The Limits of Homogenized finite elements analysis

Mathieu Simon (1), Michael Indermaur (1), Denis Schenk (1),   
Benjamin Voumard (1), Philippe Zysset (1)

1. ARTORG Centre for Biomedical Engineering Research, University of Bern, Bern, Switzerland

# Introduction

Osteoporosis is the most common metabolic bone disease in humans. This silent disease is characterized by low bone mass and deteriorated microarchitecture [1]. In 2006, osteoporosis was estimated to cause approximately 8.9 million fractures worldwide, i.e. an osteoporotic fracture occurring every 3 seconds [2]. These fractures lead to pain, increase morbidity and costs [3]. Among the possible methods used in fracture risk assessment, high-resolution peripheral quantitative computed tomography (HR-pQCT) together with homogenized finite element (hFE) analysis allows good prediction of bone strength and stiffness at peripheral locations such as the radius and tibia [4]. Despite the capacity of hFE to predict structural properties, it remains unclear if the homogenization scheme is able to catch high-strain localizations i.e. fracture lines. Therefore, the objective of this study is to investigate the compressive behaviour of the distal tibia and to assess hFE predictions with experimental tests by both qualitative and quantitative comparisons.

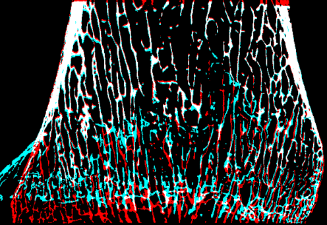
# Methods

25 fresh frozen cadaveric human tibiae were used in this study. The full bone was QCT scanned and the standard clinical distal section was scanned using HR-pQCT. Then, samples were cut out as close as possible to the HR-pQCT section, lapped, and scanned in a μCT with a 24.5 μm voxel size. Samples were tested in compression up to failure and scanned again in μCT. Scans were then downscaled to 72.5 μm voxel size, similar to HR-pQCT resolution. hFE was performed in order to reproduce the compressive experiment as closely as possible. On the other hand, registration between post- and pre-experiment scans was performed in two steps: 1) rigid registration, and 2) b-spline registration. The deformation gradient (F) was extracted in both hFE and registration. Then, spherical compression and isovolumic deformation were obtained using unimodular decomposition of F, see Equation (1). Finally, a qualitative assessment was performed by looking at the mid-slice of rigid and b-spline registration, F resulting from the registration and the hFE simulation. Quantitative assessment was performed using linear regression between hFE and registration.

(1)

# Results

Structural parameters showed good agreement between the experiment and hFE both for stiffness (R2=0.89, Slope=0.96 with 95% CI [0.82, 1.11]) and ultimate force (R2=0.97, Slope=1.04 [0.95, 1.12]). The qualitative assessment allowed the classification of the samples into categories. The quantitative assessment allowed assessing in which case hFE and registration are better in agreement and when hFE is not able to catch local deformation.

 Une image contenant objet d’extérieur, toile

Description générée automatiquement

(a) (b)

Une image contenant texte, jupe, tissu

Description générée automatiquement Une image contenant texte, jupe

Description générée automatiquement

(c) (d)

Figure 1: Example of sample presenting semi-agreement between registration and hFE. (a) Rigid registration with red: initial sample, cyan: failed sample, and white: superimposition of both. (b) b-spline registration with the same color code. (c) spherical compression resulting from registration. (d) spherical compression resulting from hFE.

# Discussion

The good correlations between hFE and experiment for structural parameters are similar to other studies [4]. This means that the current hFE scheme is able to catch the main response of the system. However, due to hFE assumptions, the simulation result highly depends on bone volume fraction and is not able to catch small discontinuities in the cortex or the trabecular bone which could lead to strain localization.

# References

1. Sözen et al, European Journal of Rheumatology, 4:46-56, 2017.
2. Johnell et al, Osteoporos Int, 17:1726–1733, 2006
3. Johnston et al, Medical Clinics of North America, 104:873–884, 2020
4. Schenk et al, Journal of the Mechanical Behavior of Biomedical Materials, 131, 2022

# Acknowledgements

We thank Prof. M. Pretterklieber for providing the 25 tibiae and Dr. P. Varga and his team for contributing to the biomechanical tests performed at the AO foundation in Davos.

This work was internally funded by the ARTORG Center.