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Proceedings of Symposium on Ultrasonic Electronics, Vol. 35 (2014) pp. 129-130
3-5 December, 2014

Two-wave propagation in *in vitro* swine distal ulna.
ブタ尺骨遠位端試料内の 2 波伝搬

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1. Introduction

The ultrasonic bone measurement system LD-100 has been developed based on the principle of the fast and slow waves phenomenon in the distal radius bone of the wrist.[1)] The transmitted ultrasonic signals through cancellous bone were theoretically and experimentally studied for both the fast and slow waves.[2~6)] In our former studies, this two wave phenomenon was observed in a column cancellous bone specimen inserted in a cylindrical cortical bone specimen. And these fast and slow waves were in agreement with the waves transmitted only in the cancellous bone specimen.[7)]

In this study, the transmitted ultrasonic signals are measured in *in vitro* swine distal ulna specimen (including cancellous bone and cortical bone) mimicking a human distal radius bone. Then these waves are compared with the fast and slow waves measured in this specimen without the surface cortical bone. We verify the existence of the two wave phenomenon in the bone specimen that consists of interconnected cortical bone and cancellous bone naturally.

2. Method

The modified LD-100 utilizes the transducer-scanning mechanisms. A pair of focused ultrasonic transducers (a transmitter and a receiver) was arranged in the water tank. The transducers were concave type and have 40 mm focal length. They were consisted of annular array elements in order to change the diameter 20 mm, 14.1 mm, 10 mm or 7.1 mm. Two pairs of transducers of diameter 20 mm and 10 mm were used in this study (**Fig. 1**). One cycle sinusoidal wave (100 V peak-to-peak) was applied to the transmitter. A 6-month-old swine left distal ulna specimen (long diameter 29 - 27 mm, short diameter 14 - 19 mm, length 33 mm, removed bone marrow) (**Fig. 2a**) was set at the focal point between the transducers. The anterior side of the specimen was set to the transmitter and the posterior side of the specimen was set to the receiver. The specimen was scanned at 37 points while moving straight from the lateral side to the medial side at intervals of 1 mm, and at 7 lines from the proximal side to the distal side at intervals of 1mm (total scanning points: 37 x 7 = 259) (Fig. 2a). The waveforms measured at the center of the bone-marrow space are used in the following analyses (Fig. 1). The cross-sectional 7 images of the specimen corresponding to the ultrasonic measurement site (7 lines) were obtained using X-ray micro-CT (SMX-160CTS, resolution: 81 μm, Shimadzu) in advance of the ultrasonic measurement. Then we removed the surface cortical bone (thickness 1 - 2.5 mm) of the specimen (**Fig. 2b**) with a handy router in order to measure the fast and slow waves only in cancellous bone, and the specimen was scanned same way as previously described. Urethane foam blocks were set in the upper and lower parts of the specimen to inhibit the propagation of the circumferential waves in water around the specimen (Fig. 1).

3. Results

The transmitted waveforms were obtained with the transducers of 20 mm diameter in the specimen before removing the surface cortical bone **(Fig. 3a)** and after removing the surface cortical bone (**Fig. 3b**). The transmitted waveforms were obtained with the transducers of 10 mm diameter in the specimen before removing the surface cortical bone **(Fig. 4a)** and after removing the surface cortical bone (**Fig. 4b)**. The cross-sectional images of the specimen were obtained by X-ray micro-CT (**Fig. 5)**. It shows that the bone marrow space becomes small in accordance with change from line 1 (proximal) to 7 (distal). The trabeculae of the cancellous bone are aligned from distal anterior to proximal posterior in this site.

In Fig. 3a, we can discriminate between the fast and slow waves at line 2, 3, 4, 5 and 6, but we cannot discriminate at line 7. The fast wave overlaps into the slow wave in accordance with change to the small bone marrow space and the high bone density of the cancellous bone shown in Fig. 5. In Fig. 3b, we can discriminate between the fast and slow waves at line 1, 2, 3, 4, 5 and 6, but we cannot discriminate at line 7, same as Fig. 3a. The wave forms of the fast waves in Fig. 3b look

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exactly the same as that in Fig. 3a. It shows that the fast and slow waves phenomenon can be obtained in distal end of long bone such as this specimen, and that the circumferential waves transmitted in the cortical bone does not influence on the fast and slow waves in this specimen.

In Figs. 4a and 4b, the wave fronts of the transmitted waves arrive fast in accordance with change from line 1 to 7. It seems that the fast wave is included. But we cannot discriminate clearly between the fast and slow waves. It may be due to the difference of the propagation path that depended on the diameter of the transducers (Fig. 1).

4. Conclusions

The fast and slow waves phenomenon was obtained in *in vitro* swine distal ulna. The diameters of the transducers may have to be selected according to the bone size in order to discriminate clearly between the fast and slow waves. It seems that the same phenomenon exists in the ultrasonic measurement of human radius that is almost same diameter as swine ulna.

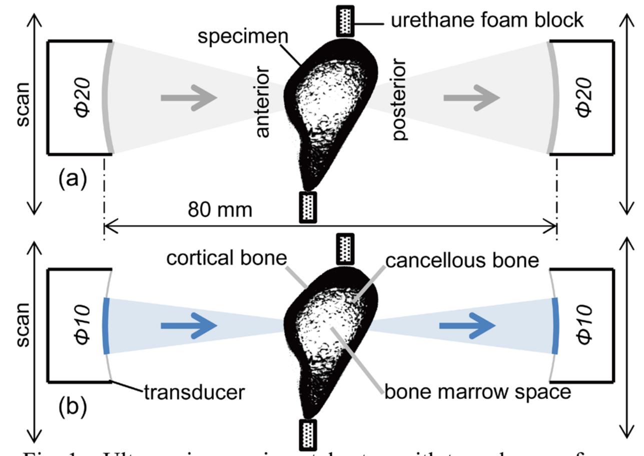

Fig. 1 Ultrasonic experimental setup with transducers of (a) 20 mm diameter and (b) 10 mm diameter

Acknowledgment

Part of this work was supported by the Regional Innovation Strategy Support Program of Ministry of Education, Culture, Sports, Science and Technology, Japan and Grant-in-Aid for Scientific Research (B) of the Japan Society for the Promotion of Science.

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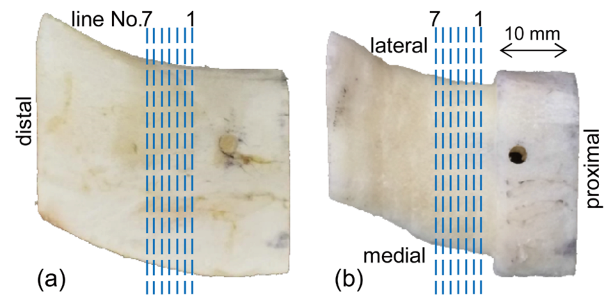

Fig. 2 Swine distal ulna specimen (a) before removing surface cortical bone and (b) after removing surface cortical bone

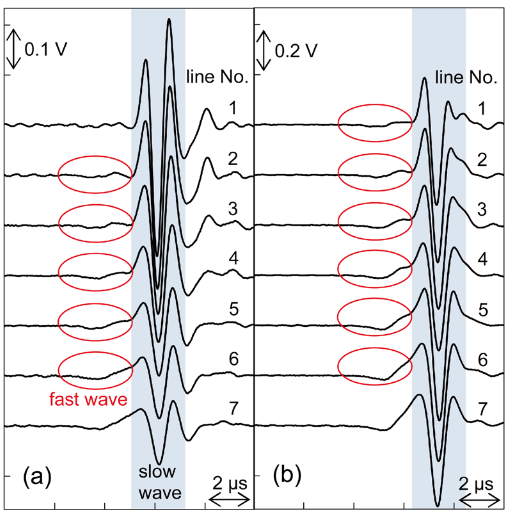

Fig. 3 Transmitted waveforms measured with transducers of 20 mm diameter in specimen (a) before removing surface cortical bone and (b) after removing surface cortical bone.

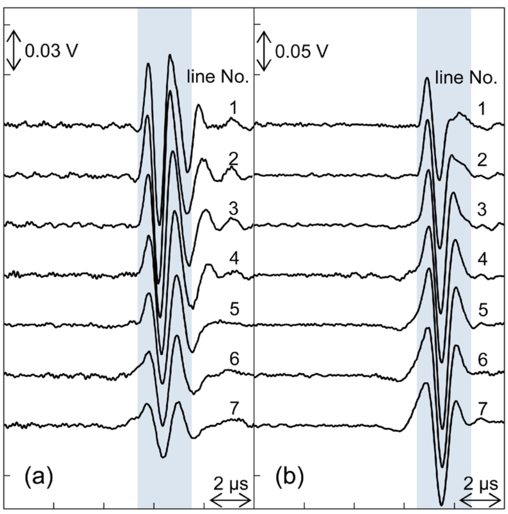

Fig. 4 Transmitted waveforms measured with transducers of 10 mm diameter in specimen (a) before removing surface cortical bone and (b) after removing surface cortical bone.

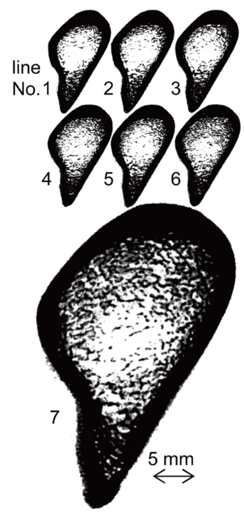

Fig. 5 Cross-sectional images of specimen with surface cortical bone obtained by micro CT.