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Wavelet transform analysis of ultrasonic wave propagation in cancellous bone

ウェーブレット変換を用いた海綿骨透過超音波の解析

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1. Introduction

Recently, the number of the osteoporosis patients is increasing in Japanese aging society. For the diagnosis of osteoporosis, ultrasonic method is expected to be a powerful tool, however, the reliability of ultrasonic method is not established yet. Hosokawa *et al.*, therefore, proposed a new method considering two wave phenomenon, which was the separating characterinstics of longitudinal wave into fast and slow waves through cancellous bone [1][2]. Otani and Mizuno *et al.* pointed the strong correlation between the received waveform and the bone volume fractions focusing on the peak amplitudes and the wave fronts of the fast and slow waves, respectively [3][4]. In these reports, the parameters describing bone characteristics were analyzed only in time domain. However, an alternative method is required because the wave separation is often obscurely depending on the specimen.

Nagatani *et al.* unveiled that fast wave requires certain propagation distance to form in-phase wave front caused by some dispersion in the propagating path of fast wave due to the random alignment of trabeculae[5]. This dispersant phenomenon causes the declining of the frequency component of fast wave compared to slow wave.

In this study, based on this fast wave phenomenon, we proposed a new method of analyzing ultrasonic waveforms using wavelet transform.

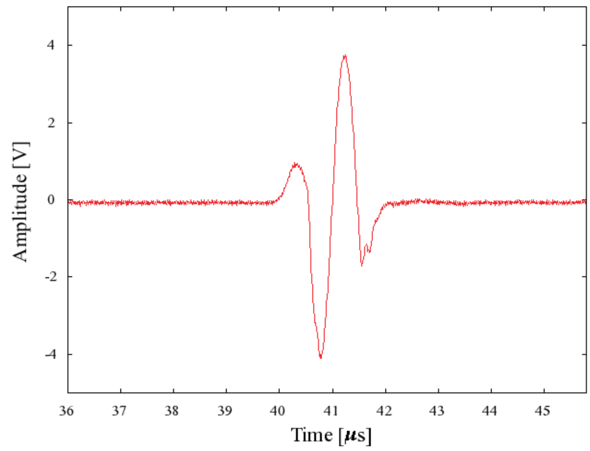
2. Measurement system

In order to compare with the advance study, we used the same condition as the measurement by Nagatani's group[6]. A star-shaped concave PVDF transmitter faced to cuboidal bovine cancellous bone. A single sinusoidal wave at 1 MHz from the transmitter was radiated to specimens. The waves propagated through the specimen were measured with plane PVDF receiver.

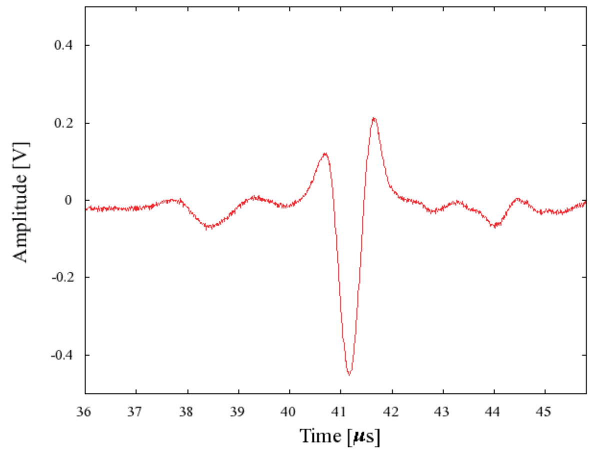
3. Results and discussions

The measured waveforms are shown in Figs.1. Figure 1(a) shows the result when the transmitted wave passes only through the water. Figure 1(b) shows the result when the transmitted wave focused on the center part of the specimen. The separation into fast and slow waves can be seen in Fig.1(b).

In order to analyze the waves propagated through the bone, we used wavelet transform. Figs.2 show the results of wavelet transform of the waveform of Fig.1(a) and Fig.1(b). The hue in the scalograms correspond to the absolute values of the spectra using complex Morlet wavelet. Due to the difference of the frequency components between fast and slow waves, the separation of the two waves in scalogram can be clearly seen in Fig.2(b).

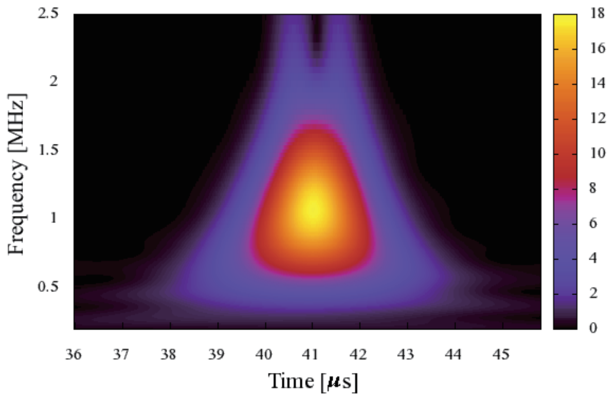


(a) Without specimen

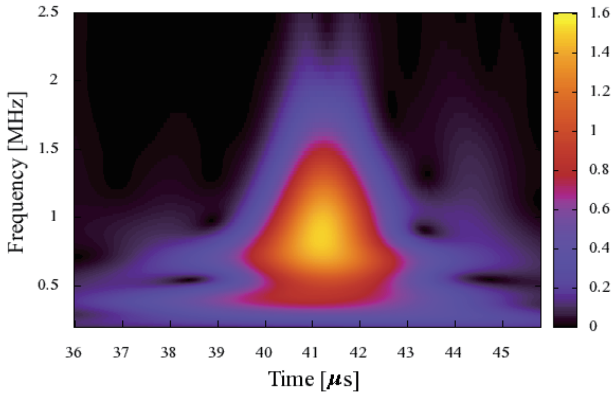


(b) With specimen

Fig.1 Experimentally observed waveforms.



(a) Without specimen



(b) With specimen

Fig.2 Scalograms of experimentally observed waveforms.

In order to decompose the fast wave component, the slow wave part was fitted by two-dimensional Gaussian function. The peak coordinate and peak value of Gaussian function were fixed to the value at the peak of slow wave part. Figure 3 shows the residual of fitting. Only fast wave component can be seen in Fig.3. Using these data, the peak amplitude of fast wave component was investigated.

Figures 4 show the relationship between fast wave amplitude and bone volume fraction. Figure 4(a) shows the relationship between bone volume fraction and the peak value of the fast wave component derived from wavelet transform. Figure 4(b) shows the relationship between bone volume fraction and the peak value of fast wave in time domain. Each result shows a great correlation. This result suggests that traditional analyzing method in time domain can evaluate overlapped waveform of fast and slow waves appropriately. Using wavelet transform method in this study, detailed and precise respective investigations of two waves are expected thanks to the proper separation of overlapping two waves.

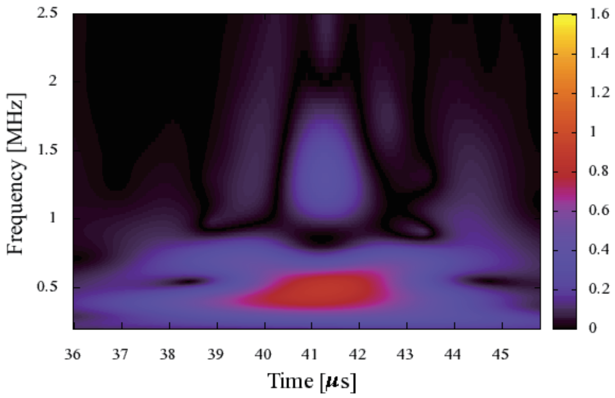
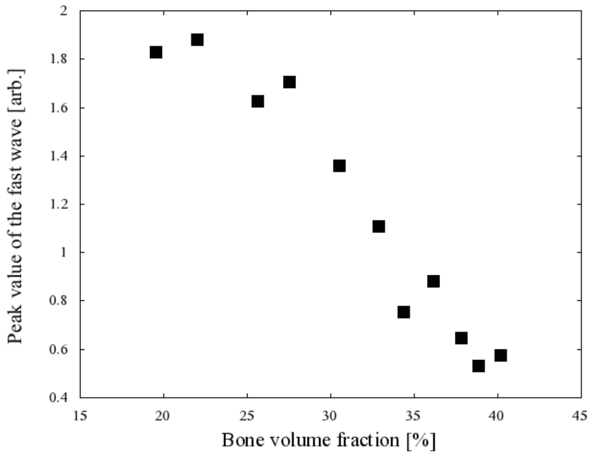
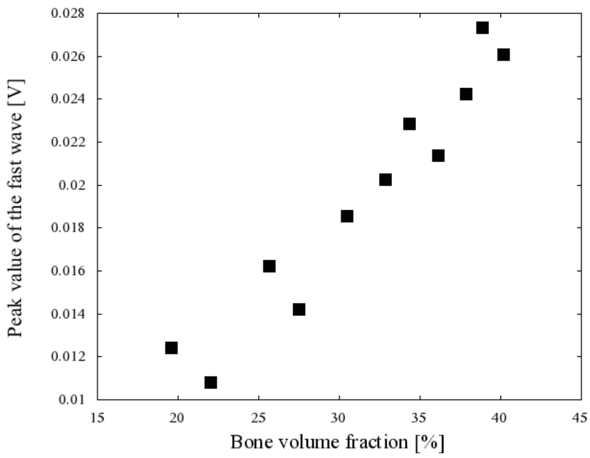


Fig.3 Residual of fitting.



(a) Peak value derived from the residual of fitting



(b) Peak amplitude derived in time domain

Fig.4 Relationship between fast wave amplitude and bone volume fraction.

References

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