## Cortical bone tissue strength is reflected in shear and longitudinal ultrasonic velocities

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## **Background, Motivation and Objective**

Ultrasound velocities in cortical bone can be measured in vivo at the radius or tibia with pulse echo techniques using a single transducer or an array of transducers for imaging. Depending on the measurement plane, longitudinal wave velocities may be determined along (velocity  $v_3$ ) or transversely ( $v_1$ ) to the axis of the diaphysis. Shear wave velocities ( $v_4$  and  $v_6$ ) can also be measured. It is in general assumed that velocities measured in vivo are indicative of the mechanical quality of bone. However, there is little data to support this assumption. The objective of this work was to quantify the relationships between ultrasonic velocities and compression strength of cortical tissue. The relationships between velocities and porosity was also investigated as porosity is a known determinant of strength.

## **Statement of Contribution/Methods**

Cortical bone cuboid samples were obtained from the femoral diaphysis of nineteen elderly human donors. The elastic stiffness tensor was measured with resonant ultrasound spectroscopy (RUS), from which the longitudinal and shear wave velocities were calculated. Vascular porosity was measured with X-ray micro-computed tomography. Tissue strength in the direction of the axis of the diaphysis was determined on the fluid-saturated samples by compression testing at body temperature. The number of samples used for the analyses were 70 (velocities vs. strength) and 39 (velocities vs. porosity), as porosity was not available for all samples.

## **Results/Discussion**

Velocities  $v_1$ ,  $v_3$ ,  $v_4$  and  $v_6$  were correlated to strength (p<10<sup>-3</sup>), with  $r^2$  =0.62, 0.55, 0.69, and 0.73, and the slopes of the linear regressions (unit m.s<sup>-1</sup>/Pa) were 5.3, 6.1, 4.0, and 4.6. The sensitivity of longitudinal and shear wave velocities to variations of strength were similar, but slightly higher for  $v_3$ . Velocities  $v_1$ ,  $v_3$ ,  $v_4$  and  $v_6$  were correlated to porosity (p<10<sup>-3</sup>), with  $r^2$  =0.49, 0.55, 0.59, 0.60 and the slopes of the linear regressions (unit m.s<sup>-1</sup>/% of porosity) were -16.7, -22.8, -13.5, -14.6. The results point at a relatively strong correlation between compression strength and shear and longitudinal ultrasonic velocities in two anatomical directions. A consequence is that velocities, which can be determined in vivo, may be considered as good proxy for tissue strength.



velocities in cortical bone versus compressionnal tissue strength. Lines indicate linear regressions ; red: v<sub>6</sub> ; blue: v<sub>3</sub>; black: v<sub>1</sub>; light blue: v<sub>4</sub>.