Introduction: Age related vertebral compression fractures, affecting 500,000 individuals annually in the US, are associated with significant physical, and psychological impairments. Quantitative ultrasound (QUS) is increasingly being used to assess bone quality at peripheral skeletal sites, but has not yet been applied to the axial skeleton (spine, hip) where osteoporotic fractures are common. We aimed to assess the feasibility and utility of vertebral QUS by attempting ultrasonic measurements in cadaver spines and correlating the acoustic properties with vertebral bone mineral density and failure load.

Methods: Eleven lumbar vertebrae were obtained from separate donor’s age ranging from 65-88 years old. Radiographs were obtained for each vertebra to exclude bone pathology with bone mineral density (BMD), in the antero-posterior (AP) and lateral (LAT) projection, measured using DXA (Hologic 2000+, Hologic, MA). A mechanical caliper (Mitutoyo, Japan, 0.01 mm resolution) was used to obtain the vertebral body mid-sagittal posterior and anterior heights. An in-house quantitative ultrasonic imaging system was used to measure a range of acoustic properties including velocity and broadband ultrasonic attenuation (BUA). These acoustic properties were averaged over a region of interest centrally within the vertebral body. Figure 1. A custom testing jig, secured to a hydraulic test system (4000, Interlaken, Eden Prairie, MN), was employed to test the vertebra under monotonically increasing compressive displacement at a rate of 5mm/min. The test was terminated at failure, defined by the vertebra registering a 50% reduction in vertebral body height. Both applied displacement and resulted compressive force were recorded at the rate of 10Hz. Stepwise multiple regression (JMP, SAS, NC) was used to investigate the relationship between vertebral strength and both the DXA parameters and the following QUS parameters: Ultrasound velocity (UV, m/s), broadband ultrasonic attenuation (BUA, dB/MHz), 200kHz attenuation (dB), 600 kHz attenuation (dB) and phase velocity at 600 kHz (m/s). Statistical significance was set at 5% level.

Essential results: All of the vertebrae tested underwent a crush fracture with the vertebrae exhibiting a mean reduction of ~28.6% and ~17.8% in the vertebral body anterior and posterior heights respectively. The mean failure load was 2076 ± 1259 N. Significant correlations were observed between QUS parameters and BMD (r = 0.56 - 0.82, p <0.05). Both AP BMD and LAT BMD correlated with failure load (r = 0.78, 0.74 respectively, p<0.01). Figure 2. Correlations between QUS and failure load ranged from r = 0.50 (p = not significant) for phase velocity to r = 0.93 (p<0.0001) for 600 kHz attenuation. Of the ultrasonic measurements, BUA was a significant predictor of failure load (r = 0.80, p < 0.001) Figure 3, but UV was not (r = 0.50, p >0.05.). In stepwise multiple regression models for predicting failure load using all of the BMD and QUS variables, BUA was the only significant predictor.

Discussion: These results confirm that vertebral QUS is feasible, at least in vitro, and that it does provide information on both spinal BMD and failure load. The ability of ultrasound to predict vertebral failure load was comparable, in the case of BUA, to that of DXA, indicating that ultrasound has the potential to be at least as useful as DXA in assessing the mechanical competence of the axial skeleton. Of the QUS parameters reported here, BUA was better than UV in predicting failure load. This contrasts earlier studies using human calcaneal bone which generally show that UV and BUA have a similar predictive ability for cancellous bone mechanical properties in vitro. This may reflect the presence of different physical interactions in the vertebral ultrasound measurements reported here compared to those reported earlier for other anatomical sites. Finally, it should be noted that substantial difficulties regarding acoustic coupling into the body and transmission through heterogeneous overlying tissue remain to be tackled before vertebral QUS could be applied clinically.

Figure 1: Quantitative ultrasound image (Broadband Ultrasonic Attenuation, BUA) for lumbar vertebral body: lateral projection.

Figure 2 Correlation of Bone Mineral Density obtained from lateral and anterior-posterior projections, with the vertebral body axial compression failure force.

Figure 3 Correlation of Broadband Ultrasonic Attenuation (BUA), obtained from a lateral projection, with the vertebral body axial compression failure force.

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