Objective: Quantitative ultrasound is now used in the clinic for the estimation of bone quality. However, the interaction between an ultrasonic wave and bone tissue remains unclear. A transient ultrasonic wave propagating in cancellous bone has been shown to separates into two waves, referred to as fast wave and slow wave, respectively.

The frequency of the fast wave is lower than that of the slow wave and the wave may last longer depending on the condition of bone specimen. These characteristics of fast wave has been interpreted as the effect of its discriminating propagation path, which is mainly inside the solid part (trabeculae) of cancellous bone. However, few precise investigations of the effect of propagation path of the fast wave has been performed because it was difficult to be evidenced experimentally.

Methods: In this study, we performed three-dimensional numerical simulations using numerical models of actual bone specimens. In order to understand the mechanism explaining the properties of the fast wave, we focused on the spatial distribution of propagating waves in cancellous bone. In the simulations, various configurations of wave propagation were simulated by artificially changing the spatial location and the planar dimension of the receiver and the thickness of the specimen.

Results: The waveforms received by the various sized sensors (from a point-sized sensor to 15x15 square-millimeter sensor) are recorded. The result showed that the shape and the temporal characteristics of the received waves varied widely depending on the location, which may be caused by not only the bone density around the propagating area but also the bone structure (alignment and connection of trabeculae). Hence, this incoherence of the waves strongly lowers the frequency of fast wave when the wave was received by a planar sensor. Although it is sure that the frequency of the waveform received by a point sensor was lower than that of transmitted wave, which may be caused by the multiple reflection inside cancellous bone, the results of the simulation showed that the effect of the surface integral on the planar sensor is also not negligible.

Conclusion: The effect of spatial distribution of bone structure should be considered in practical bone assessments using quantitative ultrasound.

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IMPACT OF AXIAL TRANSMISSION ULTRASOUND AND BONE MINERAL DENSITY ON THE BREAKING STRENGTH OF CORTICAL CUBOID BONE SAMPLES

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Objective: To date it is not clear whether Quantitative Ultrasound (QUS) measured at cortical bone can be used to obtain relevant information about bone fragility exceeding the capabilities of radiological measurements like DXA or CT. In a comprehensive study on tibia bone specimens (supported by Elsbeth-Bonhoff-Foundation, Germany) several methods were applied including different ultrasonic measurements, CT and material testing. In this analysis we concentrated on axial transmission and CT-measurements, which also are applicable in vivo, to investigate whether QUS could add relevant information in patient fracture risk assessment.

Methods: We investigated how axial transmission QUS measurements and bone mineral density (BMD) measured in the midshaft of tibia specimens correlate with ultimate stress of cuboids cut from similar bone regions. Axial transmission measurements were performed using the BDAT device (LIP, Paris) at the anterior part of the tibia. The BDAT probe was positioned at the midshaft parallel to the long axis. Through perpendicular shifting 4 measurement sites were selected covering the complete anterior region of the midshaft. Rectangular specimens were cut from these 4 regions (1 to 5 mm edge length) and tested in compression in axial direction. BDAT speed of sound of the first arriving signal (vFas) and ultimate stress were averaged over the 4 regions. On a slice perpendicular to the midshaft axis, BMD was measured using μ-CT (vivaCT, Scanco Medical). An elliptical measurement region was placed manually in the anterior cortical part.

Results: 16 specimens were included in the study (11 female, 5 male), age 81 +/- 8.6 years. vFas was 3903 +/- 122 m/s, BMD was 929 +/- 73 mg/cm3 and ultimate stress was 144 +/- 27 MPa. vFas correlated with ultimate stress ($R^2=0.35$, RMSE=21 MPa, $p<0.01$) as did BMD ($R^2=0.59$, RMSE=18MPa, $p<0.001$). Both variables contributed independently to the estimation of ultimate stress ($R^2=0.80$, RMSE=13MPa, $p<0.001$) (Figure 1).

Conclusion: These findings indicate that QUS in cortical bone might reflect aspects of bone fragility not captured by BMD. It has to be noticed that geometry and size of the tibia do not have an impact on the measurements of BMD and ultimate stress but on vFas at least in bones of small cortical thickness. Our aim was to explore the contribution of QUS on bone strength excluding size as a confounder. This is only a study with a limited sample size; however, findings are promising and should be verified using a higher number of specimens.

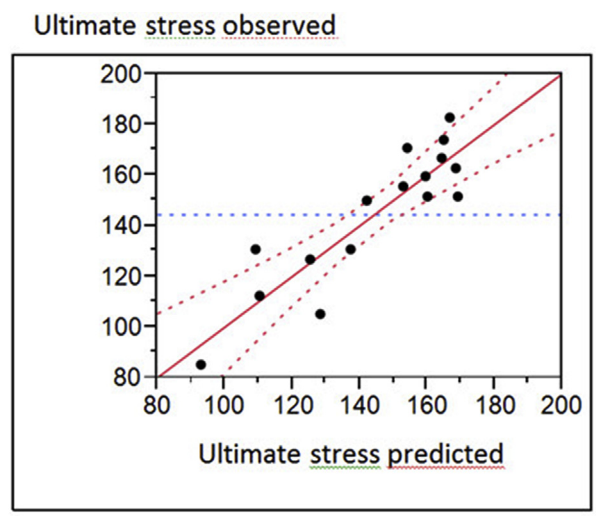

Figure 1: Observed ultimate stress versus predicted

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STATISTICAL APPEARANCE MODELING OF WHOLE-BODY BONE SHAPE AND DENSITY

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Objective: To model osteoporosis and other bone diseases in terms of their impact on systemic bone shape, size, and density using whole-body DXA imaging and statistical appearance modeling.

Background: To date, osteoporosis has been described using regional DXA bone density assessments (lumbar spine, total hip, neck, etc.) and average values for these regions. Bone shapes have also been studied as additional risk factors (hip axis length, hip structure analysis, etc.). However, these approaches use only a small fraction of the bone shape and density variance observed in a population, and they are indexed by age and development of osteoporosis or other bone-compromising conditions such as diabetes. Statistical appearance modeling (SAM) is a method that captures most of the variance in a set of images in a manageable set of orthogonal variables. Hitherto, SAM has not been applied to whole-body DXA imaging. Our goal is to model 95% of the variance of bone shape and density using SAM. Such a model could improve understanding of how bone form relates to function, and support new hypotheses regarding fracture risk reduction.

Methods: Hologic whole-body DXA images are being acquired on a healthy pilot population. Acquired images were converted into pixel-specific masses of bone, fat, and lean tissue. 102 fiducial points were placed on skin and bone edges using an active appearance modeling software package developed by the University of Manchester. A training subset was used to semi-