Microdamage assessment of bone-cement interfaces using *in situ* testing, digital volume correlation and finite element analysis

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**Introduction:** The longevity of fixation in cemented hip replacements relies on the mechanical stability of the bone-cement interface. Whilst debonding of the bone-cement composite has been mainly associated with acetabular loosening [1], early damage in the cement mantle was found to be concentrated at the bone-cement interface in the femoral side [2]. However, the role of bone structure in promoting microdamage initiation at the bone-cement interface is still unclear.

**Aims:** 1) To investigate the microdamage evolution of three types of bone-cement interface, using mainly trabecular, mixture of trabecular/cortical and mainly cortical bones under monotonic compression. 2) To evaluate, for the stiffest type, the residual strain distribution as a measure of the initial damage accumulation under cyclic compression loading.

**Materials and Methods:** Trabecular (BC1), mixture of trabecular/cortical (BC2) and compact bovine bones (BC3) were used to interdigitate with Simplex P (Stryker) cement. *In situ* testing of bone-cement samples was carried out following [3]. Specimens were µCT (X-Tek) imaged (55-80kV, 110-150µA, voxel size=20µm) and monotonically compressed (0.01mm/s) *in situ* (Deben) up to a global strain of 4%. Cyclic compression was conducted on BC3 (Si-Plan) under the same monotonic displacement with a frequency of 5Hz. The test was stopped to allow µCT of the sample at selected intervals (10, 100, 200 cycles). LaVision DVC software was used to compute the 3D displacement ($v_z$) and strain fields for both static ($\varepsilon_{zz}$) and cyclic ($\varepsilon_{zz,\text{res}}$) compression. For each of the three bone-cement composites FE models (Abaqus) were developed, based on the approach reported in [3].

**Results:** The highest compressive strains ($\varepsilon_{zz}$) were associated with localised microdamage at the trabeculae level for both BC1 and BC2. BC3 experienced lower strains, which were mainly distributed in the interdigitated and cement regions. The predicted percentages of yielded cement volume within the interdigitated region were 0.04%, 2.60% and 17.12% for BC1, BC2 and BC3, respectively. Under cyclic compression a gradual reduction of stiffness for BC3 was observed. The DVC map confirmed the presence of relatively high levels of residual strain ($\varepsilon_{zz,\text{res}}$) associated with microdamage at the interface and in the cement mantle (Figure 1).

**Conclusions:** Insufficient trabecular bone exposure during bed preparation could promote microdamage initiation at the bone-cement interface and in the cement mantle, after only a few compressive cycles. Furthermore, the cyclic load magnitude used in this study can be achieved in physiological activities such as normal walking and going up stairs.

**References:**


![Figure 1. Strain map and 3D reconstruction of selected sub-volumes (a-b) of BC3, where microdamage was identified with regions of high residual strain ($\varepsilon_{\text{res,zz}}$) at 200 cycles.](image-url)