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Experimental study on longitudinal wave propagation in human radius model.
模擬ヒト橈骨中を伝搬する縦波超音波の実験的検討

Fuminori Fujita[1‡], Takuma Hachiken[1], Yoshiki Nagatani[2], Isao Mano[1], Katsunori Mizuno[3] and Mami Matsukawa[1] ([1]Wave Electronics Research Center, Doshisha Univ.; [2]Kobe City Coll. Tech.; [3]Univ. Tokyo.)
藤田 文理[1‡], 八軒 卓磨[1], 長谷 芳樹[2], 眞野 功[1], 水野 勝紀[3], 松川真美[1] ([1]同志社大 波動研究セ, [2]神戸高専, [3]東大生研)

1. Introduction

Osteoporosis is a disease which causes a decrease of bone strength. In the future, in Japan, there is a possibility that the incidence of osteoporosis is increased. Therefore, monitoring of bone strength is important.

Quantitative Ultrasound (QUS) method is suitabale for mass screening because this method is non-invasive, measurement time is short, and it dose not require a special technician and medical facility. It also has another potential. In previous studies, the ultrasonic wave separation into fast and slow waves in the cancellous bone is reported if it propagates along the trabeculae[1)]. The fast wave mainly propagates in the bone trabeculae, and the slow wave mainly propagates in bone marrow. The wave speed changes due to the bone density or bone volume fraction, which are related to the elastic properties[2)]. Then, currently, a new concept *in vivo* QUS device using a two-wave propagation has been proposed[3,4)]. The measurement site is distal radius. It enables to mesure the radius BMD (Bone mineral density), elastic modulus, and cortical thickness. The wave propagation in the radius bone, however, is not perfectly understood yet due to the complicated propagation process.

In this study, we have experimentally studied two wave phenomenon in a human radius model. In addition, we have visually observed the propagation wave in the similar model by numerical simulations using elastic finite-difference time domain (FDTD) method.

2. Sample preparation

The cancellous bone was obtained from 29-month-old bovine, and shaped into an elliptic cylinder. The cortical bone was also obtained from the same bovine and shaped into elliptical annular. The size of these specimen is almost the same as the human radius. Further, to fabricate the model with elliptical annular, we put two halves directly in contact with the trabecular bone with polystyrene form in the middle. Then, 3D images of the specimen were obtained using an X-ray micro-CT (Shimadzu, SMX-160CTS).

3. Ultrasonic measurements

Figure 2 shows the ultrasonic measurement system. Ultrasonic pulse measurements were performed using a PVDF focus transmitter (Custom made, Toray, 20 mm in diameter with a focal length of 40 mm) and a hand-made PVDF receiver (2.8 mm in diameter).

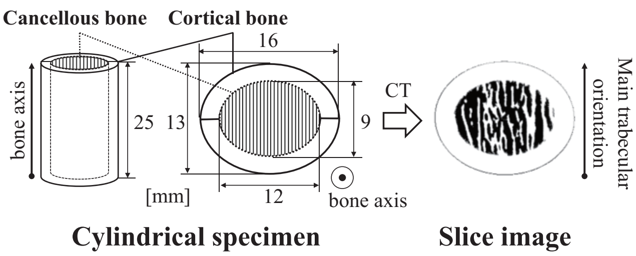

Fig. 1 Human radius model preparation.

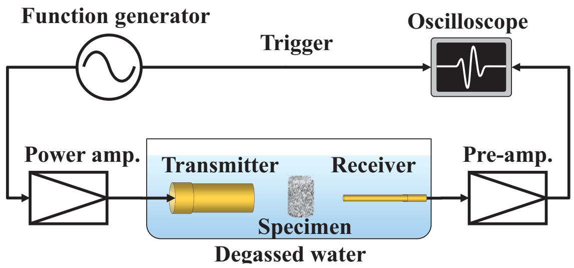

Fig. 2 Ultrasonic experimental system.

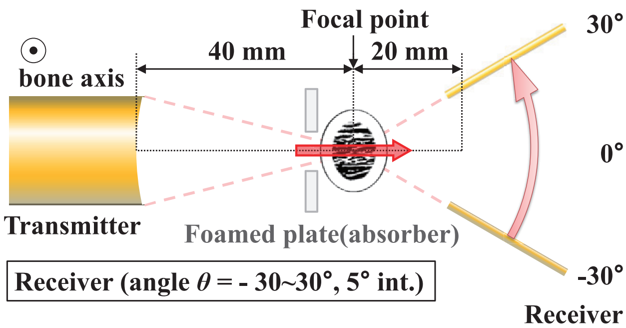

Fig. 3 Layout of transducers and specimen.

mmatsuka@mail.doshisha.ac.jp

A single sinusoidal wave at 1 MHz, with amplitude of 5 Vp–p from a function generator (Agilent Technologies, 33250A) was amplified 20 dB by a power amplifier (NF, HSA 4101), and applied to the transmitter. The waves that passed through the sample were converted into electrical signals by the receiver and investigated by a digital oscilloscope (Tektronix, TDS 524A) with 20 dB preamplifier (NF, BX-31). We set the focal point of wave on the central axis of the cylindrical specimen. By changing the incident angle θ of wave to the specimen (the range was from -30 to 30 degrees, where 0 degree is the direction of minor axis of the specimen), ultrasonic wave passed through the specimen was observed (Fig. 3).

4. Results and Discussion

Waveforms propagated through the human radius model, which is composed of cortical layer and trabecular bone, were observed. To discuss on the effect of circumferential wave at each angle, we investigated the arrival times of the received waveforms using the 1st peak.

Figure 4 shows that fast waves arrives earlier than the circumferential waves when the angle is smaller than 10 degrees. However, at higher angles, the effects of circumferential wave seem strong. The fastest part of the wavefront of the received waveform was influenced by the incident angle. More precise studies on the effect of the circumferential wave are required for a detailed understanding of this phenomenon.

Figures 5 show the distributions of the ultrasonic waves obtained with the FDTD method, that can visualize longitudinal wave propagation in the model. As you see in the figures, the wave in the cortical layer propagates faster than the wave which passes through the trabecular bone directly and seems to affect the direct wave. In fact, this fastest wave that temporarily propagates in cortical layer is difficult to be defined as a typical *circumferential wave* in this model. The circumferential wave in the cortical layer continually leaks into the trabecular part and, depending on the condition, it may result in the faster wave than the wave passing through the trabeculae directly. In the future, it is necessary to investigate the influence of this wave in detail.

5. Conclusion

We investigated two wave phenomenon in a human radius model by experimental measurements and numerical simulations. When the transducer angle was smaller than 10 degrees, fast wave arrived earlier than the circumferential wave. In

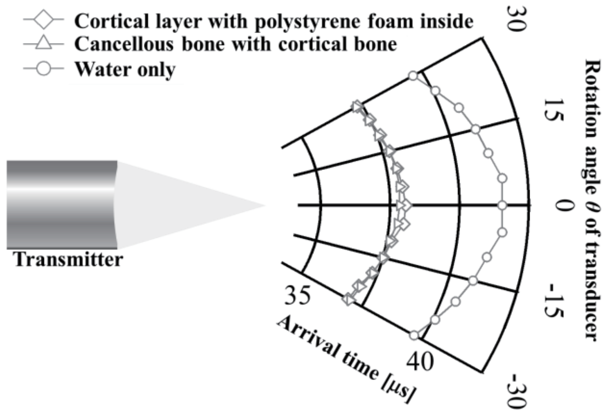

Fig. 4 Distribution of arrival times using a first peak point.

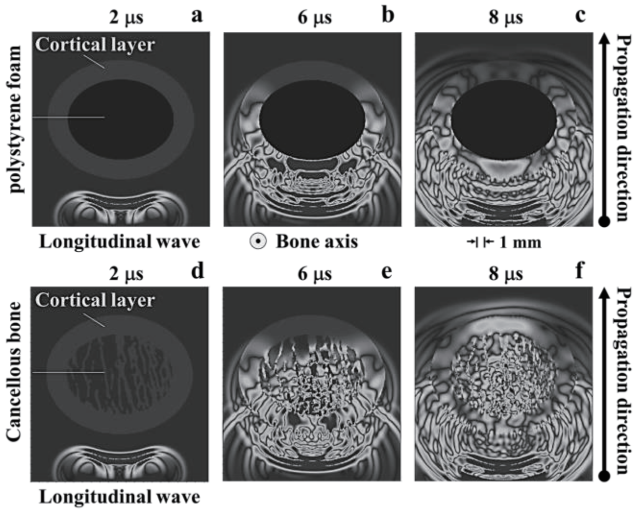

Fig. 5 Human radius model and screenshots of the distribution of sound pressure in the three-dimensional simulation field. (a), (b), (c) Cortical layer only (inside part is assumed to be vacuum). (d), (e), (f) Human radius model. Cancellous bone with cortical bone.

these angles, it may be possible to measure thespeed of fast wave which propagated in the cancellous part using the two wave phenomenon.

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