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Current Challenges in Ultrasound Imaging of Cortical Bone Thickness

Guillaume Renaud, Jean-Gabriel Minonzio

The recent article by Gokcek et al. (1) reported an increased cortical thickness associated with osteoporosis at the ultradistal radius and tibia using conventional ultrasound imaging. This result contradicts a large body of work, including ex vivo and in vivo studies. In particular, numerous studies with high-resolution peripheral quantitative computed tomography (HR-pQCT) have shown that the cortical thickness at the distal radius and at the distal tibia decreases with osteoporosis (2–7). In our opinion, the study by Gokcek et al. (1) holds two severe flaws:

1) Current clinical ultrasound scanners are incapable of recovering an accurate and sharp image of the bone cortex.
2) The "echo length" from the ultradistal outer bone surface in the ultrasound image is not the cortical thickness.

CURRENT CLINICAL ULTRASOUND SCANNERS ARE INCAPABLE OF RECOVERING AN ACCURATE AND SHARP IMAGE OF THE BONE CORTEX

The authors of (1) cited our work (8), where we demonstrated that advanced ultrasound image reconstruction can recover the accurate cortical thickness at the diaphysis of long bones. Our approach enables the correction of (1) refraction as ultrasound enters or exits the bone cortex since the ultrasound wave speed in cortical bone is typically more than twice larger than that in soft tissues surrounding the cortex and (2) ultrasound wave speed anisotropy in cortical bone since the organized microstructure of cortical bone tissue causes direction-dependent ultrasound wave speed. However, such advanced ultrasound image reconstruction is not yet available on clinical ultrasound scanners. Until now, clinical ultrasound scanners have been dedicated to soft tissue imaging, assuming the scanned region is made of a uniform soft-tissue medium during image reconstruction. Thus, current clinical ultrasound scanners are incapable of reconstructing an accurate and sharp image inside the bone cortex and hence incapable of evaluating the cortex thickness because they do not take into account the complex ultrasound physics in cortical bone.

THE "ECHO LENGTH" FROM THE ULTRADISTAL OUTER BONE SURFACE IN THE ULTRASOUND IMAGE IS NOT THE CORTICAL THICKNESS

The authors in (1) used the apparent "echo length" of the ultrasound echo generated by the reflection at outer surface of the bone cortex to evaluate the cortical bone thickness. However, the apparent "echo length" is not the cortical thickness, and it depends on multiple factors:

i. The method chosen to determine the echo length, i.e., how is the beginning and the end of the echo defined, as well as the display settings chosen on the ultrasound scanner (gain, dynamic range…)
ii. The spatial resolution provided by the ultrasound transducer
iii. The cortical thickness

The method used to measure the "echo length" of the reflection at outer surface of the cortex is poorly described in (1), as the authors only wrote, "*The outer and the inner start and end locations of the first and the most echogenic linear line of the bone cortex in the relevant region were measured perpendicular to the relevant bone cortex axis by optimal focus and zoom adjustment on B-Mode US images*" (page 517 in (1)). The value obtained with this subjective approach depends on the display settings chosen on the ultrasound scanner. A criterion to calculate the apparent echo length must be defined and would likely require postprocessing of the images using a dedicated algorithm and software.

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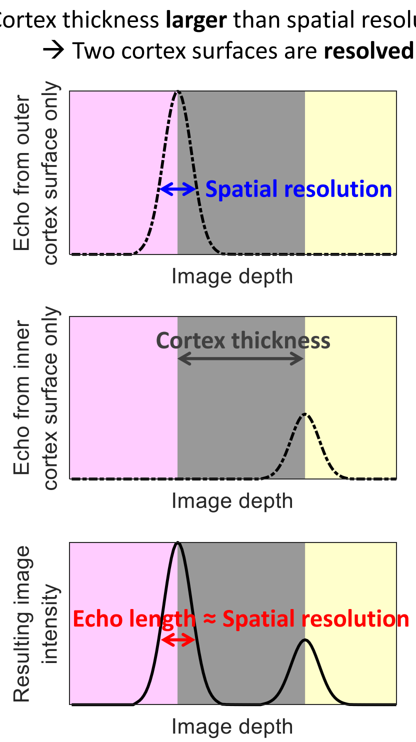

Figure 1. Influence of the cortical thickness and the spatial resolution on the apparent echo length from the outer bone surface in the ultrasound image. Left: case where the inner and outer surfaces of the bone cortex are resolved. Right: case where the cortex surfaces are not resolved.

Thickness measurement or distance measurement between two *resolved* interfaces is reliably performed with ultrasound imaging, for instance, in obstetrics, to evaluate normal fetal growth. Two neighboring interfaces are *resolved* in the ultrasound image if the distance separating them is larger than the spatial resolution in the ultrasound image (Fig 1, left column). In their study, Gokcek et al. (1) used an ultrasound probe that transmits a short ultrasound wavelet with a central frequency close to 7.5 MHz (L12-3E; Mindray Medical International). This probe provides a spatial resolution close to 0.4 mm in cortical bone. If the cortical thickness is larger than 0.4 mm, the outer and the inner surfaces of the bone cortex are resolved and appear as two bright lines in the ultrasound image (Fig. 8 and 9 in (8) and Fig 1, left column). Conversely, if the cortical thickness is smaller than 0.4 mm, the outer and the inner surfaces of the bone cortex are not resolved because the echoes from the two surfaces overlap (Fig 1, right column). As a result, a single bright line appears in the ultrasound image that may be thicker than the spatial resolution.

It is also important to be aware that the relationship between the apparent echo length and the cortical thickness is not monotonic. As illustrated in Figure 2, the apparent echo length shows a maximum value if the cortical thickness is close to the spatial resolution. However, the apparent echo length is smaller and approaches the spatial resolution if the cortical thickness is larger or smaller than the spatial resolution.

Numerous studies with HR-pQCT have reported the cortical thickness at the ultradistal radius (9.5 mm away from

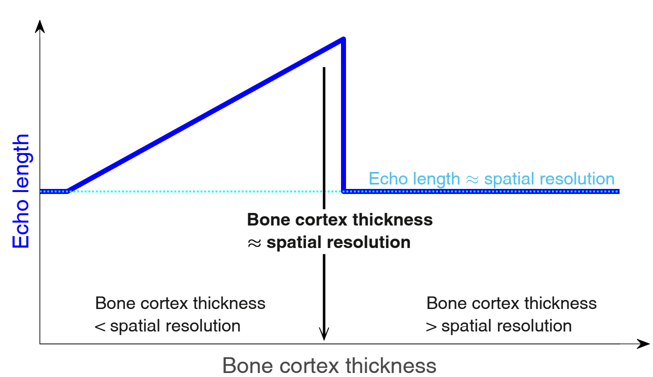

Figure 2. Nonmonotonic relationship between the apparent echo length and the bone cortex thickness.

the joint) and at the ultradistal tibia (22.5 mm away from the joint) (2–7). The ultradistal tibial cortical thickness is slightly larger than that at the ultradistal radius (4). The ultradistal cortical thickness is close to 1 mm in young healthy individuals, and it can become thinner than 0.5 mm in elderly osteoporotic subjects (9). In (1), the authors reported an "echo length" of 0.5 mm in normal individuals and close to 0.6 mm in osteoporotic subjects. The "echo length" of 0.5 mm in normal individuals is thus about twice as smaller than the expected cortical thickness because the "echo length" is unrelated to the cortical thickness and solely determined by the method chosen by the authors to estimate the "echo length" in the image. The apparent increase in "echo length" from the outer bone surface in osteoporotic subjects is very likely caused by the overlapping of the echoes from the outer and inner surfaces of the bone cortex when the true cortical thickness is smaller or close to the spatial resolution in cortical bone (about 0.4 mm with the ultrasound transducer used in (1)).

The use of the apparent "echo length," as proposed in (1), could potentially be an interesting clinical parameter for bone health assessment, because simple. However, it is crucial to understand that the apparent "echo length" depends on multiple factors and that the relationship between the apparent "echo length" and the cortical thickness is not monotonic. And most importantly, the echo length should not be confused with the true cortical bone thickness.

DECLARATION OF COMPETING INTEREST

G.R. has patent for Method For Characterising Bone Using Ultrasonic Waves issued to Sorbonne University/Centre National de la Recherche Scientifique/Institut National de la Sante et de la Recherche Medicale/Ecole Superieure de Physique et de Chimie Industrielles de la Ville de Paris.

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