Three-point bending test of cortical bone - experiment and numerical simulation

Grzegorz Kokot\textsuperscript{1}, Marcin Binkowski\textsuperscript{2}, Antoni John\textsuperscript{1}, Tomasz Konopka\textsuperscript{1}

\textsuperscript{1}Department of Strength of Materials and Computational Mechanics, Silesian University of Technology
ul. Konarskiego 18A 44-100 Gliwice, Poland
e-mail: grzegorz.kokot@polsl.pl
antonii.john@polsl.pl

\textsuperscript{2}Department of Biomedical Computer Systems, Institute of Computer Science, University of Silesia,
ul. Będzisza 39, 41-200 Sochaczew, Poland
e-mail: marcin.binkowski@us.edu.pl

\textsuperscript{3}Medical College, Jagiellonian University,
ul. Grzegorzecka 16, 31-531 Kraków, Poland
e-mail: konopka@wp.pl

Abstract

The paper presents the results of research on obtaining the bone mechanical properties using the 3-point bending test and computational simulation. The FE numerical model is build on the base of scans from X-ray microcomputed tomography (XMT) using the specialized software. The density phantom was scanned together with the specimen to enable quantitative measurement of the bone mineral density. The non-homogeneous material properties were assumed. Simulation were performed using the MSC.Nastran solver. The experimental material parameters are gathered on the base of scans from X-ray microcomputed tomography (XMT) scanner (Nikon Metrology, XMT-22, Tring, UK). Scanning settings (kV, mA, no filter, 2000 projections, voxel size 20 µm) were adjusted using the manufacturer software. The density phantom was scanned together with the specimen to enable quantitative measurement of the bone mineral density. After image acquisition reconstruction of cross-sectional axial images were performed. The total volume of interest contains 2000x2000x2000 voxels from about 356,000 voxels were busy with the bone friction. The reconstructed volume was stored in the single file (32-bits real, little endian) on the computer hard drive. Known density of the phantom was linked to the grey values of the phantom imaged on the reconstructed slices. It enables estimation of the calibration curve, which was then applied to calculate calibrated bone density and then material parameters in the FE model.

2. Materials and methods

2.1. Sample preparation

The studies have been performed using human femora dissected from cadaver body from female donor 30 years old. The 8 specimens were dissected from femora diaphysis. The 4x4x40 mm cube shape size of each sample was mechanically machined. Each sample where measure by digital slide caliper (Mitutoyo, resolution 0.01 mm) to control the accuracy of the machining.
2.4. Numerical simulation

The FE model with material parameters was generated automatically, based on approach described by [4] and own developed software [5]. For each voxel contained bone one element (HEXA 8-noded) was defined. Based on calibrated grey value material parameters (Young modulus $E$, ultimate strength $S$) have been defined. Relationship which connects calibrated bone density with material properties were defined based on following equations:

$$E = 10.5 + 0.0102 \rho_{\text{QCT}};$$  \hspace{1cm} (1)
$$S = 63.8 + 0.184 \rho_{\text{QCT}}$$  \hspace{1cm} (2)

-where $\rho_{\text{QCT}}$ – density calibrated based on greyscale and calibration curve.

This gives the model with non-homogenous material parameters what is closer to the reality then taking into account the model with one material with linear properties. The FE model was built using the HEXA 8-noded elements and consist of about 3 mln DOF. Specimen with material parameters is presented on Fig 2.

Boundary condition were taken from the experiment and modelled in the MSC.Patran (Fig. 3). Simulation were performed using the MSC.Nastran solver.

3. Results

Performing the mechanical tests the obtained result (the one specimen) is Young modulus $E = 22200$ MPa and ultimate tensile strength $S = 319$ MPa with max. deflection $y = 0.69$ mm. The finite element analysis gives the results presented on Fig 4. The max. normal stress is $\sigma_x \geq 314$ MPa and deflection $y = 0.73$ mm. It means that stresses and deflection are comparable with results obtained from experiments.

4. Discussion and conclusions

The results from simulation matched the results from the experiment. The numerical calculations using finite element method give the deflection and stresses comparable with experimental results. It shows that the numerical analysis of models generated on the base of X-ray microcomputed tomography (XMT) scans with material parameters described based on Hounsfield scale can be used as the tool for determining the mechanical properties of bone. The computational methods primary used in mechanics are useful for solving the biomechanics problems too.

References


