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Time-Amplitude mapping of ultrasonic wave propagating in the cancellous bone -evaluation of anisotropic structure-

高速波・低速波の伝搬波形マッピングによる海綿骨の骨梁構造評価手法の検討

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1. Introduction

Osteoporosis is a disease which causes a decrease of bone strength. For mass-screening, there are 2 main methods to evaluate bone *in vivo*, DXA (Dual-energy X-ray Absorptiometry) and QUS (Quantitative Ultrasound). The latter, QUS method has many advantages. It enables to measure two parameters, SOS (Speed of Sound) and BUA (Broadband Ultrasonic Attenuation) which are related to the elastic properties. However, in the present systems, these two parameters are obtained without considering complex bone structures and heterogeneity. This problem results in the poor reproducibility of parameters. Therefore, new QUS methods have been investigated from many points of view.1) The cancellous bone, which has porous structure and reflects the disease in the early stage, is also focused on for new *in vivo* QUS method. Ultrasound in the cancellous bone often separates into fast and slow waves, depending on the bone volume fraction and trabecular orientation. A new method using this phenomenon have also been proposed in Japan.2,3)

In previous study, we have studied the ultrasound propagation in cancellous bone, and clarified the variation of wave velocity due to the trabecular structure. When ultrasound propagates along the trabecular orientation, two waves can often be observed. On the other hand, when ultrasound propagates normal to the trabecular orientation, two waves usually overlap, and the velocity decreases.4-6) Therefore, the investigation of two-wave phenomenon gives us information of trabecular orientation. If we can visualize the phenomenon, it will be a useful tool for the diagnostic system.

In this study, we have experimentally evaluated the anisotropic structure of cancellous bone using two-dimensional imaging of ultrasound.

2. Sample preparation

The cancellous bone specimens were obtained from the distal part of 30-month-old female bovine femur. The specimens were defatted, and shaped into cylinders: diameter 11.00 mm ± 0.05 mm. Before measurements, the specimens were degassed in water for 2 hours to remove air bubble in the specimen. In addition, we obtained 3D images of trabecular structures by X-ray micro CT (Shimadzu, SMX-160CTS). The structural parameters were calculated by Tri 3D-Bon (Ratoc) software. They are main trabecular orientation and DA (Degree of Anisotropy).

3. Ultrasonic measurements

Figure 2 shows the ultrasonic measurement system. A conventional ultrasonic pulse technique was performed. A PVDF concave transmitter (Toray Engineering, 20 mm in diameter with a focal length

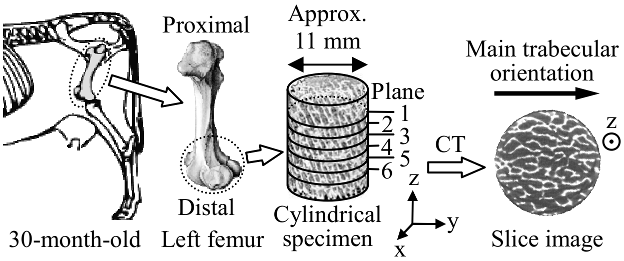

Fig. 1 Sample preparation.

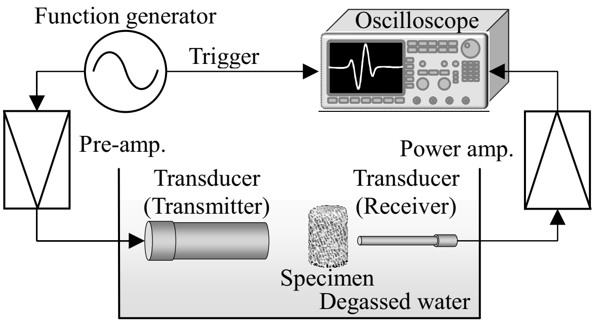

Fig. 2 Ultrasonic experimental system.

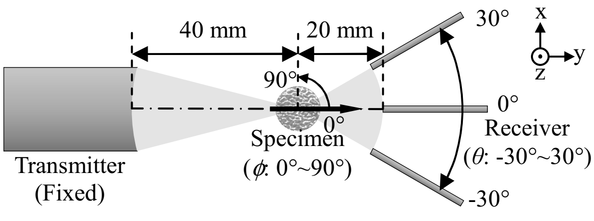

Fig. 3 Layout of transducers and specimen. (Top view)

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of 40 mm) and a hand-made PVDF receiver (2.8 mm in diameter) were used. A function generator (Agilent Technologies, 33250A) delivered electrical pulses to the transmitter. A single sinusoidal signal with a center frequency of 1 MHz and amplitude of 50 V_{P-P} was applied to the transmitter. It was converted into ultrasonic pulse wave. The receiver converted ultrasound into an electrical signal. The signal was amplified for 40 dB at preamplifier (NF, BX-31) and observed with an oscilloscope (Tektronix, TDS520D). We set the focal point of wave on the central axis of the cylindrical specimen.

Figure 3 shows the top-view measurement setup in water. In previous studies, both PVDF transducers were mounted coaxially. In this study, we rotated the receiver on the central axis of the cylindrical specimen, and measured at different points. The angle range was -30~30° (sound axis is 0°). The measurements were also performed by changing position of the specimen along the direction of cylindrical axis z.

4. Results

We performed imaging by converting amplitudes of received ultrasound into grayscale and obtained images of “receiver angle vs. time”. Here, in order to emphasize the fast wave with small amplitude, the image of slow wave with large amplitude is saturated.

Figure 4 shows the images at Plane 1 where the trabecular shows relatively strong alignment (DA = 2.40). When the trabecular direction is along sound axis, fast wave reaches earliest at 0°. The time when the fast wave arrives changes with the rotation of specimen. However, when the specimen angle becomes larger than 60°, fast and slow waves overlap. These data mean that the fast wave apparently “refracted” in the smaller angles.

Figure 5 shows temporal difference of 1st zero-cross time of received wave at each receiver angle (positive value means the early arrival). The stronger the trabecular alignment becomes (high DA values), the earlier zero-cross time shifts to the trabecular alignment direction (Plane 1).

5. Conclusion

We evaluated the ultrasound propagation in bovine cancellous bone, and showed images of ultrasound passed through the bone. The temporal difference of 1st zero-cross time of received waves would be a good index to evaluate the trabecular orientation quantitatively. The apparent “refraction” of fast wave has also been studied by numerical simulation.[7] Our present experimental data supports the study and seem useful for new *in vivo* evaluation method.

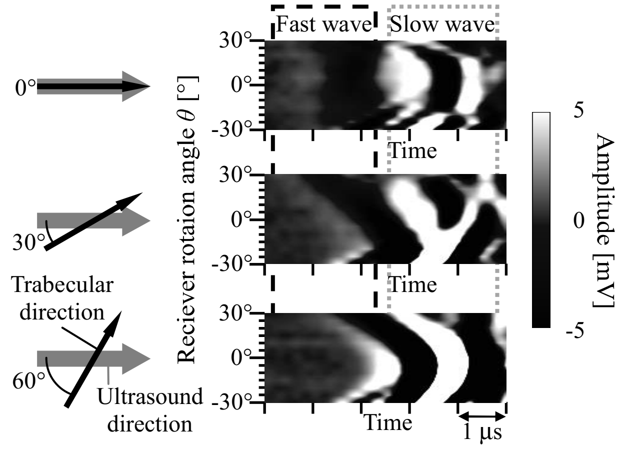

Fig. 4 Time-amplitude mapping (Plane 1).

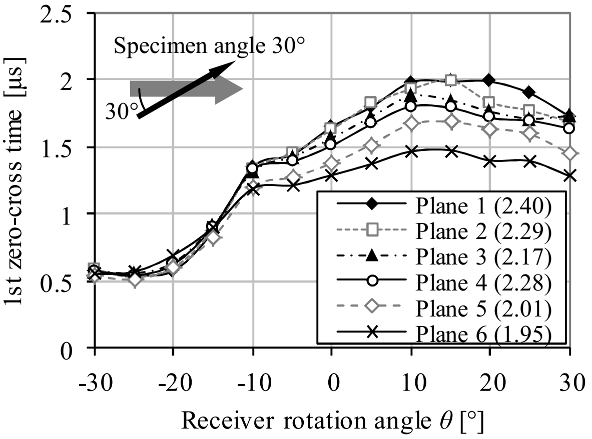

Fig. 5 Difference of 1st zero-cross time of observed waveform.
(Numbers in parentheses indicate DA values)

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