3P5-27

Proceedings of Symposium on Ultrasonic Electronics, Vol. 34 (2013) pp. 543-544
20-22 November, 2013

Influence of the circumferential wave on the fast and slow waves.

回り込み波の高速波・低速波への影響

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1. Introduction

The transmitted ultrasonic signals through cancellous bone were theoretically and experimentally studied for both the fast and slow waves.[1~4] This two wave phenomenon is observed in the cancellous bone sample covered with cortical bone.[5] The ultrasonic bone measurement system LD-100 has been developed based on the principle of the fast and slow wave phenomenon in the distal radius bone of the wrist.[6] Ultrasonic system is good for children and pregnant women because of non-invasive measurements. But there are some problems in the measurement of small size bone as children. The circumferential waves in cortical bone or in soft tissue around the cortical bone overlap with the fast and slow waves. We present here some experimental studies on the influence of the circumferential waves on the fast and slow waves.

2. Method

A modified system of LD-100 was used. A pair of focused ultrasonic transducers was arranged in the water tank and the bone specimen was set at the focal point between the transducers. The transducers were concave type and have 40 mm focal length. They were consisted of annular array elements (**Fig. 1**) 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 (elements: 1+2+3+4) and 10 mm (elements: 1+2) were used in this study. One cycle sinusoidal wave was applied to the transmitter. The applied voltage to the transducers of the diameter 20mm was 25 V peak-to-peak, and for the diameter 10 mm was 50 V peak-to-peak. The cylindrical cortical bone specimen (outer diameter 13 mm, inner diameter 9 mm, length 21 mm) was prepared with *in vitro* bovine distal femur mimicking a children's radius bone size. The columned cancellous bone specimen (diameter 9 mm, length 17 mm) was prepared with *in vitro* bovine distal radius to make it possible to insert into the cortical bone specimen.

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3. Results

Ultrasonic transmitted waves through the cortical bone and the cancellous bone obtained with the transducers (diameter: 20 mm and 10 mm) are shown in **Fig. 2**. The direction of trabeculae alignment of the cancellous bone was selected to the ultrasonic propagation direction in order to obtain the fast and slow waves.[7] The observed waves include the fast and slow waves, the circumferential wave in the cortical bone and the circumferential wave in water around the cortical bone. It is difficult to discriminate each other.

In order to remove the circumferential wave in the cortical bone, the cortical bone was cut to 2 pieces, and the polystyrene foams (thickness 0.3 mm) were held in the 2 gaps (**Fig. 3, Fig. 4**). Furthermore, in order to remove the circumferential wave in water around the cortical bone, the urethane foam blocks were set in the upper part and the lower part of the cortical bone. In Fig. 3, the solid line shows the waveform of only the fast and slow waves measured with the transducers 20 mm in diameter. Fig. 4 shows the case of the transducers 10 mm in diameter. The fast and the slow waves can be discriminated clearly in both waveforms. They are in agreement with the fast and slow waves which transmitted only in the cancellous bone specimen. In Fig. 3 and Fig. 4, the dashed line shows the waveform including the fast and slow waves and the circumferential wave around the cortical bone. In Fig. 3, the circumferential wave around the cortical bone appeared at 53.2 μs, and has overlapped with the wavefront of the slow wave. In Fig. 4, the circumferential wave appeared at 54.4 μs, and has not overlapped with the wavefront of the slow wave. This time lag depends on the distance between edges of both the transmitting and receiving transducers. **Fig. 5** shows the waveform transmitted in water measured with the transducers 20 mm in diameter. The wave appeared at 53.2μs same as Fig.3.

4. Conclusions

When measuring a small bone, in addition to the circumferential wave in the cortical bone, the circumferential wave around the cortical bone influences on the fast and slow waves. If the diameters of the transducers are small, appearance time of the circumferential wave around the cortical bone becomes late, and it can avoid influence on fast and slow waves.

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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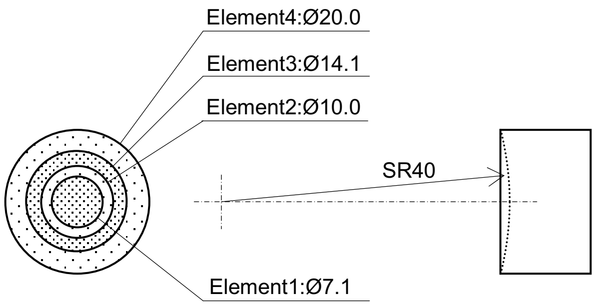

Fig. 1 Annular array transducer

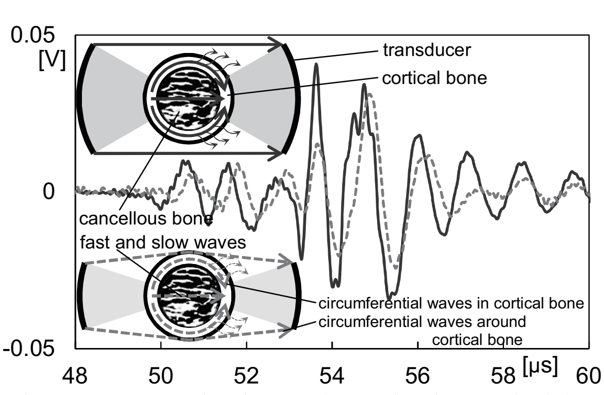

Fig. 2 Transmitted waveforms in the cortical bone and the cancellous bone. Solid line: measured by the 20 mm diameter transducers. Dashed line: measured by the 10 mm diameter transducers.

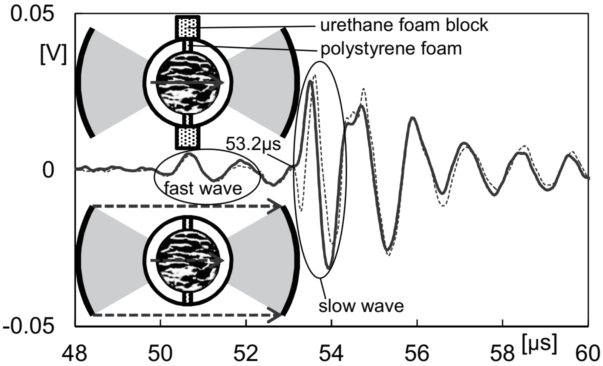

Fig. 3 Transmitted waveforms in the cortical bone with 2 polystyrene foam gaps and the cancellous bone measured by the 20 mm diameter transducers. Solid line includes only the fast and slow waves. Dashed line includes the fast and slow waves and the circumferential waves around the cortical bone.

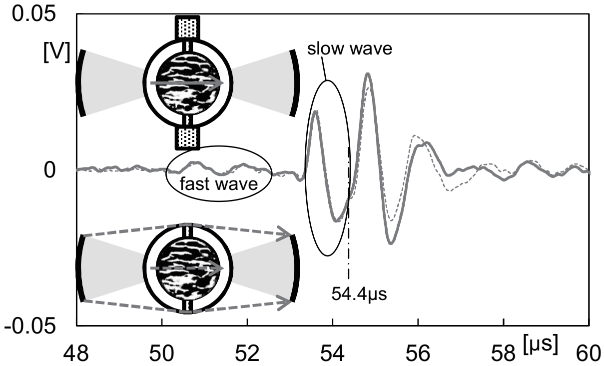

Fig. 4 Transmitted waveforms in the cortical bone with 2 polystyrene foam gaps and the cancellous bone measured by the 10 mm diameter transducers. Solid line includes only the fast and slow waves. Dashed line includes the fast and slow waves and the circumferential waves around the cortical bone.

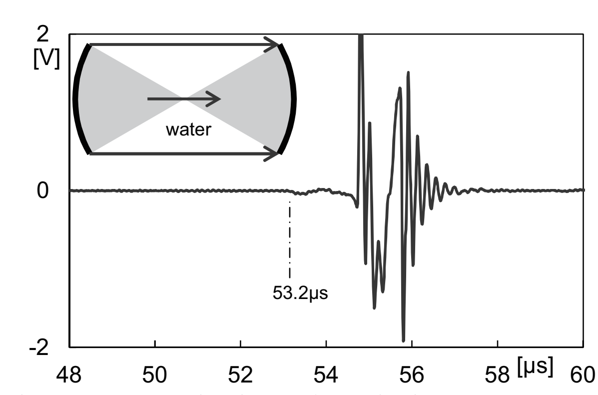

Fig. 5 Transmitted waveforms in the water measured by the 20 mm diameter transducers.