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In vivo estimation of ultrasound wave-speed anisotropy in human cortical bone with ultrasound imaging: a precision analysis

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Background, Motivation and Objective

Measurement of ultrasound wave-speed in bone tissue can help assess bone mechanical strength and the risk of osteoporotic fracture. Several dedicated ultrasound devices have been proposed to measure the ultrasonic wave-speed in the cortex of different skeletal sites [1].

Bone exhibits anisotropic properties, allowing for the extraction of independent measures indicating its mechanical characteristics. [2] introduced the first joint *in vivo* assessment of wave-speed in all bone directions using ultrasound imaging of bone. This method was initially tested on two healthy volunteers [2], yet there is currently no study on the precision of this method.

This study presents the first *in vivo* evaluation of wave-speed precision in bone tissues using this technique. The aim is to determine whether it can detect significant changes in bone material properties using the estimated wave-speed and anisotropy form parameter. We provide wave-speed values in both radial and axial directions of the human tibia, along with an anisotropy form parameter.

Statement of Contribution/Methods

Measurements were taken at the middle and proximal third of the tibia of 11 healthy male volunteers with a mean age of 28 (2.5) years. Transverse and longitudinal ultrasound acquisitions were conducted using a single-element transmission synthetic aperture imaging sequence with a research ultrasound system and a 2.5 MHz phased array transducer. Each acquisition was repeated five times with repositioning, guided by real-time visualization to ensure accurate image alignment.

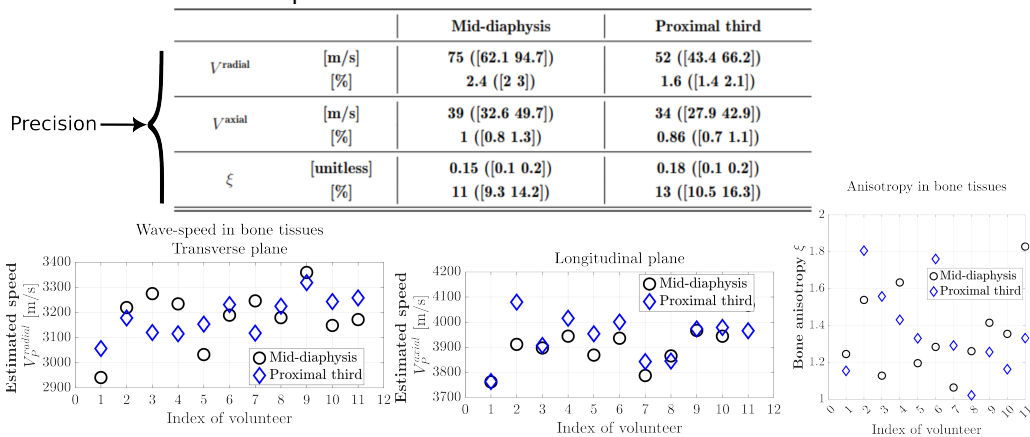
The wave-speed in cortical bone is estimated using a weak transverse isotropy model with parameters including wave-speed in the direction of the material symmetry axis (V^{axial}) and in a direction normal to the material symmetry axis (V^{radial}), and an anisotropy form parameter χ [2,3]. V^{radial} and χ were estimated using an autofocus approach, while V^{axial} was estimated as the headwave velocity. V^{radial} is estimated with transverse acquisitions while V^{axial} and χ are estimated with longitudinal acquisitions.

Precision is assessed by calculating the root-mean-square (RMS) average [4] of the standard deviation (SD) from five measurements, expressed as a percentage relative to the mean group value.

Results/Discussion

The figures present wave-speed in the axial and radial directions and anisotropy form parameter (bottom) and the table gives precision on each parameter with 95% confidence intervals (top). Precision is less than 3% for V^{radial} and less than 1.5% for V^{axial} . With cortical porosity ranging from 2 to 25%, radial wave-speed can decline by up to 15% in total [5,6]. Given the precision of less than 3% found for V^{radial} in this study, ultrasound imaging is able to discern multiple levels of cortical porosity. Furthermore, during adulthood, V^{axial} declines on average by 5% [7]. Hence, given the precision of less than 1.3% found for V^{axial} in this study, ultrasound imaging might be able to monitor longitudinal cortical porosity change.

In conclusion, our findings suggest that the precision with which the radial and axial wave-speeds are assessed is sufficient to identify and monitor individuals with low cortical bone mechanical quality at risk of osteoporotic fracture. Future work will evaluate precision in a clinical context.



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