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In Application

The Application of Digital Volume Correlation (DVC) to Study The Microstructural Behaviour of Trabecular Bone during Compression

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Introduction

The mechanical properties of bone have been extensively studied for clinical applications. However, measuring and computing full-field strain measurements at a microstructural level are challenging. Traditional experimental techniques include strain gauging, digital image correlation (DIC), shearography, and thermal stress analysis but these are restricted to the surface of specimens. In order to predict internal strains, finite element (FE) models are commonly used, and whilst FE is improving, the complexity of the subject means that it is necessary for these predictions to be validated against experimental data.

LaVision's DVC system is a comprehensive tool which can provide that validation by capturing a full volume analysis of the specimen. DVC exploits the bone's internal structure to track the displacements. A novel aspect of this particular investigation is the coupling of DVC with the virtual fields method (VFM) to demonstrate the possibility of identifying Poisson's ratio of trabecular bone.

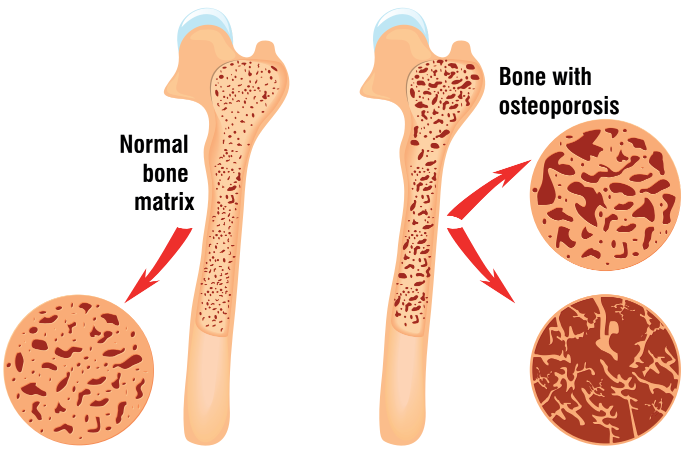

Figure 1: *Illustration of the difference in internal bone material structure - the natural structure is the pattern used in the DVC calculation process*

For further details refer to Gillard et al. (2014) Journal of the Mechanical Behaviour of Biomedical Materials 29, 480-499.

Experimental Setup

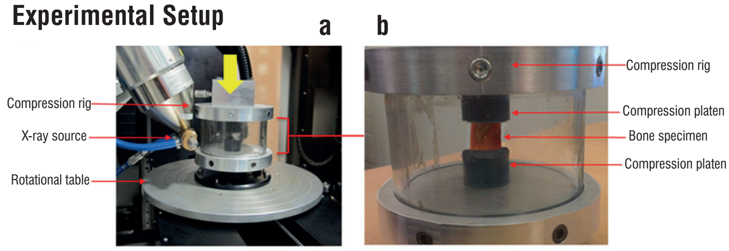

Figure 2: *Complete experimental test setup with a) yellow arrow showing compression direction, b) close up of bone specimen placed between compression platens prior to compression*

In this investigation a cubic specimen of ~ 20 mm^3 trabecular bone taken from the femoral head of a porcine femur. A customized Nikon/ Metris HMX ST microCT scanner at the University of Southampton was used to image the specimen. The imaging resolution was 24.6 µm per voxel and DVC calculations were performed with 64 % sub-volume size with 50% overlap and 2 passes. Strain resolution was calculated through a series of noise studies by comparing images of the static specimen, and one having undergone a rigid body shift. Subsequently the specimen was axially compressed in six steps under displacement control and microtomography measurements were taken at each stage.

Results

For both the stationary and rigid body correction evaluations it was found that a 64 voxel sub-volume was an adequate compromise between strain resolution and spatial resolution.

For this setting, the strain resolution for the rigid body translation was 7×10^{-4} strain. During compression a crushed layer formed adjacent to the boundary plate which increased in thickness as the specimen was further deformed. The structure of the crushed layer was altered to such an extent that it confounded the correlation method. It was found that for reliable strain calculations a correlation coefficient of 0.90 or above was required. Good agreements between the results and published bone strain failures were obtained. Poisson's ratio was identified for each compression step using the virtual fields method (VFM).

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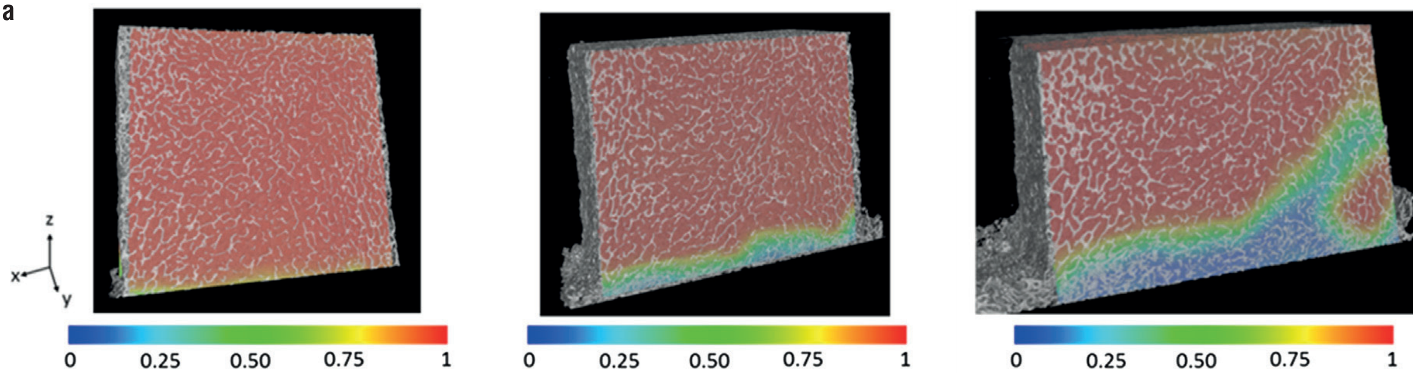

Figure 3a: Correlation coefficient maps for 1st, 3rd and 6th compression step

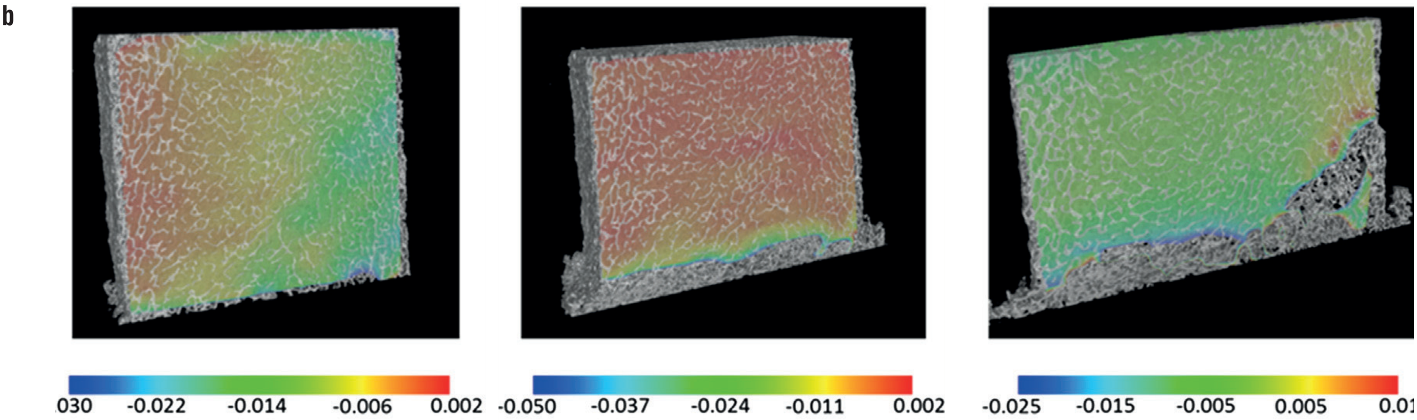

Figure 3b: E_{zz} strain map for 1st, 3rd and 6th compression step

It was found that for a given region outside of the crushed zone the Poisson ratio decreased from 0.32 to 0.21 between the first and the final compression steps due to the bone geometry and its resulting deformation behaviour.

This study has presented a repeatable method for assessing the precision and accuracy of using LaVision‘s DVC system with µCT volume images of trabecular bone to investigate sub-surface deformation and strain under loading. The low noise associated with the reconstructed volumes allowed strains to be identified which were due to material behaviour, allowing identification of true material behaviour. The study identified a means of utilising a correlation coefficient threshold to ensure authentic strains were calculated as the material was crushed and the pattern excessively changed. A novel aspect of this study was the successful coupling of DVC and the VFM to extract the Poisson’s ratio and determined a decreasing trend with increasing compression. DVC is the only way the researcher can validate their FE models of this complex material under loading.

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