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Distribution of ultrasonic wave velocities in radial direction of bovine cortical bone
ウシ皮質骨の径方向音速分布

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1. Introduction

Osteoporosis is a disease characterized by low bone mass and micro-architectural deterioration of bone tissue, leading to enhanced bone fragility and a consequent increase in fracture risk [1)]. It is then important to detect the earlier symptom. Bone quantitative ultrasound (QUS) methods are suitable for mass screening, and widely used for the assessment of osteoporosis. However, QUS methods have lower reproducibility than the DEXA (dual energy X-ray absorptiometry) because of anisotropy and the heterogeneity of bone. Yamato et al. have actually reported complicated velocity distribution in the axial direction of bovine cortical bone and pointed that longitudinal wave velocity of bovine cortical bone changed due to the measurement positions and microstructures [2, 3)].

Osteoporosis and some endocrine diseases are known to decrease the cortical thickness. This is a problem because cortical bone is important to support body weight. Therefore, ultrasonic wave velocities in radial direction are required to be accurately obtained for the estimation of precise cortical bone thickness. However, the character of velocity distribution in the radial direction is not known yet. In this study, we have investigated longitudinal wave velocities in this direction.

2. Samples

The cortical bone samples were obtained from the mid-shaft part of the bovine femora (25-31 months old) as shown in **Fig. 1**. The samples were processed into the rectangular shapes (5.0-7.0×10×30 mm^3), three samples have plexiform structure and four samples have haversian structure. We observed structure of all samples by an optical microscope. **Figure 2** shows observed micro-structures of the samples.

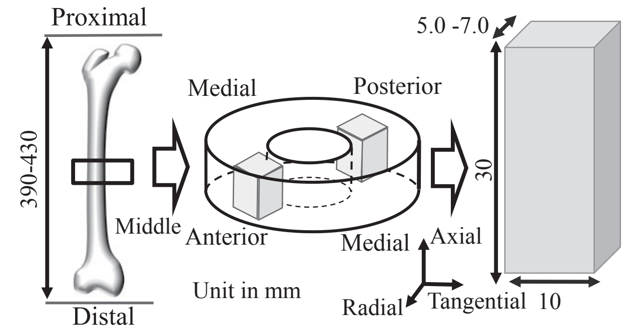

Fig. 1 Sample.

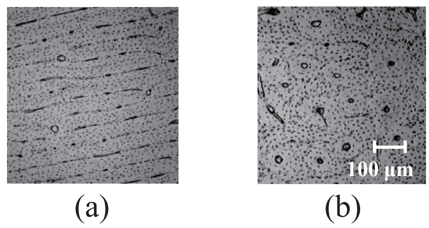

Fig. 2 Microscopic structures of bovine cortical bone: (a) plexiform and (b) haversian structures.

3. Results and Discussion

Figure 3 shows the experimental system used. A single sinusoidal wave in the range from 1 to 5 MHz, with an amplitude of 2 Vp-p from a function generator (Agilent Technologies, 33250A) was amplified 20 dB by a power amplifier (NF, HAS

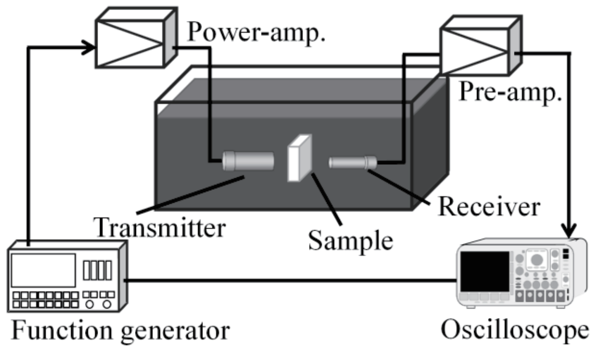

Fig. 3 Experimental System.

4101), and applied to the transmitter. We used a PVDF focus transmitter (Custom made, Toray, 20 mm in diameter with a focal length of 40 mm). The waves that passed through the sample in the radial direction were converted into electrical signals by the receiver (handmade, 3 mm in diameter) and observed by a digital oscilloscope (Tektronix, TDS 524A) with 20 dB preamplifier (NF, BX-31). The measured sample was placed in the focal zone of the sound field, and the transmitter was prepared to be 60 mm away from the receiver in the degassed water. We scanned surface area of the sample with a step of 2.0 mm. The bone thickness at each measurement

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point was measured using a micrometer. By reducing the sample thickness gradually with Δd = 1 mm, the distribution of the wave forms were measured until thickness of 2 mm. The velocity and attenuation in the bone were estimated from the arrival times and amplitude spectra of observed waves which passed through the bone and water.

4. Results and Discussion

The averaged velocity of all samples was around 3.445×10^3 m/s. The velocities in the haversian samples were 3.383×10^3 m/s. The velocities in the plexiform samples were 3.505×10^3 m/s. These values were in good agreement with the data of Yamato *et al*. [4)]. **Figures 4 (a) and (b)** show one of the results, the distributions of ultrasonic wave velocities in the radial direction of bovine cortical bone at 1 MHz. Additionally, we obtained the velocity in each of 1mm slice of the sample, and found that the velocities of innermost layer showed significantly higher values than those of outermost layer at 1MHz ($P < 0.05$) (**Fig. 5**). The velocity of the inside was 1.2-7.9 % higher than those of the outside. However, the frequency dependence of velocity was small in all samples. The maximum standard deviation of the velocities in one sample surface was 59.8 m/s. These velocity data are important to accurately estimate the cortical bone thickness.

The averaged attenuation coefficient in the plexiform samples at 1 MHz was 1.2 dB/cm. That of the haversian samples at 1 MHz was 1.0 dB/cm. These values were in agreement with the data of Sasso *et al*. [5)].

5. Conclusion

We have experimentally investigated the longitudinal wave velocities in the radial direction of bovine cortical bone. The averaged velocities in radial direction were around 3.445×10^3 m/s and depended on the positions. The inside velocities seemed faster than those of outside. These data give us the information of heterogeneity of cortical bone in radial direction, which result in the dispersion of cortical thickness measurements. Human bone mainly consists of haversian structure, and is also considered to have heterogeneity of velocity.

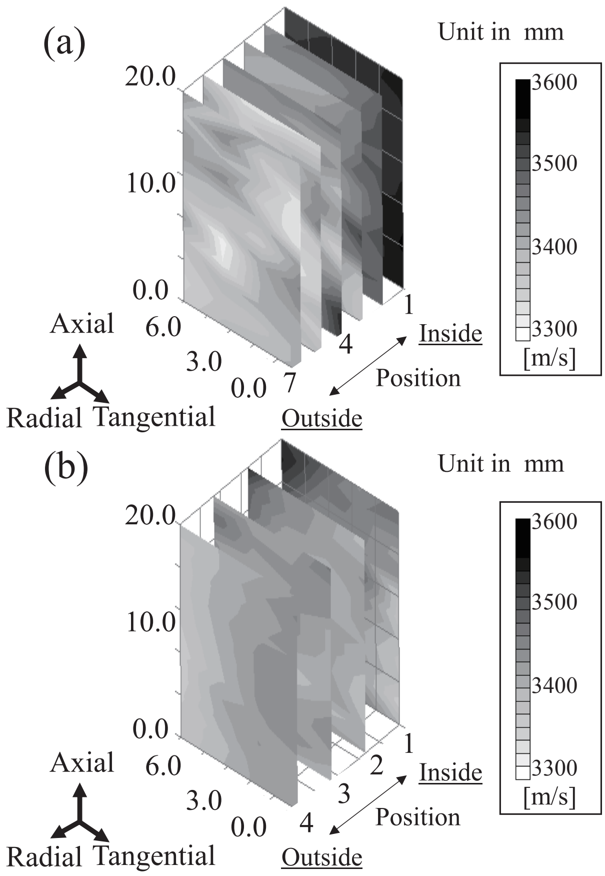

Fig. 4 Distributions of ultrasonic wave velocities: (a) plexiform and (b) haversian structures.

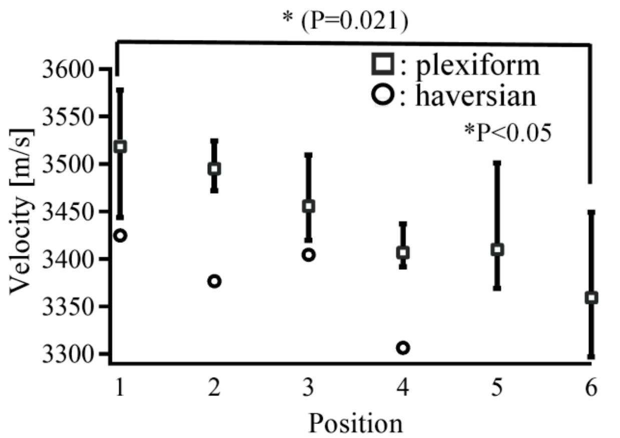

Fig. 5 Averaged ultrasonic wave velocity in each slice of 1mm in radial direction of plexiform and haversian structure sample.

References

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