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# Ultrasonic wave propagation in cancellous part of swine metacarpal bone

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## 1. Introduction

Quantitative ultrasound (QUS) is becoming an important technique to assess the bone status. One attempt is the measurement of cancellous bone, which is a good indicator for the osteoporosis. We have reported on the characteristic wave propagation of two longitudinal waves in the cancellous bone, the fast and slow waves [1, 2]. A new in vivo measurement system is also developed making use of this phenomenon. In the in vivo assessments, however, ultrasonic wave passes through both cortical and cancellous parts of bone, which also induces more complexity in the wave propagation. In addition, there are a few in vitro reports of ultrasonic wave propagation through both cancellous and cortical parts of bone. In this study, then, we have investigated the wave propagation in the cancellous bone covered by cortical bone with both experimental and simulation approaches.

## 2. Materials and methods

### 2. 1 Sample preparation

Cancellous bone specimen was obtained from the proximal part of left swine metacarpal. The size of the swine specimen used was about 13×13×6 $mm^3$. One surface of cancellous bone specimen was covered by cortical bone. The specimen was defatted before the measurements by boiling.

### 2. 2 Measurements

#### 2.2.1 Ultrasonic measurements

Measurements of longitudinal wave were performed using a conventional ultrasonic pulse technique. A PVDF focus transmitter (diameter 20 mm, focal length 40 mm) and a PVDF receiver (diameter 10 mm) were used in this experiment. The beam width at the half maximum values of the wave amplitude was approximately 1.5 mm at the focal point [3]. Both PVDF transducers were mounted coaxially with distance of 60 mm in degassed water at about 25°C. A single sinusoidal signal with a center frequency of 1 MHz and amplitude of 50 $V_{p\text{-}p}$ was applied to the transmitter. The longitudinal wave propagated through water, sample and water. The other transducer received the wave, and converted it into the electrical signal. The received signal was amplified by a 40-dB preamplifier and visualized in an oscilloscope. The front of the cancellous part of specimen was placed in the focal zone of the sound field as shown in **Fig. 1**. CT image of the specimen was obtained using X-ray micro-CT (SMX100-CT Shimadzu).

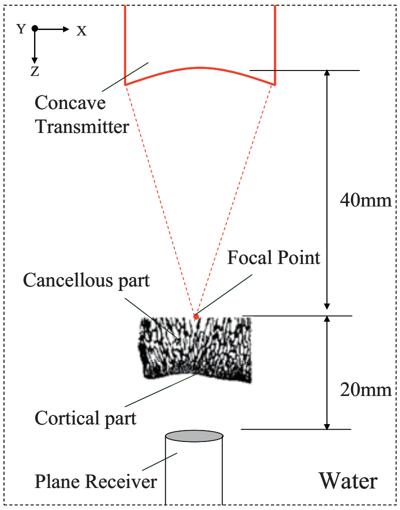


Fig. 1 Schematic representation of the measurement system. The inside porous area and outside the specimen were filled with degassed water.

#### 2.2.2 FDTD Simulation

We have used the governing equations of 3 dimensional elastic FDTD (finite-difference time-domain) method. For example, the empirical equations for the $x$ direction are shown here.

$$\frac{\partial \sigma_{xx}}{\partial t} = (\lambda + 2\mu)\frac{\partial v_x}{\partial x} + \lambda\frac{\partial v_y}{\partial y} + \lambda\frac{\partial v_z}{\partial z}, \qquad (1)$$

$$\frac{\partial \sigma_{xy}}{\partial t} = \mu\left(\frac{\partial v_x}{\partial y} + \frac{\partial v_y}{\partial x}\right), \qquad (2)$$

$$\frac{\partial v_x}{\partial t} = \frac{1}{\rho}\left(\frac{\partial \sigma_{xx}}{\partial x} + \frac{\partial \sigma_{xy}}{\partial y} + \frac{\partial \sigma_{zx}}{\partial z}\right), \qquad (3)$$

Here, $\sigma ij$ is the normal and shear stresses, $vi$ is particle velocity, λ and μ are Lame's coefficients, and ρ is density of the medium. In this simulation, elastic anisotropy and attenuation were not considered. Using the same equations for $y$ and $z$ directions, the stress and particle velocity were calculated alternately both in the spatial and time domains. The FDTD simulation software was originally programmed by our group [4].

## 3. Results and discussion

### 3.1 Experimental results

The experimentally observed waveforms are shown in **Figs. 2** (a) and (b). Figure 2 (a) shows the result when the transmitted wave passes only through water, Figure 2 (b) shows the result when the transmitted wave passes water and specimen. In Fig. 2 (b), the clear separation of fast and slow waves was not seen, then, the waves were overlapped in this measurement.

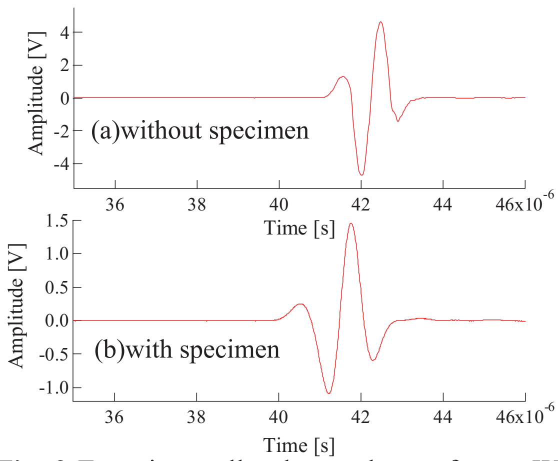


**Fig. 2** Experimentally observed waveforms. Waves pass through the experimental setup, (a) without the specimen, or (b) with the specimen.

### 3.2 Numerical results

**Figures 3** show the screenshots of the distribution of sound pressure (in liquid portion) or root-mean-square value of normal stresses (in solid portion) in the x-y plane of the three-dimensional simulation field. The fast wave and slow waves can be seen as shown in Fig. 3 (b), (c) and (d), and the fast wave which passed thorough solid part (trabecular) was clearly observed. The slow wave, however, was unclear in Fig. 3 (e) and (f). The pore size near the cortical part was smaller than that in the cancellous part. The slow wave, then, reflected or entered the trabecular near the cortical part. In addition, the tail of fast wave was overlapped when the slow wave entered the trabecular near the cortical part as shown in Fig. 3 (e) and (f). **Figure 4** shows the numerically observed waveform passed thorough water and specimen. The clear separation of fast and slow waves was not also seen. The fast wave (first and second peaks in Fig. 3) was clearly observed, and the following waves (third peak as shown in Fig. 3 (f)) were appeared after fast wave.

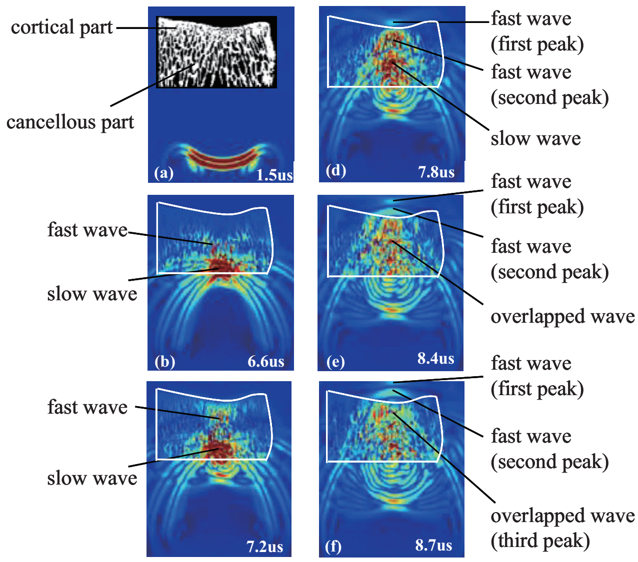


**Fig. 3** Screenshots of the distribution of sound pressure in the x-z plane of the three-dimensional simulation field.

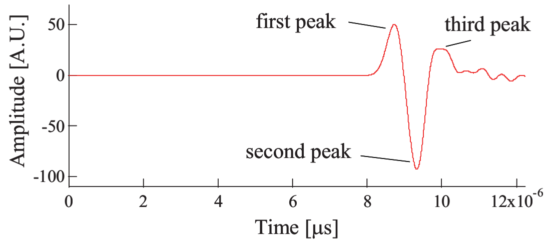


**Fig. 4** Numerically obtained waveforms which passed through water and the specimen.

## 4. Conclusion

Ultrasonic wave propagation in swine metacarpal bone specimens with both cortical and cancellous bones was investigated. The clear separation of fast and slow waves was not seen in both experimental and numerical measurements. The slow wave, however, existed in cancellous part and became unclear around the cortical part. It indicates that the slow wave is strongly affected by the cortical part in the cancellous bone.

## References

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