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# Estimation of thickness and wave speed in cortical bone using ultrasound imaging: an ex vivo study

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## Background, Motivation and Objective

Measurement of cortical thickness ( $Ct.Th$ ) and ultrasound wave-speed ( $Ct.V$ ) in bone tissue can help assess bone mechanical strength and the risk of osteoporotic fracture [1]. Ultrasound imaging of the cortex of long bones enables the measurement of  $Ct.Th$  and  $Ct.V$  in young healthy individuals [2]. However, microstructure degradation in osteoporotic bones leads to elevated ultrasound scattering by intra-cortical pores, which deteriorates image quality and may prevent the identification of the internal bone surface (endosteum) [3].

In this study, we report for the first time ex-vivo refraction-corrected ultrasound imaging of the bone cortex from elderly donors with moderate to high pore volume fraction (porosity). The objective was to validate the measurement of  $Ct.Th$  and  $Ct.V$  in this population and investigate the influence of pore size and porosity on image quality.

## Statement of Contribution/Methods

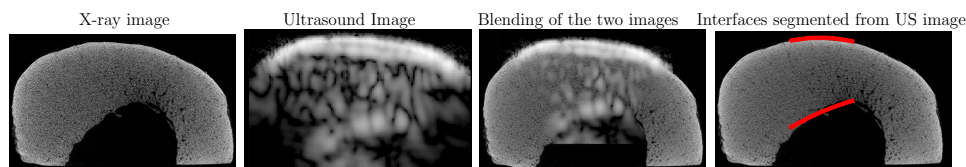
Samples extracted from human femoral shafts were chemically fixed, scanned with micro-computed x-ray tomography ( $\mu$ CT, Skyscan 1176, voxel size 9 microns). After degassing, the samples were immersed in water and imaged with a phased-array transducer (central frequency 2.5 MHz) using a synthetic aperture sequence. Image reconstruction was performed using a delay-and-sum algorithm with optimized receive f-number, correction of refraction at the water-bone interface and sample-specific ultrasound wave speed estimated with an autofocus approach [2].  $Ct.Th$  was measured as the distance between the segmented periosteum (outer bone surface) and endosteum. Ground truth cortical thickness ( $Gt.Ct.Th$ ) was obtained from  $\mu$ CT images.

## Results/Discussion

Preliminary results on four samples are given in the Figure. Measured  $Ct.Th$  are in agreement with ground truth except for sample 3 which has the highest porosity and pores with larger diameter. These results are in agreement with previous numerical study [3] suggesting that high porosity and the presence of large pores can prevent the detection of the endosteum and hence the estimation of cortical thickness in ultrasound images generated at 2.5MHz.

Estimation of  $Ct.Th$  and  $Ct.V$  using ultrasound imaging at 2.5 MHz center frequency

Cortical thickness measured on sample 4



$Ct.Th = 8.0 \pm 0.9$  mm

	Measured $Ct.Th$	Ground truth $Gt.Ct.Th$	Autofocus estimated $Ct.V$
Sample 1 (Low porosity)	$3.2 \pm 0.1$ mm	$2.9 \pm 0.4$ mm	$3367 \text{ m.s}^{-1}$
Sample 2 (Moderate porosity)	$4.8 \pm 0.8$ mm	$4.5 \pm 0.6$ mm	$3067 \text{ m.s}^{-1}$
Sample 3 (High porosity)	-	$2.9 \pm 0.6$ mm	-
Sample 4 (Low porosity)	$8.0 \pm 0.9$ mm	$7.9 \pm 1.0$ mm	$3300 \text{ m.s}^{-1}$

[1] Grimal *et al* IRBM 2018 [2] Renaud *et al* *Phys. Med. Biol.* 2018

[3] Dia *et al* SSRN 2022 [preprint], <http://dx.doi.org/10.2139/ssrn.4072583>