity models and the results were compared to in-vitro experiments as well as to a reference material model (D).*

## Discussion

In conclusion, the CF plasticity model provided good strength and damage predictions, especially for the femora in simulated side-fall and for the vertebral bodies, which were surprisingly close to the results of the reference model. The CF model requires only three material parameters, two dimensionless shape parameters and the compressive yield strength as function of bone density, which enables easy scaling for different strength-density-relations. Moreover, it is already implemented in many commercial FE solvers. This makes the CF model a promising and easily applicable tool for non-invasive, quantitative assessment of hip and spine fracture risk in future studies.

## REFERENCES

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