NONLINEAR ULTRASOUND MONITORING OF SINGLE CRACK PROPAGATION IN CORTICAL BONE

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Introduction
The origin of bone fracture is still in debate but initiation and propagation of a single critical crack is thought to be one of the main processes leading to bone rupture. Non-invasive means for detecting and monitoring the propagation of a single crack is thus highly desirable. We showed in a previous mechanical fatigue experience that nonlinear resonant ultrasound spectroscopy (NRUS) is sensitive to the accumulation of microcracks in cortical bone [Haupert, 2012]. As a logical extension, the objective of the study was to investigate the sensitivity of NRUS to the controlled propagation in calibrated cortical bone samples of a single crack induced by 4-point bending mechanical loading.

Methods
Twelve human cortical bone specimens were machined as parallelepiped beams (50*2*2mm) to unambiguously identify resonant modes for NRUS measurements. A central notch of 600 µm was made to control crack initiation and propagation during four-point bending loading. The nonlinear hysteretic elastic coefficient ($\alpha_f$) was derived from NRUS measurements achieved in dry conditions for all undamaged (control state) and damaged (final state) specimens. The experimental setup consists of a piezoceramic emitter bonded with cyanoacrylate at one end of the sample. The longitudinal displacement is measured at the other end by a laser vibrometer [Haupert, 2011]. Each bone specimen was probed by a swept-sine around its first compression mode, applying progressively increasing drive levels. Moreover, the buried crack length was assessed by synchrotron radiation microcomputed tomography (SR-μCT) with a spatial resolution of 1.4µm.

Results
$\alpha_f$ increased significantly (up to 60-fold) in the damaged state (44.9±85.4) compared to the initial value (5.5±1.5) in the control undamaged state (Fig.1a). Crack length was significantly correlated to the nonlinear elastic parameter $\alpha_f$ ($r^2=0.78$, $p<0.001$) (Fig.1b).

Discussion
Altogether with our previous results from fatigue experiments, these results suggest that NRUS is sensitive to damage accumulation and can be used as a marker of bone damage, specifically to monitor single crack propagation.

References
Haupert et al, Inter Bone Densitometry Workshop, Breckenridge, CO, USA, 2012.