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Measurement of the lateral distribution of ultrasonic fields transmitted through bovine bones by the hydrophone scanning method

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1. Introduction

Increase of the elderly population has evoked the necessity of simple and low-cost methods of diagnosing osteoporosis, to which ultrasonic technology can be effectively applied. Intensive studies on ultrasonic diagnosing procedures as well as the development of clinical instruments have been done in this decade.[1-5] In many practical instruments, ultrasound is radiated towards a site on a human heel (or a wrist) and its transmitted waves are detected. Diagnosis is done based on the velocity and the attenuation of ultrasound, all of which are determined from the time-domain or the frequency-domain signals.

We have been studying the spatial distribution of the ultrasound transmitted from bones, because animal bone's structure consisting of cortical and cancellous bones inevitably causes the distortion of ultrasonic wavefronts, which can give a new key to improve the performance of the diagnosing instruments. We have thus far reported on the field distribution of ultrasound transmitted through bovine bones using the schlieren visualization method.[5] In the present paper, we show the results of the ultrasonic field visualization by another method, in which a small-sized hydrophone was two-dimensionally scanned to obtain the lateral distribution of ultrasound that had passed through bovine bones.

2. Experimental Setup

Fig. 1 shows the fundamental part of the experimental setup. A bovine bone sample and a transducer are immersed in water. The transducer periodically radiates tone-burst ultrasonic waves towards the bovine bone sample. A needle-type hydrophone is placed where the transmitted ultrasound propagates. This hydrophone is held by a two-dimensional mechanical stage the motion of which is electrically controllable. The hydrophone is scanned in the XY-plane, and the ultrasonic tone-burst waves are triggered by the positioning signals of the stage. The output signals of the hydrophone are detected with a certain time delay after every ultrasonic transmission, and are finally composed to give an entire image representing the ultrasonic field distribution in the XY-plane.

Experiments were performed at two different ultrasonic frequencies, 1.07 MHz and 3.5 MHz. The diameter of the transducer was 10 mm for the former frequency, and 13 mm for the latter. The radiating surface was flat for both cases. Tone-burst signals having 10 μs duration were applied to the transducers with a 500 W power amplifier. The hydrophone (Toray, Needle-Type), was placed Z_0=30 mm away from the transducer surface and was scanned over the area of 30(X)×30(Y) mm. Its output signal was detected at 256(X) and 256(Y) positions, at each of which the signal was sampled 16 times in series with 1 μs intervals. These data was rearranged by a computer to give 16 different images that show the evolution of the lateral distribution of a single ultrasonic wave packet propagating across the plane at Z_0=30 mm.

All the bone samples were bovine bones. Marrow part in the cancellous bone was removed beforehand, and the hollow area of the trabecular part was filled with water in the experiment. The thickness of the bone sample was 7 mm both for cortical and cancellous bones.

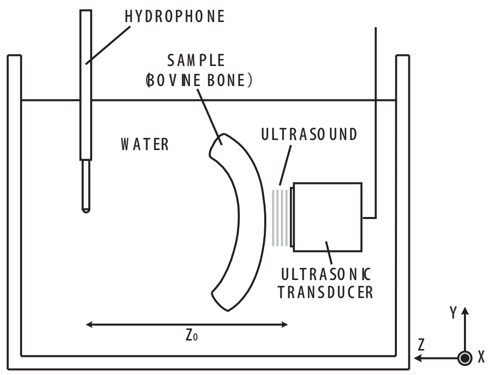

Fig. 1 Experimental Setup

3. Experimental Results

Fig. 2 shows the experimental results for an ultrasonic frequency of 1.07 MHz. Fig. 2(a) shows the ultrasonic field without the bone sample (free space), which represents a plane wave part at the center and a ring pattern resulted by the diffraction. Fig. 2(b) and 2(c) are the results when a cortical

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bone was inserted. Fig. 2(b) shows the field of the beginning part of a wave packet, whereas Fig. 2(c) shows the field 6 μs after Fig. 2(b). These images show that the wavefront was bent along the Y-direction. Fig. 2(d) and 2(e) are the results when a cancellous bone was inserted. Conditions for Fig. 2(d) and 2(e) are the same as Fig. 2(b) and 2(c). Both in Fig. 2(d) and 2(e), the central part of the wavefront shows smaller distortion compared to the results for the cortical bone. This result coincides with our previous results by the schlieren method.[5)]

Fig. 3 shows the results for the ultrasound at 3.5 MHz. Notations for (a) - (e) are identical as those in Fig. 2. The field in free space (Fig 3(a)) shows fewer diffraction rings than 1.07 MHz case, which is resulted from the smaller ratio of the wavelength to the transducer diameter. The result for a cortical bone (Fig. 3(b) and 3(c)) shows that the wavefront was bent along the Y-direction, in a similar manner as in Fig. 2(b) and 2(c). The results for a cancellous bone, Fig. 3(d) and 3(e), show some distinct features. First, the central part of the wavefront is deformed much more than 1.07 MHz case. Second, the diffracted waves are observed in a very large area. These features are more prominent than our previous results obtained by the schlieren method.[5)] The schlieren method has a tendency to visualize plane wavefronts more distinctively than bent wavefronts because of its integral effect along the optical axis. In this sense, we believe our new results by hydrophone scanning are more reliable to investigate the field distribution of ultrasound that may contain various spatial components.

4. Summary

Visualization by the hydrophone scanning method have shown that the ultrasonic field transmitted through cancellous bones are strongly scattered at 3.5 MHz. We intend to connect this spatial information on ultrasonic fields to the diagnosis of osteoporosis in the future work.

References

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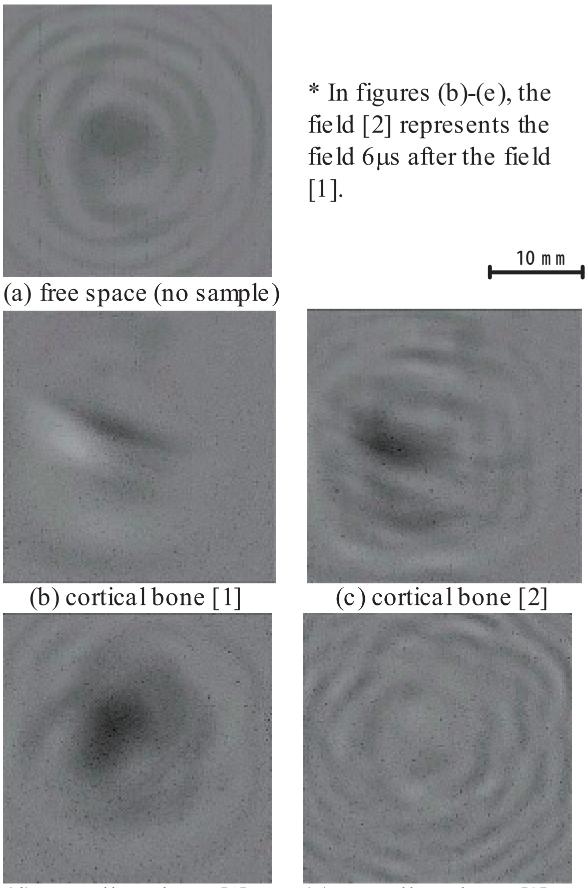

Fig. 2 1.07 MHz ultrasonic fields after passing through bone samples

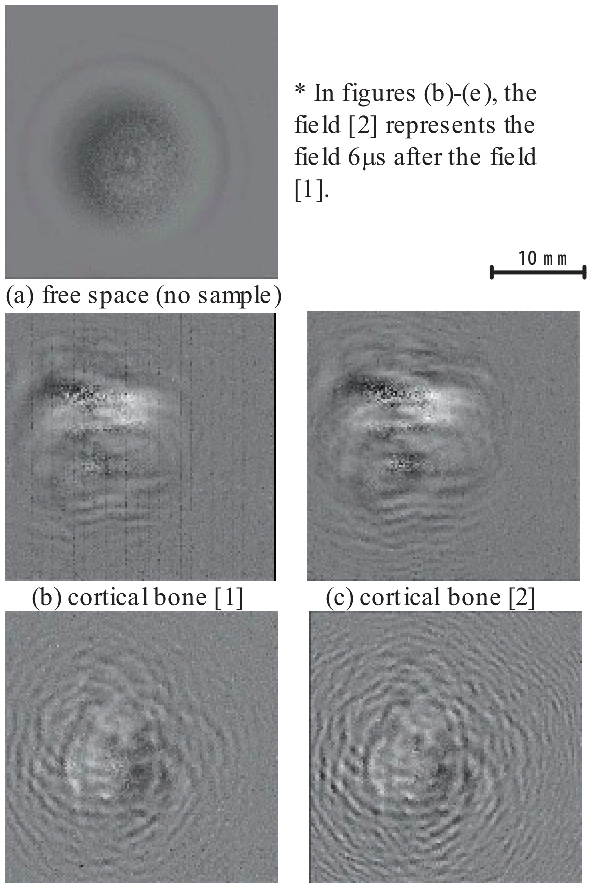

Fig. 3 3.5 MHz ultrasonic fields after passing through bone samples