MECHANICAL PROPERTIES OF INDIVIDUAL OSTEOPOROTIC AND CONTROL TRABECULAE IN COMPRESSION

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Introduction

Osteoporosis, is characterized by increased bone fracture risk and remains a disease with high morbidity for the elderly. One known cause of increased fracture risk is the decrease of bone mass. In this context, the putative change of mechanical (material) properties of trabecular bone tissue remains to be fully elucidated and is complicated to assess, due to open porous structure of the tissue. Here, we excluded structural influence by performing compression tests on individual trabeculae excised from cadaveric and osteoporotic human donors.

Methods

12 cadaveric (control group: CTRL) and 15 osteoporotic (osteoporotic fracture: FRAC) human trabeculae were excised from human femoral heads and furnished with a speckle pattern for optical strain measurement. Samples were aligned and glued into custom-made 3D printed chambers with modified epoxy resin (Best-KL 6009). Compression tests were performed using a servo-electric load frame (SEL-mini, Thelkin), equipped with a 10 N load sensor (S2M-10, HBM), a video camera (Kitocam, Kitotec) and a water bath. Preparation and compression tests were done in Hank's Balanced Salt Solution (pH 7.4) to mimic physiological conditions. Sample geometry was obtained via micro-computed tomography (µCT100, SCANCO Medical) at a nominal resolution of 3.3 µm (voltage 70kVp, current 145 µA). Calculated stress is based on mean cross-sectional area, strain was calculated by tracking speckle positions at multiple points at the top and bottom of the samples as shown on the right in Figure 1. Statistical analysis was done in Python with using a two-tailed t-test (scipy.stats.ttest_ind).

Results

Determined mechanical parameters are (mean ± std) shown in Table 1.

Properties	CTRL (12)	FRAC (15)
E [GPa]	11.2 ± 7.2	15.7 ± 7.7
σ_y [MPa]	35.1 ± 13.9	36.3 ± 18.3
ε_y [%]	0.5 ± 0.5	0.3 ± 0.1
σ_u [MPa]	66.8 ± 24.7	79.5 ± 26.2
ε_u [%]	3.0 ± 3.0	2.0 ± 1.2

Table 1: Mechanical properties of individual trabeculae tested in compression. E tangent modulus, σ_y yield stress, ε_y yield strain, σ_u ultimate stress, ε_u ultimate strain.

Mechanical properties (CTRL vs. FRAC) are not significantly different from each other. The transition (yield) point is reached at nearly the same stress and strain values. Figure 1 illustrates a selected stress-strain curve under cyclic compressive load. Experiments were performed under displacement-control; therefore, the number of partial unloading cycles vary from three to seven per trabecula.

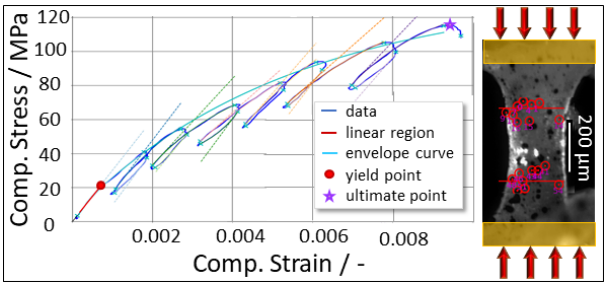

Figure 1: Stress-strain diagram. Measured data in blue, linear region at beginning of curve in red, followed by a turquoise envelope curve. The red point indicates transition (yield) point. The magenta star shows the max. comp. stress in the seventh cycle. (Right) tracking of the speckle points during compression tests.

Discussion

Our compression test enables determination of mechanical properties of individual trabeculae under compression. Results can be compared to individual trabeculae of the same donor cohort loaded in tension with apparent moduli (8.5 ± 5.1) GPa for CTRL and (7.7 ± 4.4) GPa for FRAC [1]. In compression, trabeculae seem stiffer to tension, however, variation is large and more samples need to be tested for a clear statement. Nevertheless, this highlights the importance of the load case for determination of material properties of bone. The mechanical testing data (cf. Fig. 1) show that individual trabeculae do not behave linear elastically in compression, all partial loading-unloading and re-loading exhibit hyteresis. Similar to tensile tests we will apply a rheological model [2] to our data for identifaction of visco-elastic, visco-plastic properties. We expect our results to further clarify putative differences in tissue properties with osteoporosis and improve fracture risk estimation via computer models.

References

1. Frank, M., et al, JBMR Plus, 4;5(6): e10503, 2021.
2. Reisinger, et al, Biomech Model Mechanobiol., 19(6):2149-2162, 2020.