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Effect of material properties of cancellous bone on fast and slow wave velocities

海綿骨の材料特性が高速波・低速波音速に及ぼす影響

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1. Introduction

Osteoporosis is a skeletal disease that increases the risk of fracture due to a decrease in bone strength. Quantitative Ultrasound (QUS) method is used because it is non-invasive and simple without a special technician. One recent technique of QUS is the use of two wave phenomenon in the cancellous bone. The two wave propagation phenomena occurs when the wave propagates pallallel to the trabeculae. The fast wave mainly propagates through the cancellous part, and the slow wave mainly propagates through the bone marrow part. There are several studies of the two wave phenomenon with consideration of the trabeculae structure and the bone volume[1] [2].

On the other hand, it is well known that the abnormal collagen cross-linking induces changes in the elastic properties of the bone. The unexpected the bone fracture is often reported due to the abnormal cross-linking formation[3].

In this study, we obseved two waves in the cancellous bone samples with the abnormal collagen cross-linking.

2. Bone sample

The cancellous bone samples were obtained from the distal part of the bovine radius (31 month old) (Fig. 1). The samples were processed into the rectangular shape (23 × 23 × 15 mm^3). Three bone samples were immersed in the incubation (PBS, D-(-)-Ribose, Protease Inhibitor Cocktail Set III, Penicillin-Streptomycin) in order to form the abnormal collagen cross-linking. These bone samples were kept in the incubator at 37 ℃ during the incubation period. One sample was freezed for comparison. Incubation period and freezing period in this study was about 320 hours.

3. Experimental method

3.1 X-ray micro-CT measurements

Tree-dimensional structure of the bone samples were obtained by X-ray micro-CT (Shimadzu, SMX-160CTS). Using the reconstructed 3D CT data, the bone volume fraction (BV/TV) was obtained using “3D-Bon” software (Ratoc). With the 3D data, we obtained Dgree of Anisotropy (DA) of the sample[4]. High DA values mean strong anisotropy.

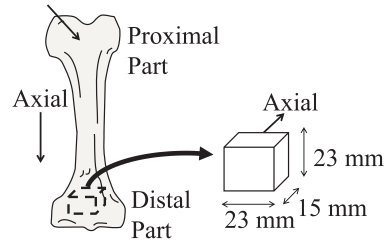

Fig. 1 Fabrication of a bone sample.

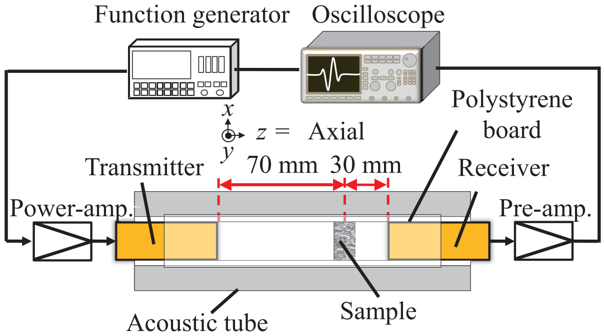

Fig. 2 Experimental system.

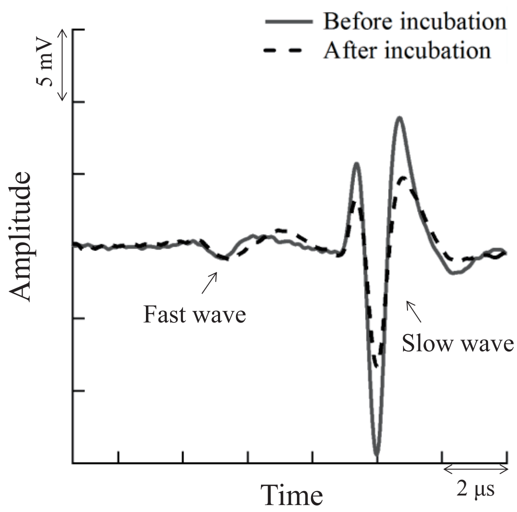

Fig. 3 Wave forms observed.

3.2 Ultrasound measurements

The acoustic tube experimental system is shown in Fig. 2. Plane PVDF piezoelectric transducers (20×20 mm^2) were used as a transmitter and a receiver with distance of 100 mm. The bone sample was set in the position 70 mm from the transmitter. A single sinusoidal wave at 0.8 MHz, with amplitude of 7 Vpp from a function generator (Agilent Technologies, 33250A) was amplified 20 dB by a power amplifier (NF, HSA 4101), and applied to the transmitter. The waves that passed through the sample were converted into electrical signals by the receiver and investigated by a preamplifier (NF, BX-31, 40 dB) and a digital oscilloscope (Tektronix, TDS 524A).

The longitudinal wave propagated through the bone sample and the water. The typical waveforms passed through the bone sample before and after the incubation are shown in Fig. 3. We also measured the wave which passed the water only. The ultrasound velocity was obtained from the phase difference between the water wave and the wave which passed through the bone. In all experiments, the measurement temperature was 24.3 ± 0.3 ℃.

4. Results and Discussion

Figure 4 shows the ultrasound velocities in the cancellous bone sample frozen for 320 hours. The ultrasound velocity changes were at most 15 m/s in the fast wave, and 10 m/s in the slow wave. From these results, the freezing effect was vely small.

The ultrasound velocities of the fast waves in each incubation period is shown in Fig. 5. Measured ultrasound velocities decreased before and after the incubation. One of the reasons is considered to result from the abnormal collagen cross-linking. The decrease seems to show the low elastic properties due to the glycation.

The ultrasound velocities of the slow waves in the bone samples are shown in Fig. 6. The velocities were almost constant. The slow wave was not affected by the abnormal collagen cross-linking because the slow wave mainly propagates in the liquid part of the cancellous bone.

5. Conclusion

We measured the fast and slow wave velocities in the bovine cancellous bone with the abnormal collagen cross-linking. The slow wave velocities did not change, but the fast wave velocities decreased due to the abnormal collagen cross-linking.

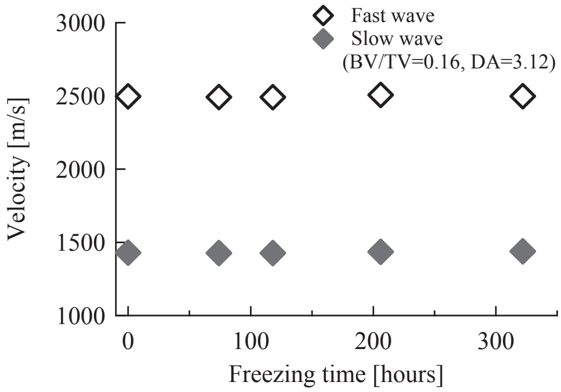

Fig. 4 Freezing effect on velocity.

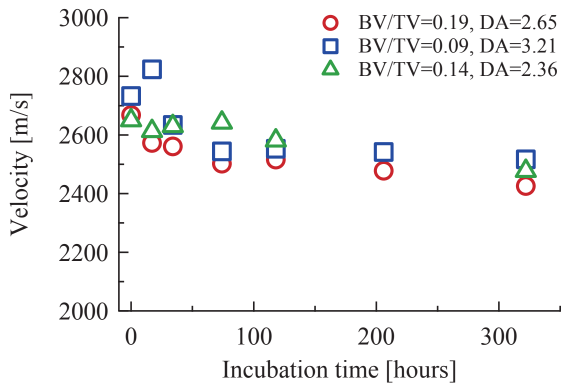

Fig. 5 Ultrasound velocity of the fast wave (Abnormal cross-linking).

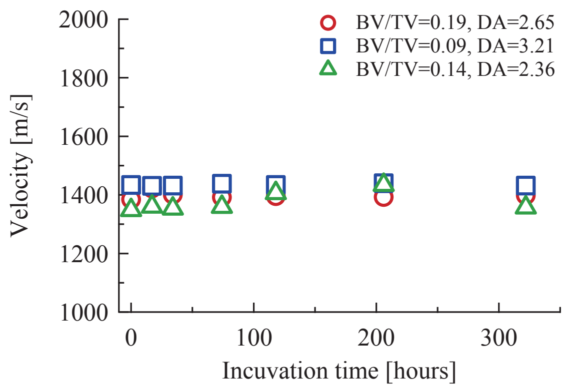

Fig. 6 Ultrasound velocity of the slow wave (Abnormal cross-linking).

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