3P-57

Proceedings of Symposium on Ultrasonic Electronics, Vol. 31 (2010) pp. 569-570
6-8 December, 2010

Temperature and site dependence of ultrasonic wave properties of bone marrow in a bovine femur

ウシ大腿骨における骨髄中の超音波音速・減衰の温度および部位依存性

Tomohiro Kubo‡, Kazuki Fujimori, Nicolas Cazier and Mami Matsukawa
(Doshisha Univ.)
久保 智弘‡, 藤森 一樹, カジエ ニコラ, 松川 真美 (同志社大)

1. Introduction

Cancellous bone, which might be affected by osteoporosis, is a porous medium composed of an inter-connected network of solid rods and plates (called as trabeculae) filled with marrow. One interesting phenomenon is that the longitudinal wave in cancellous bone separates into fast and slow waves depending on the trabecular structure [1]. The fast wave mainly propagates in the trabecular part, whereas the slow wave propagates in the bone marrow. The potential measurements of the two-wave phenomenon open new perspective for *in vivo* assessment of bone status [2]. In fact, it has been reported that bone density of cancellous bone can be estimated from slow wave [3].

In order to understand the characteristics of slow wave, it is necessary to understand the ultrasonic properties of bone marrow. However, there are a few researches of ultrasonic properties of pure bone marrow [4]. The objective of this study is then to investigate temperature and site dependence of ultrasonic wave properties in bone marrow, using an ultrasonic pulse technique.

2. Materials and Methods

2.1. Bone marrow preparation

A left femur was obtained from a 30-month-old female bovine. Cylindrical bone marrow samples were obtained from each site of shaft of the bovine femur, proximal, middle, and distal parts, without destruction. The size of cylindrical columns was about 30 mm in diameter. In the measurement, aluminium pipe (inner diameter 23mm) was filled with marrow to prevent collapse by compression. Before measurements, the samples were degassed for 15 min to remove air bubbles trapped inside.

2.2. Ultrasonic measurement

A conventional pulse measurement was performed using a self-produced polyvinylidene fluoride (PVDF) transmitter and receiver (diameter 10 mm), as shown in **Fig. 1**. A function generator (Agilent 33250A) delivered electrical pulses to the transmitter, which was converted into ultrasonic waves. Several sinusoidal signal (5-15 waves) with

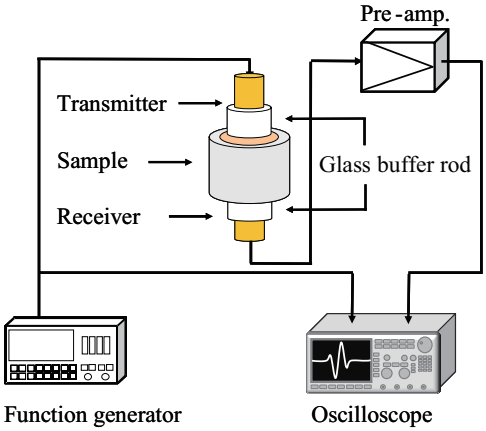

Fig. 1 Ultrasonic measurement set-up.

amplitude of 10 $V_{p\text{-}p}$ was applied to the transmitter. The longitudinal wave propagated through bone marrow. 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 DPO7054). The measured frequency range was from 3 to 10 MHz, and temperature range was from 15 to 40 °C.

The transmitter and receiver were connected to the cylindrical glass (diameter 19 mm) for the purpose to protect the transducers from heat, and the improvement of parallelism. During measurements, we observed direct wave and reflected wave which reflected twice at the interfaces between the glass and marrow. In this case, the wave velocity values were obtained from the time difference between direct and reflected waves (Δt). The wave velocity in the marrow was derived from Δt and d, the gap of connected glasses (sample thickness: 1.8-2.4 mm). The wave attenuation was obtained from the amplitude difference between the direct (V_D) and reflected (V_R) waves. The wave attenuation in the marrow was derived from,

$$\alpha = \frac{20}{2d}\log\left\{\frac{V_D}{V_R}\left(\frac{Z_G - Z_M}{Z_G + Z_M}\right)^2\right\}, \qquad (1)$$

where d is the distance between transducers, Z_G and

mmatsuka@mail.doshisha.ac.jp

Z_M are the acoustic impedance of connected glass and bone marrow, respectively. Measurement error of velocity was about 1 %.

For the temperature control, we used the water loop from a thermostatic water bath, which goes around the marrow sample. The temperature of the sample was measured by a type K thermocouple.

3. Results and Discussion

We measured velocity and attenuation in bone marrow in the range of 3-10 MHz and 15-40 °C. The velocity data of the marrow sample obtained from each site of bovine femur at 5 MHz are shown in **Fig. 2**. Site dependence of wave velocity in bone marrow was small. Measured wave velocity values decreased as the increase of temperature. This decreasing tendency was in good agreement with the velocity data of coarsely filtered yellow marrow of El-Sariti [4], although values of filtered marrow were lower than those of our data. The velocity decrease slightly changed, showing a kink around 23-24 °C, where a transition from soft solid to oily liquid occurred. Below this temperature, frequency dispersion was observed. The relaxation strength at the small kink was in the range of 0.023-0.027. Bone marrow is mainly composed of fat cells. Therefore, this transition of bone marrow at around 23-24 °C possibly indicates the melting of fat.

The attenuation data of a marrow sample obtained from the middle part of bovine femur are shown in **Fig. 3**. Measured wave attenuation decreased as the increase of temperature. The frequency dispersion of attenuation was large at low temperatures, whereas that was small at high temperatures. These tendencies were in good agreement with the transition from soft solid to oily liquid. The frequency dependence of attenuation data of the bone marrow and fat [5] are shown in **Fig. 4**. The fat data was estimated from the reference. The values of the exponent on frequency of attenuation ranged from 1.3-1.6 for bone marrow, and 1.7 for fat. The frequency dependence of attenuation of bone marrow was similar to fat, but the values were a little larger.

4. Conclusion

Ultrasonic wave properties in bovine bone marrow were investigated. Both wave velocity and attenuation in marrow tended to decrease as the increase of temperature. Bone marrow shows a transition from soft solid to oily liquid at around 23-24 °C. Frequency dispersion was also observed below transition temperature.

Detailed researches of ultrasonic wave properties in bone marrow were very few. The small site dependence of wave velocity possibly comes from the compositions and we should next focus on the interindividual difference of the femur.

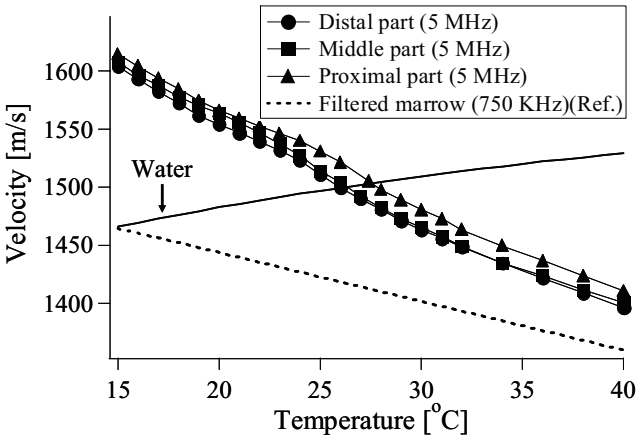

Fig. 2 Wave velocity in the bovine bone marrow at each site.

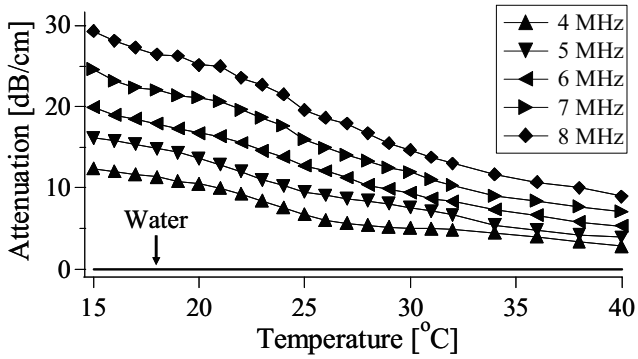

Fig. 3 Wave attenuation in the bovine bone marrow in the middle part.

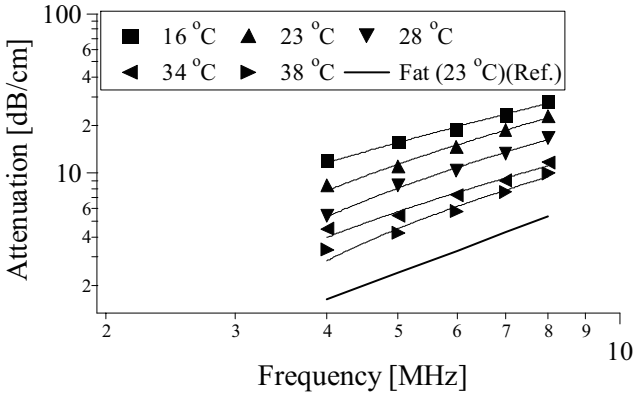

Fig. 4 Frequency dependence of attenuation in the bovine bone marrow in the middle part.

References

1. A. Hosokawa, T. Otani: J. Acoust. Soc. Am. **103** (1998) 2718-2722.
2. T. Otani: Jpn. J. Appl. Phys.**44** (2005) 4578-4582.
3. T. Otani, et. al.: Jpn. J. Appl. Phys. **48** (2009) 07GK05.
4. A. El-Sariti, *et al*.: Ultrasound in Med & Biol. **32** (2006) 985-989.
5. N. Akashi, *et al*.: J. Acoust. Soc. Am. **98** (1995) 3035-3039.