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Ultrasonic wave properties of bone marrow in human femur and tibia

ヒト大腿骨および脛骨の骨髄中における超音波伝搬特性

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1. Background

Several osteoporosis diagnoses focus on the cancellous bone, because it reflects the initial symptom. Cancellous bone is a porous medium composed of trabeculae filled with bone marrow. In the MHz range, the longitudinal wave in cancellous bone often separates into fast and slow waves depending on the trabeculae structure [1]. The fast wave mainly propagates in the trabecular part, and the slow wave mainly propagates in the bone marrow. The density of cancellous bone can be estimated from the slow wave amplitude [2].

In order to understand the characteristics of slow wave, it is necessary to understand the ultrasonic properties of bone marrow in addition to the bone structure. However, there are a few researches of ultrasonic wave properties of pure bone marrow [3]. Especially, the study of human bone marrow is rare. Therefore, the objective of this study is to evaluate ultrasonic wave properties in bone marrow, using an ultrasonic pulse technique.

2. Measurement method

2.1 Bone marrow preparation

Left distal femora and proximal tibias were obtained from three 68-71 years old female humans (71 years old: sample A, 68 years old: sample B, C). After bone marrow samples were taken out, we put it in a polystyrene rectangular cell (inner width: 10 mm, outer width: 12 mm) and measured within 3 hours. Before measurement, the sample was degassed for about 30 min to remove air bubbles trapped inside. Several samples were frozen after the first measurement.

2.2 Ultrasonic measurement

Ultrasonic measurements were performed using a self-produced polyvinylidene fluoride (PVDF) transmitter and receiver (diameter 3 mm), as shown in Fig. 1. A function generator (Agilent 33250A) delivered electrical pulses to the transmitter, which were converted into ultrasonic waves. Several sinusoidal signal (2-6 waves) with amplitude of 10 $V_{p\text{-}p}$ was applied to the transmitter. The longitudinal wave propagated through bone marrow or water in the cell. The other transducer received the wave and converted it into an electrical signal. The signal was amplified by a 40 dB preamplifier (NF BX-31) and visualized with an oscilloscope (Tektronix DPO3054). The measured frequency range was from 3 to 10 MHz, and temperature range was from 30 to 40 °C. For the temperature control, we used a water loop from a thermostatic water bath (EYELA NTB-221), which went around the marrow sample. The temperature of the sample was measured by a type K thermocouple.

Figure 2 shows two typical propagated waveforms; upper wave is the one propagated through the cell with marrow, lower wave is the one propagated through the cell with water. Wave velocity and attenuation values in the marrow were obtained from the time and amplitude difference between water and marrow waves.

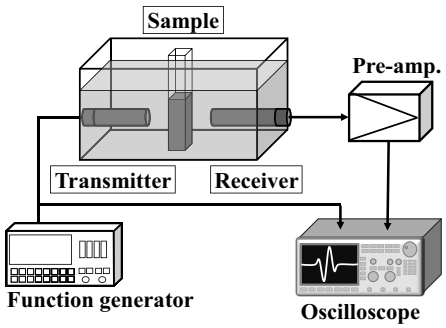

Fig. 1 The measurement system.

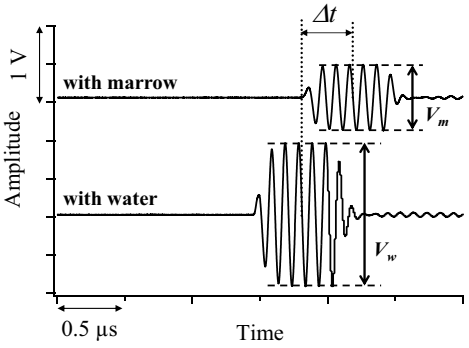

Fig. 2 Typical propagated waveforms at 10 MHz.

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3. Results and Discussion

The first measurement was performed just after the operation of the patients. In order to check the freezing effects on the samples, we have next measured wave properties before and after freezing. The velocity data of the marrow sample A are shown in Fig. 3. Measured wave velocity values decreased as the increase of temperature. The influence of freezing was very small even after 2 weeks.

Figure 4 shows the comparison of wave velocities in human and bovine bone marrow [4]. Site dependence of wave velocity in human bone marrow was very small. However, the velocity of human bone marrow was not similar to those of bovine bone marrow. Akashi has reported that the velocity range of bovine fat was 1441-1450 m/s at 20-40 MHz and 22-24 °C [5]. These values are very similar to the velocity of human bone marrow, considering the extrapolation of our data. Therefore, the velocity of human bone marrow is similar to those of bovine fat rather than bovine bone marrow. The human bone marrow looked like oily liquid. On the other hand, bovine bone marrow looked like oily liquid with fibrous tissues. The difference of velocities may come from the tissues.

The frequency dependence of wave attenuation is shown in Fig. 5. The fat data was estimated from the reference [5]. The values of the exponent on frequency of attenuation ranged from 1.4-1.7 for human bone marrow, 1.7 for bovine fat, and 1.5-1.7 for bovine bone marrow [4]. The frequency dependence of attenuation of human bone marrow was similar to those of bovine fat and marrow. However, the values of attenuation in human bone marrow were lower than those of bovine bone marrow. This difference also may come from the fibrous tissues.

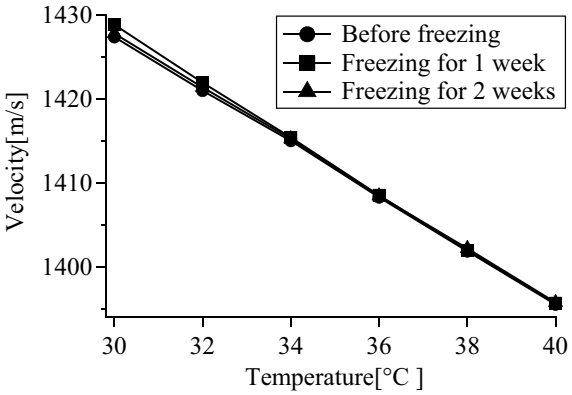

Fig. 3 Freezing effect on velocity in human bone marrow at 5 MHz (Sample A).

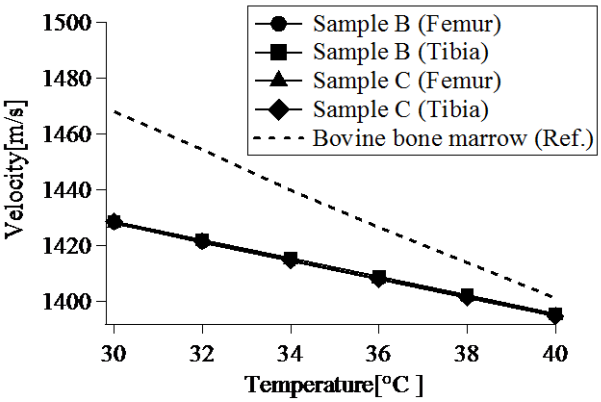

Fig. 4 Wave velocity in human bone marrow samples at 5 MHz.

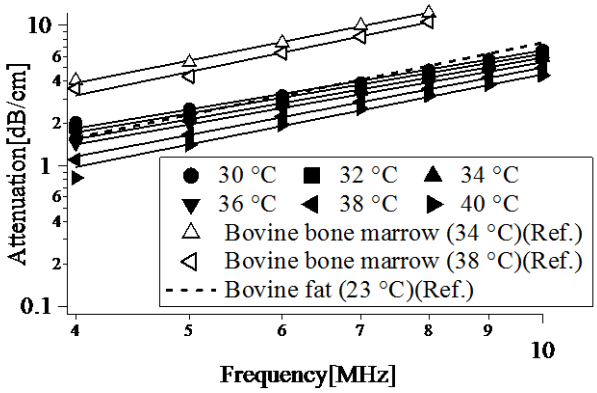

Fig. 5 Frequency dependence of attenuation in bone marrow sample in a proximal tibia of (Sample B).

4. Conclusion

In human bone marrow, Wave velocity and attenuation decreased as temperature increased. Ultrasonic wave properties of human bone marrow were similar to those of bovine fat.

Acknowledgment

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