

Towards validation of computational analyses of peri-implant strains: a feasibility study using experimentally obtained strain maps

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INTRODUCTION

Through recent advances in computational power and micro-finite-element (μ FE) analyses it has become possible to simulate the mechanical behavior of endosseous implants taking into account the detailed microstructure of the surrounding bone. To validate local values of strain obtained from μ FE analysis, experimental data are needed. Image-guided failure assessment (IGFA) combines mechanical testing of bone samples with high-resolution computed tomography (CT) [1]. Step-wise mechanical loading is intermitted by CT scanning, resulting in a sequence of time-lapsed, three-dimensional images. By using deformable image registration, strain maps can be obtained from these images [2]. It was the aim of this preliminary study to qualitatively compare μ FE results with experimentally derived strain maps.

METHODS

A dynamic hip screw (DHS) was manufactured from the high-performance polymer Torlon and implanted into a human femoral head. For the IGFA experiments, a custom-designed mechanical loading device and a high-resolution CT system (XtremeCT, Scanco Medical AG, Switzerland) were employed (resolution: 82 μ m). The screw was fully constrained at the bottom part of the system, whereas at the upper part the femoral head made contact with a concave PMMA bed to mimic the distributed load as present in the human hip joint. The specimen was subjected to compressive loading steps, until failure of the bone-implant interface occurred.

The strain mapping procedure consisted of an initial digital volume correlation to align regions of the images, followed by the 'Demons' deformable image registration algorithm for a finer and more localized alignment [3]. The Green-Lagrange strain tensor and von Mises equivalent effective strain were calculated based on the Gaussian filtered displacement field. This procedure was carried out for the bone portion of the images only.

Concomitantly, a μ FE model was derived from the segmented specimen geometry. A concave PMMA embedding was virtually added to mimic the real experimental setup. The elastic material properties used in the model are given in Table 1.

Table 1: Elastic material properties used in the μ FE models

	Bone	Screw	PMMA
Young's modulus (GPa)	10	5	4
Poisson's ratio	0.3	0.3	0.36

Direct voxel-to-element conversion was performed, resulting in a model with 39.7 million elements. Compressive deformation was applied to the model on the screw side, while the PMMA was fully constrained. A PCG based parallel solver [4] was used to solve this large

problem on a CRAY XT5 system using 1024 processors.

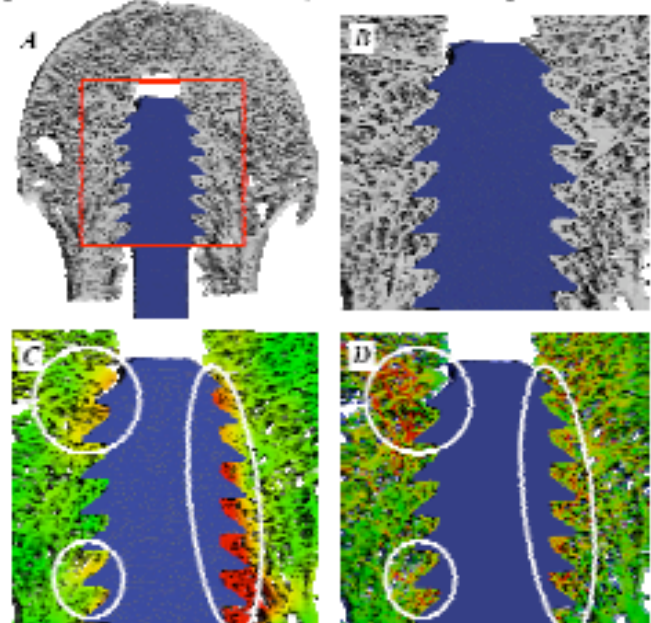


Figure 1: segmented image of full femoral head specimen (A); close-up of thread region (B); strain mapping of thread region (C); strains calculated by μ FE simulation (D)

RESULTS

Both the μ FE analysis and the strain mapping procedure were able to provide detailed local peri-implant strain values. First qualitative comparisons were encouraging as both techniques were able to identify regions of locally high strains; however, limited quantitative agreement was observed (Fig. 1).

DISCUSSION

To our knowledge, this is the first study using strain mapping to investigate the mechanical behavior of large endosseous implants. The accuracy of the strain mapping may be limited in this case due to the image resolution of 82 μ m. Hence, prior to a quantitative comparison of strain mapping and μ FEA, a validation of the strain mapping procedure for use with XtremeCT data is required.

REFERENCES

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