A MATERIAL TESTING 2.0 METHODOLOGY FOR CORTICAL BONE

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Abstract

Background

Cortical bone mechanical properties (stiffness, damage, failure stress) are essential to understand the effects of osteoporosis or to predict accident-related trauma, for instance. Legacy mechanical testing rests on simple load configurations (uniaxial tension/compression, bending) and point deformation information (extensometer, strain gauges) (1), often even using the machine crosshead displacement to measure deformation, which is highly questionable. This leads to large dispersions in literature data for which it is hard to decide what is due to bone variability and what is caused by inaccurate testing procedures. Moreover, while cortical bone is generally assumed orthotropic or transversely isotropic, few studies address the full set of stiffness components and doing so requires different specimens which is a major difficulty for Human bone and adds to the scatter.

The advent of full-field deformation measurements like Digital Image Correlation (DIC, (2)) and inverse identification techniques like the Virtual Fields Method (VFM, (3)) has given rise to a new paradigm in mechanical testing of materials called Material Testing 2.0 (MT2.0) (5). This paper illustrates how this new paradigm can be used to identify the full set of orthotropic stiffness components of Human trabecular bone from a single test.

Experimental setup

Ten femoral and tibial cortical bone samples were sectioned from two elderly female donors (ethics reference: 19/YH/0184). The designed test configuration was a deep notched specimen mounted off-axis in the test machine. Speckle patterns of between 20 and 40 μm were transferred onto the samples using a stamp and the ink from a permanent marker. The samples were loaded in displacement control until 400 N (based on the linear region before failure from trial tests) and then unloaded. Each sample was tested repeatedly to assess repeatability and different speckle patterns. Back-to-back 2D DIC was used to extract the displacement and strain fields with the MatchID software.

Results

The four in-plane orthotropic stiffness components of each specimen were obtained using noise-optimized virtual fields (3). A thorough uncertainty analysis was conducted by simulating each individual test with its specific speckle pattern using synthetic image deformation

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(7). This allowed for the application of individual correction factor on the mean value identified for each stiffness component, as well as the prediction of uncertainty bounds due to the camera noise.

The results show that it is possible to identify the four orthotropic stiffness components of cortical bone on one single specimen (7). Thanks to the numerical simulation, it was found that the inter-specimen scatter was smaller than the inter-test scatter when the same specimen was tested several times. This suggests that in the literature on testing of biological materials, the large scatter generally reported may be partly caused by test scatter. This new methodology has great potential to produce higher quality data and will be extended to non-linear behaviour in the future.

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