TRABECULAR TORSION CAN LOCALISE FRACTURE IN VITRO

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Introduction

Predicting the fracture in a trabecular bone sample is still a challenging task not for what is related to load magnitude but also for the "simple" localization of the fracture onset. Fracture appears as a chain of events where a local phenomenon triggers a sort of butterfly effect on an increasingly growing surrounding area.
The fracture onset appears not related to strain/stress concentration as it emerges from linear models [1]; on the other hand, models embedding constitutive non-linearities are not providing further insights. The complexity of those models, combined with their significant computational cost, makes the identification of a reliable, robust and accurate model still an open challenge.
Skeletonisation is an algorithm able to extract essential features about the topology of a 3D structure from its digital imaging. Using this approach, the intricated trabecular architecture can be described as a graph of truss/beam elements. In this study skeletonisation was applied to µCT images of trabecular bone samples; the resulting graph was used to initialise a FE model of beam elements to replicate the experimental uni-axial compression test conducted in vitro up to failure.

Materials and Methods

Datasets µCT of 14 bone samples (cylinders, D=10mm, h=20mm, BVTV 9.36+/-2.33%) from the LHDL dataset were binarised (fixed global threshold 143) and skeletonised (in-house Matlab script, homotopic thinning algorithm [2]). Trabeculae were identified between the nodes of the resulting graph; each trabecula was modeled as a beam element (homogeneous and isotropic linear material, E=19GPa, ni=0.3); circular cross sections were defined for each trabecula by computing the average distance between the skeleton and the bone surface on the binarized dataset. Nodal constrains were applied to replicate the uni-axial compression (nodes on the bottom region fully constrained; nodes at the top region imposed axial displacement and null transverse displacement). FE models were solved using Abaqus on a standard laptop. The map of the resulting nodal displacements and rotation were compared with the map of the fractured areas as identified by comparison between registered pre and post fracture µCTs [3]. For each model, the axial torsion (i.e. axial twist divided by the trabecular length) was calculate for all the trabeculae; the trabeculae having a torsion bigger than the 99th percentile were identified and for each one the minimum distance from the surface of the fractured volume was computed.

Results and Discussion

For all the models, the map of the magnitude of the nodal rotation showed an excellent match with fractured areas with damaged regions systematically overlapping the regions with highest values of nodal rotations. This information is not physically meaningful though, since it can embed rigid motions. Trabeculae over the 99th percentile of torsion appeared distributed at the average distance of 1.208 ±0.475mm from the fractured volume and the trabecula with highest value always appear within 0.01mm.

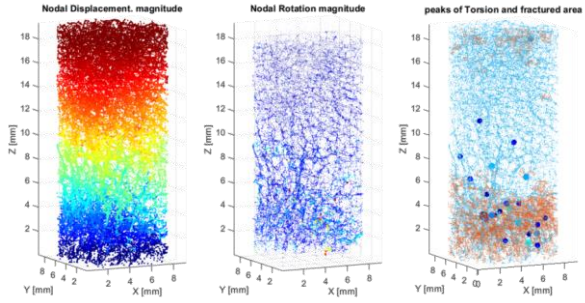

Figure 1: nodal displacement (left), nodal rotations (centre) and localization of the most torqued trabeculae (solid spots) vs fractured volume (in orange)

The results suggested that beam models based on the skeletonisaton of the µCT datasets were able not only to capture the overall mechanical response of the trabecular structure but also to provide an indicator to localize the fracture onset. Trabecular torsion (an information not achievable from voxel-based µFEM) appeared spatially aligned with fractures for all the samples, being the trabecular with the highest value of torsion always close to the fractured volumes. This appear consistent with the laminar structure of the trabeculae for which torsion is likely to produce delamination of the lamellar pack.
The proposed modelling strategy based on beam elements is simple, and computationally light: this modelling approach makes it potentially feasible to embed the laminar structure of each trabeculae in the formulation of the beam elements; constitutive nonlinearities as well as large deformation would be also approachable for studying the post-deliamination phase. Both these topics would be problematic and demanding with µFE approach.

References

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