Trabecular-level strain measurements

Verhulp, E.; van Rietbergen, B.; Müller, R.; Huiskes, H.W.J.

Published: 01/01/2002

Document Version
Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:
• A submitted manuscript is the author's version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
• The final author version and the galley proof are versions of the publication after peer review.
• The final published version features the final layout of the paper including the volume, issue and page numbers.

Link to publication

Citation for published version (APA):

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

• Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
• You may not further distribute the material or use it for any profit-making activity or commercial gain
• You may freely distribute the URL identifying the publication in the public portal?

Take down policy
If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Download date: 07. Dec. 2018
Trabecular-level strain measurements

E. Verhulp¹, B. van Rietbergen¹, R. Müller², R. Huiskes¹

¹Eindhoven University of Technology, Department of Biomedical Engineering
²Swiss Federal Institute of Technology (ETH) and University of Zurich, Institute for Biomedical Engineering

Introduction
Trabecular bone is the spongy, porous type of bone found at the end of long bones and within flat and irregular bones, such as the pelvis and vertebral bodies. The structure consists of interconnected rods and plates called trabeculae. Information about stresses and strains at the level of the bone tissue is essential for a better understanding of bone failure and load adaptive processes in bone, but presently, no method exist to measure strains at this level.

Objective
The objective of this work is to develop a 3D image correlation technique for the calculation of strains at the bone tissue level. High-resolution sequential images of undeformed and deformed porous structures made with a micro-CT device are used as the basis for this technique.

Methods
3D Image Correlation
A widely used two-dimensional image correlation technique [1] was extended to three-dimensions. The solid structure was meshed with a marching-cubes method [2] for two reasons. First of all, the meshing technique uses a threshold to separate the solid structure from the pores. The solid part is filled with tetrahedral elements and the displacement is calculated in the element nodes. This means that the displacements and strains are calculated in the solid structure only. Secondly, the resulting tetrahedral mesh enables easy processing of the obtained results.

Experiments
A micro-compression device [3] was used to compress open-cell aluminum foam samples with a structure similar to trabecular bone (Fig. 1). The samples were compressed to complete failure in a number of steps. Three-dimensional reconstructions of the sample were obtained with a micro-CT device (µCT-80, Scanco Medical AG, Switzerland). Image correlation was applied to the three-dimensional images (with an isotropic spatial resolution of 36µm) of the original and deformed structures (Fig. 2).

Results
A single trabecula from the aluminum foam sample was analyzed (Fig. 2). First, the image of the trabecula was meshed with the marching-cubes method. The interior and surface of the mesh were relaxed and in each element node the displacement components were calculated with the 3D image correlation technique. Then, a deformation tensor was calculated in each node and the mesh was deformed according to this tensor. The total equivalent Green-Lagrange strain and the deformed mesh are shown in figure 3.

Conclusions
The 3D image correlation technique enables displacement and strain measurements at the level of the individual trabeculae. This technique can be used to study the failure behavior of porous trabecular-like structures such as aluminum foam and trabecular bone. Also, the recently developed non-linear finite element models for the simulation of trabecular bone failure (e.g. [4]) can now be validated at the level of the individual trabeculae.

References:

Figure 1: The structure of aluminum foam (left) closely resembles the structure of trabecular bone (right).

Figure 2: Original (left) and deformed (right) aluminum foam samples. The trabecula in the red circle is analyzed.

Figure 3: Original (top) and deformed (bottom) trabecula from two different angles: a comparison between the CT-scans and the calculated deformation with the 3D image correlation technique. The total Green-Lagrange strain is shown.