Limitations of Homogenized finite elements analysis OF distal tibia sections

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# Introduction

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 distal radius and tibia [1]. Despite the capacity of hFE to predict structural properties, it remains unclear if the homogenization scheme is able to capture high-strain localizations i.e. actual fracture surfaces [2]. Therefore, the objective of this study is to investigate the compressive post-yield behavior of the distal tibia and to compare hFE predictions with experimental tests by both qualitative and quantitative means.

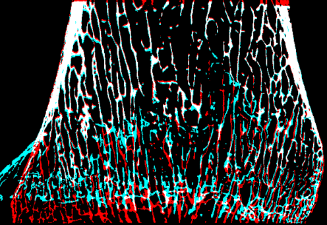
# Methods

Twenty-five fresh frozen cadaveric human tibiae were used in this study. The standard clinical distal section was scanned by HR-pQCT (XCT II, Scanco Medical, Switzerland). 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, volumetric (det**F**) and the norm of isovolumic deformation (||||) were obtained using the unimodular decomposition of F (equ. 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 registration assessment was performed using Dice coefficient.

(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 quantitative assessment showed an increase of mean Dice coefficient from 0.57 (rigid registration) to 0.62 (b-spline registration). The qualitative assessment allowed the classification of the samples into 3 categories: bad agreement (14 samples), semi (6), and good (5).

 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) detF resulting from registration. (d) detF resulting from hFE.

# Discussion

The good correlations between hFE and experiment for structural parameters are similar to other studies [1] but qualitative assessment presents low agreement rate between hFE and registration. This means that the current hFE scheme is able to catch the main response of the system. However, due to hFE assumptions and experimental boundary conditions, the simulation is not able to catch small discontinuities, which could trigger local buckling and strain localization.

# References

1. Schenk et al, Journal of the Mechanical Behavior of Biomedical Materials, 131, 2022
2. Varga et al, Journal of Biomechanics, 42, 2009

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