

# Study for imaging of inside bone using FM chirp-pulse wave

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**Abstract:** In the previous study, we found the special phenomena that the intensity of the ultrasonic wave penetrated through a sample bone (spine) started to increase from 500kHz and became maximum at about 2MHz using the FM-chirp pulse wave. In this paper, we report a new imaging method utilizing the special phenomena

**Key words:** Bone, ultrasonic image, FM chirp-pulse wave, acoustic amplitude spectrum

## A. Introduction

Recently, bone diseases increase with advancing age. Ultrasound is non-invasive, easy to use and inexpensive compared with X-ray (CT) or MRI. Therefore, the diagnosis of the bone using the ultrasonic image is eagerly desired. The characteristics of the bone for ultrasound imaging have been studied [1]-[3], and the imaging of the bone has been investigated [4]-[8]. In the previous study [3], we investigated the characteristics of sample bones (rib, femur and spine) using the FM-chirp pulse waves with the wide frequency range (100 kHz to 5 MHz). In the experiment, the FM-chirp pulse waves transmitted from a transducer were received by a hydrophone before and after inserting a sample bone between them. The received ultrasonic wave and the frequency spectrum were displayed simultaneously on an oscilloscope. Then, the amplitude spectra of the received waves before and after inserting the sample bone were calculated in a PC (personal computer). Using the data, the acoustic magnitude spectrum (frequency dependent penetration) of the sample bone was obtained. Thus, the measurements and calculations were done in each sample bone using three transducers that have the different center-frequencies (0.5, 1 and 2.25 MHz). As the results, the special phenomena were found regarding the femur and the spine. In these case, the intensity of the penetrated signals through the bone increases at the frequency near 2 MHz. It seemed that the special phenomena such as a sound resonance occur in the bone. One of the phenomena was remarkable on the spine (vertebra), which may provide a new information on the bone imaging.

In this paper, we report a new imaging method utilizing the phenomenon.

## B. Method

### B.1. Experimental system

A schematic of the experimental system is illustrated in Fig.1. In the experiment, a 2.25 MHz focused-transducer (Panametrics A395S) is used [Fig.2]. The frequency range of the transducer is 1.5 MHz to 3 MHz. As the sample bone, a vertebra is used [Fig.2]. The sample bone is placed at the focal point (approximately 11 cm) of the transducer. And a hydrophone with large diameter (9 mm) is located in the position of 10 mm far from the focal point of the transducer in order to avoid the diffraction [9]. In the function generator, not only the FM-chirp pulse but also the single pulse and the burst pulse can be generated by computer control. In the previous study, we found the special phenomena using not only the FM-chirp pulse but also the single pulse and the burst pulse. Therefore, in this experiment, the single pulse is used.

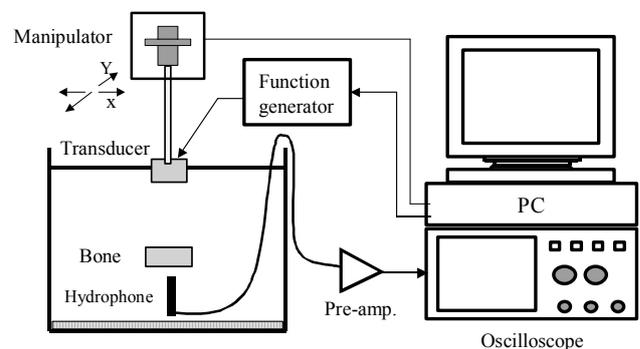


Fig.1. Schematic of the experimental system

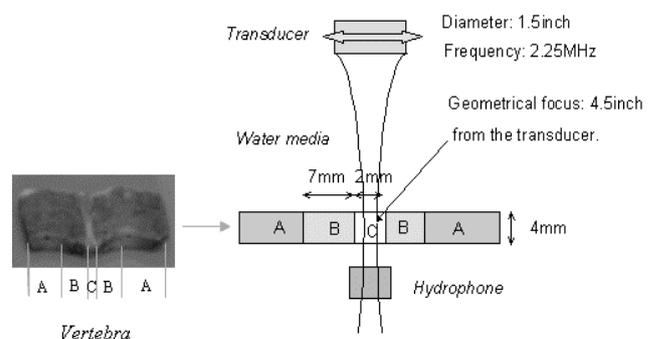


Fig.2. Sample bone and focused ultrasound beam.

### B.2. Measurements

At first, a single pulse wave transmitted from the transducer is received directly by the hydrophone. In the same manner as the previous study, the amplitude spectrum of the received wave before inserting the bone is obtained.

Next, the sample bone is inserted at the focal point of the transducer, and the penetrated wave through the bone is received by the hydrophone. The calculation method for the amplitude spectrum and the acoustic amplitude spectrum is the same as the previous study. The amplitude spectrum of the received wave before inserting the bone is given by  $A_w(f)$ . Where,  $f$  is the frequency in Hz. The amplitude spectrum of the penetrated wave after inserting the bone is given by  $A_B(f)$ . The acoustic amplitude spectrum  $[A(f)]$  of the bone is obtained by dividing  $A_B(f)$  by  $A_w(f)$ .

$$A(f) = A_B(f) / A_w(f).$$

In order to perform the measurements of the bone extending from A to C [Fig.2], the transducer is moved to the X and Y direction over the bone using the manipulator controlled by a stepping motor. The part of A and B is the vertebral body and C is the marrow nucleus. The interval of the movement of the transducer, that is the scanning interval of the ultrasound beams, is 1mm. The entire scanning range of X and Y direction is 40mm and 15mm, respectively [Fig.3]. Therefore, the number of the acoustic amplitude spectrums obtained is 600.

### B.3. Imaging of the sample bone

The imaging of the sample bone is performed by modulating the magnitude of the acoustic amplitude spectrums to the brightness as the video signal. That is, the 600 acoustic amplitude spectrums obtained in the measurements are modulated to the brightness, and an ultrasonic image is obtained. Thus, the ultrasound images for any frequency within the bandwidth of the transducer can be obtained. In the experiment, we tried to make the ultrasonic images at six frequencies.

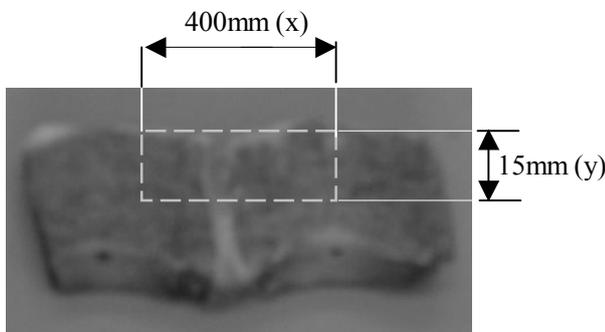


Fig.3. Estimated scanning area on the sample bone

### C. Results and Discussions

The amplitude spectrum of the received ultrasonic

wave before inserting the bone is obtained [Fig.4.]. As shown in Fig.4, the effective frequency range (within -6 dB) of the transducer is approximately 1.5 MHz - 3.5 MHz. After inserting the sample bone between the transducer and the hydrophone, the amplitude spectrum for each part (A, B, B-C and C) of the sample bone is shown in Fig.5 - Fig.8. As shown in Fig.5- (a), the effective frequency range for the part C (marrow nucleus) is approximately 1.6 MHz - 3.5 MHz. In the similar manner, the range for the part B-C (the border of the vertebral body and the marrow nucleus) is approximately 1.4 MHz - 3.0 MHz [Fig.6- (a)]. The range for the part B (vertebral body) is approximately 1.6 MHz - 2.8 MHz [Fig. 7- (a)]. And the range for the part A (vertebral body) is approximately 700 kHz - 1.6 MHz [Fig. 8- (a)].

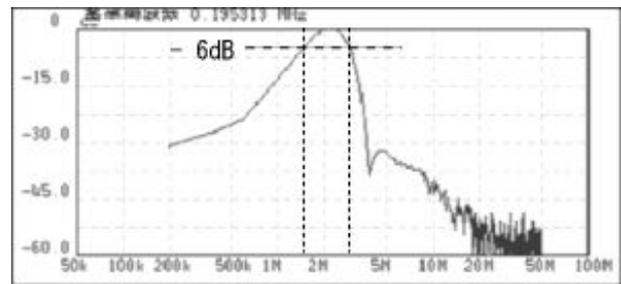
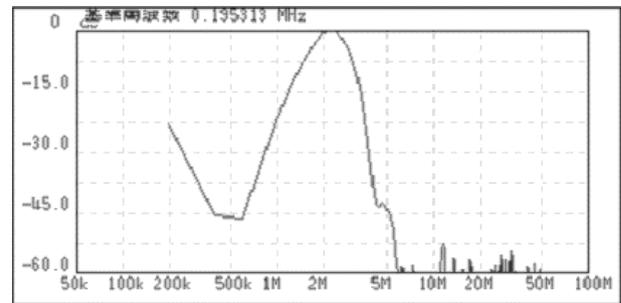


Fig.4. Amplitude spectrum before insertion of the sample bone

a)



b)

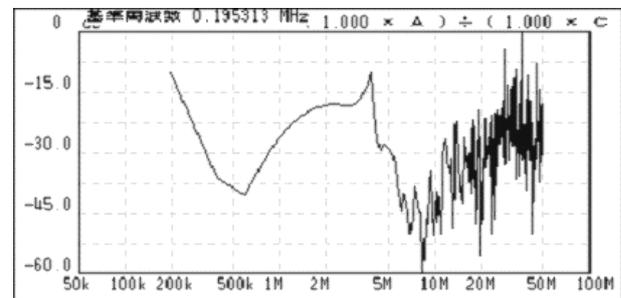
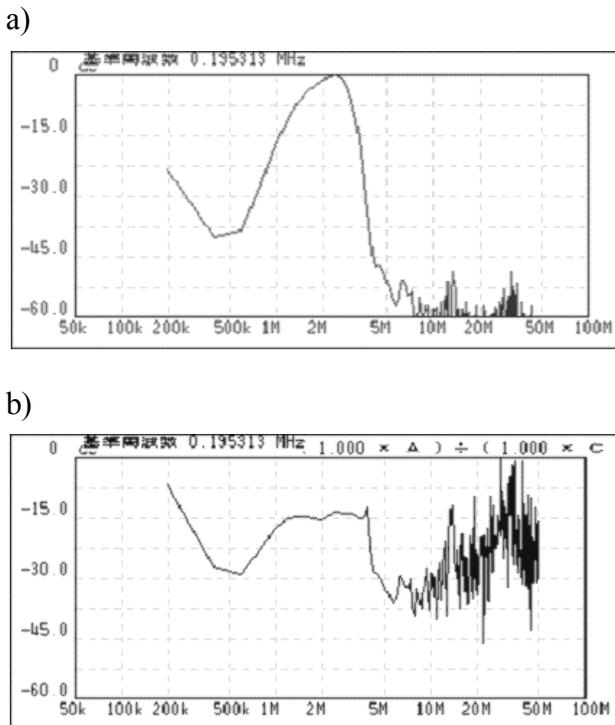


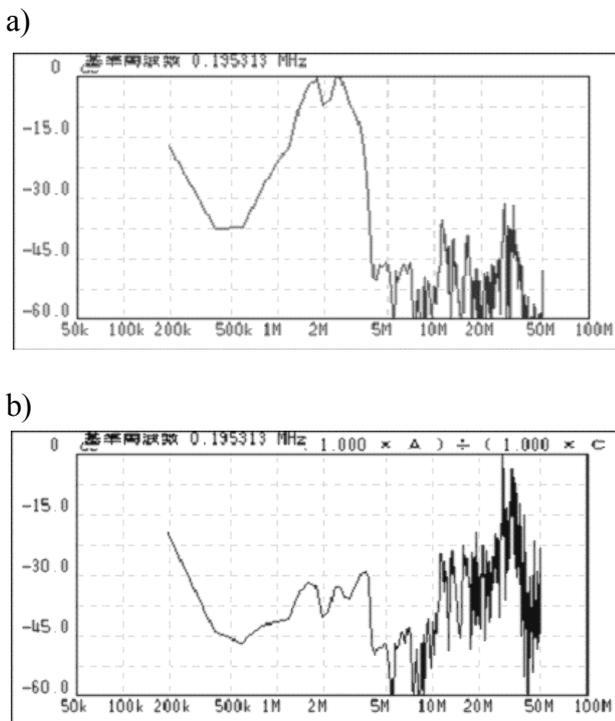
Fig.5. Amplitude spectrum (a) and acoustic amplitude spectrum (b) for the center C of the sample bone

On the other hand, the magnitude of the acoustic amplitude spectrum (frequency dependent penetration)

for the part C is reduced to -18 dB compare to it before inserting the bone and the frequency range is approximately 1.2 MHz - 4.0 MHz [Fig. 5- (b)].



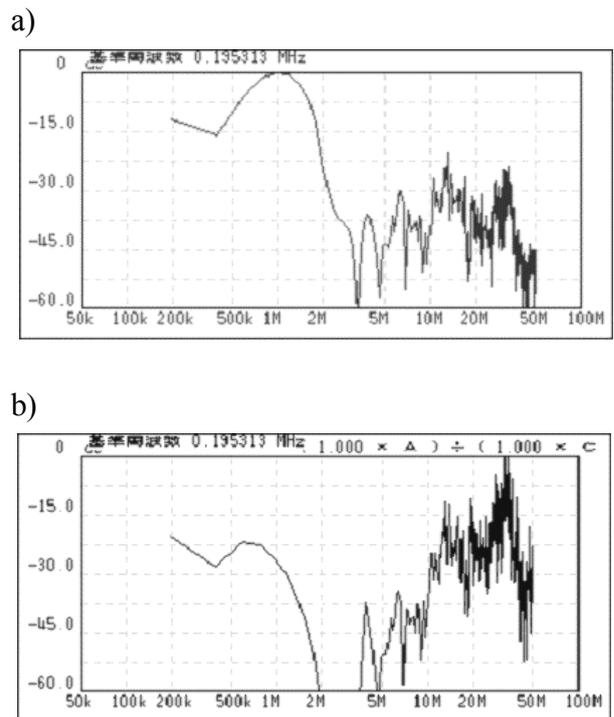
**Fig.6.** Amplitude spectrum (a) and acoustic amplitude spectrum (b) for the part B-C of the sample bone



**Fig.7.** Amplitude spectrum (a) and acoustic amplitude spectrum (b) for the part B of the sample bone

In the same manner, the part B-C is approximately -15 dB and 800 kHz - 4.0 MHz [Fig.6- (b)], the part B is approximately -32 dB and 1.2 MHz - 4.0 MHz [Fig.7- (b)], and the part A is approximately -22 dB and 600 kHz - 750 kHz [Fig.8- (b)], respectively.

As the result of these, it is suggested that the imaging of the marrow nucleus and the surrounding (vertebral body) tissue should be performed using the transducer with the frequency range of approximately 1.5 MHz - 3.0 MHz. On the other hand, it seems that the imaging of the part A should be done using the transducer with the frequency range of approximately 500 kHz - 1.0 MHz.



**Fig.8.** Amplitude spectrum (a) and acoustic amplitude spectrum (b) for the part A of the sample bone

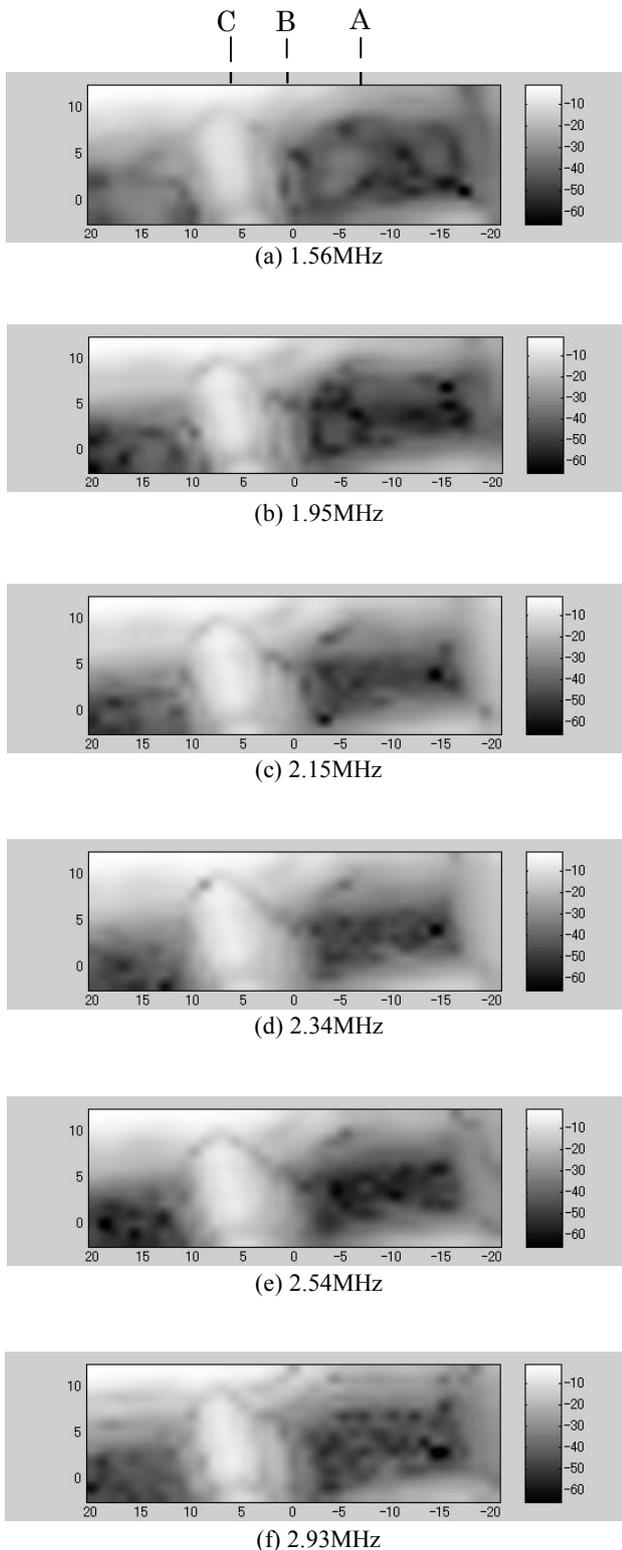
The results of the imaging of the sample bone (vertebra) are shown in Fig.9. The frequencies described in (a) - (f) of Fig.9 are the center frequencies of the transmitted ultrasonic waves.

Regarding the part C (marrow nucleus) and the part B-C (the border of the vertebral body and the marrow nucleus), the image of Fig.9- (f) is clear in comparison with the other images. This is in accordance with the result of the measurement (Fig.5 and Fig.6).

Similarly, regarding the part B (vertebral body near the marrow nucleus), the images of Fig.9- (b) and (c) seems to be clear in comparison with the other images. This is in accordance with the result of the measurement (Fig.7).

Regarding the part A (vertebral body far from the marrow nucleus), the image of Fig.9- (a) seems to be clear as compared with the other images. As described above (Fig.8), it seemed that the imaging should be

performed using the transducer with the lower frequency (approximately 1 MHz).



**Fig.9.** Ultrasonic images of the sample bone obtained by penetration method using the acoustic amplitude spectrum

## D. Conclusion

As the result of this experiment, one of the most important things regarding the bone imaging is that the frequency-dependent characteristic of it should be considered. It will be able to obtain the high quality and high sensitive ultrasonic image, and helpful for diagnosing the bone diseases.

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