Introduction: Osteoporosis occurs most frequently in post-menopausal women and the elderly. It is defined as a systemic skeletal disease characterized by low bone mass and micro-architectural deterioration of bone tissue, with a concomitant increase in bone fragility and fracture risk \(^1\). Until recently, the structural analysis of these fractures has been limited to two-dimensional sections. Due to the inherent destructiveness of this method, dynamic assessment of fracture progression has not been possible. An image-guided technique, utilizing micro-compression in combination with micro-computed tomography (micro-CT), has been developed, which allows for the first time, the direct three-dimensional visualization and quantification of fracture progression on the microscopic level. This technique allows for the definition of the mechanical testing, to relate the global failure properties of trabecular bone to those of the individual trabeculae. The goal of this project was first, to design a micro-mechanical testing system, composed of the micro-compression device (MCD) and the material testing and data acquisition system (MTDAQ), and second, to validate the testing system to perform step-wise testing of trabecular bone specimens using image-guided failure analysis (IGFA) technique and micro-CT imaging. This technique has been implemented before by using a standard mechanical testing machine and aluminum foam specimens. However, in order to obtain better results on bone specimens, the design and manufacture of the abovementioned MTDAQ was deemed necessary.

Methods: IGFA is based on the step-wise or time-lapsed compression and imaging of bone specimens. It is a three-dimensional and dynamic technique that allows for the study of bone failure beyond the elastic region. It is also capable of studying the influence of local variation of bone tissue and structure on the mechanical behavior of bone. IGFA allows simultaneous micro-CT imaging as bone tissue is progressively compressed beyond yield. The testing protocol consists of applying sequential compression steps of 0\%, 2\%, 4\%, 8\%, 12\%, 16\% and 20\% global strain, while simultaneously measuring nominal stress. The specimen is imaged after each strain step to observe microstructural deformation.

The MCD is designed to house the test specimens and act as a transportable mechanical testing station, incorporating it with the strain measurements of the specimens. Another limitation was the method of displacement measurement. The current LVDT measures the displacement of the end-effector, which is prone to compliance. This artifact can be partially accounted for by calculating the compliance and incorporating it with the strain measurements of the specimens. Another limitation was the method of displacement measurement. The current LVDT measures the displacement of the end-effector, which is prone to compliance and end-effect artifacts. In order to measure the mid-axis strain within the specimen, optical methods will be considered. Spatial constraints of the micro-CT prevented us from using longer brass end-caps to further reduce end-effect artifacts.

In conclusion, step-wise micro-compression yields the same mechanical properties as classical continuous tests for biological specimens, and IGFA provides insight in the pre and post failure behavior of microstructural bone.

**Institute for Biomedical Engineering, ETH and University Zürich, Zürich, Switzerland.

Reference:

Figure 1- Images acquired from step-wise testing of a whale trabecular bone specimen at 0\% strain (right) and 20\% strain (left) respectively.

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