# Trabecular-level strain measurements

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## 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.

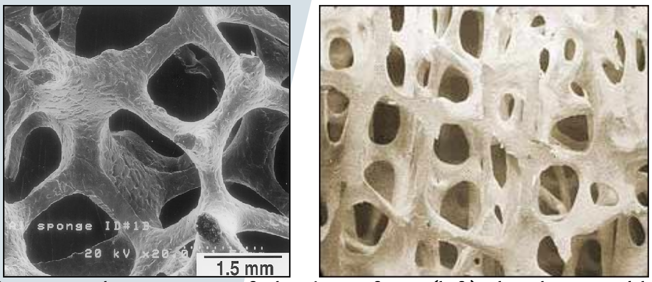


**Figure 1:** *The structure of aluminum foam (left) closely resembles the structure of trabecular bone (right).*

### 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 ($\mu$CT-80, Scanco Medical AG, Switzerland). Image correlation was applied to the three-dimensional images (with an isotropic spatial resolution of 36$\mu$m) of the original and deformed structures (Fig. 2).

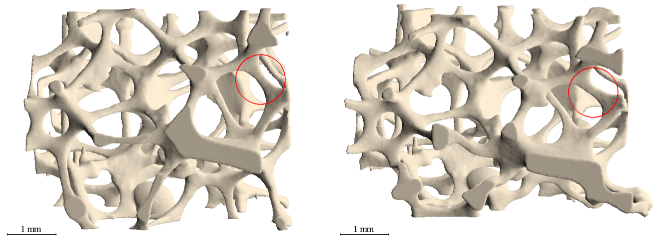


**Figure 2:** *Original (left) and deformed (right) aluminum foam samples. The trabecula in the red circle is analyzed.*

## 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.

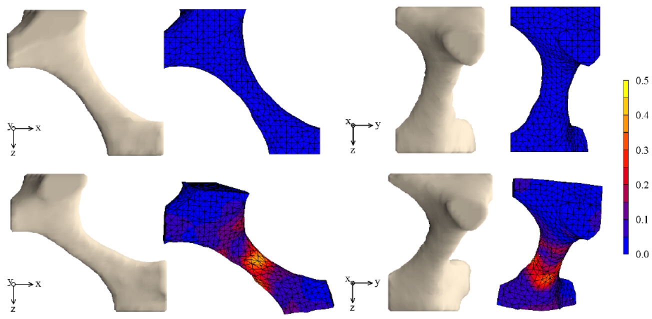


**Figure 3:** *Original (top) and deformed (bottom) trabecula from two different angles: a comparison between the CT-scans and the calculated deformation with the 3D image correlation technique. The total Green-Lagrange strain is shown.*

## 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.

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