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Experimental Observation of Piezoelectric Effect in Cancellous Bone under Ultrasound Irradiation
超音波照射下での海綿骨における圧電効果の実験的観測

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1. Introduction

Bone formation can be driven by mechanical loads on the bone.[1] This mechanism has been applied to the clinical healing of bone fracture by irradiation of low-intensity pulsed ultrasound (LIPUS).[2] Moreover, bone formation can be accompanied by the piezoelectric effect in the bone.[3] Recently, the piezoelectric potential generated in cortical bone by ultrasound irradiation could be experimentally observed.[4,5] However, to the best of the author's knowledge, a clear observation of the piezoelectric effect in cancellous bone at an ultrasound frequency is not reported yet.

In this study, a piezoelectric cell of cancellous bone was experimentally produced to receive an ultrasound wave. The ultrasound sensitivity of cancellous bone was estimated to compare with those of cortical bone and poly(vinylidene fluoride) (PVDF).

2. Piezoelectric Cell of Cancellous Bone

The piezoelectricity in bone is too low to experimentally observe. Okino, *et al.* succeeded to receive ultrasound waves using the ultrasound transducers made of bovine cortical bone. Considering this, a piezoelectric cell (PE-cell) of cancellous bone, which had an electrically shielded structure, was experimentally produced in this study.

Figure 1 shows a cross-sectional view of the PE-cell of cancellous bone. A parallelepiped cancellous bone specimen of approximately 25 × 25 mm^2 area and 8.5 mm thickness was cut from a bovine femur. The whole porosity was approximately 0.65 (65%), and the orientation of the trabecular network tended to be parallel to the thickness direction. The pore spaces, in which bone marrow was removed, were saturated with air. As shown in Fig. 1, the cancellous bone specimen was electrically shielded by brass plates and an aluminum (Al) electrode on the front bone surface. The other Al electrode of 20 × 20 mm^2 was set on the back bone surface. The Al electrodes on the front and back bone surfaces were conducted to negative and positive terminals of a BNC connector, respectively. The active (or receiving) area of the PE-cell of cancellous bone was 20 × 20 mm^2 of the positive electrode. The back of the cancellous bone specimen was filled with air.

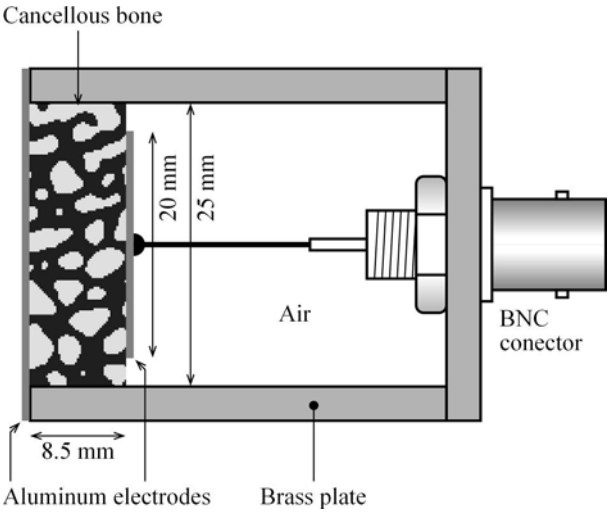

Fig. 1 Cross-sectional view of a PE-cell of cancellous bone.

3. Experimental Method

To observe the piezoelectric effect in cancellous bone under ultrasound irradiation, it was attempted to receive an ultrasound wave using the PE-cell of cancellous bone. A Pb(Zr,Ti)O_3 (PZT) ultrasound transducer with a resonance frequency of 1.0 MHz was used to transmit an ultrasound burst wave in water at room temperature. The distance between the PE-cell of cancellous bone and the PZT ultrasound transducer was 50 mm. The ultrasound signal received by the PE-cell of cancellous bone was converted to the electric signal and was displayed on a digital oscilloscope after passing through a preamplifier and a band-pass filter. For comparison, the ultrasound wave was received using a PE-cell of cortical bone and a PVDF ultrasound transducer. The PE-cell of cortical bone was made of a bovine cortical bone disk of approximately 11 mm diameter and 1 mm thickness. The active areas of the PE-cell of cortical bone and the PVDF ultrasound transducer were circles of 9 and 8 mm diameters, respectively.

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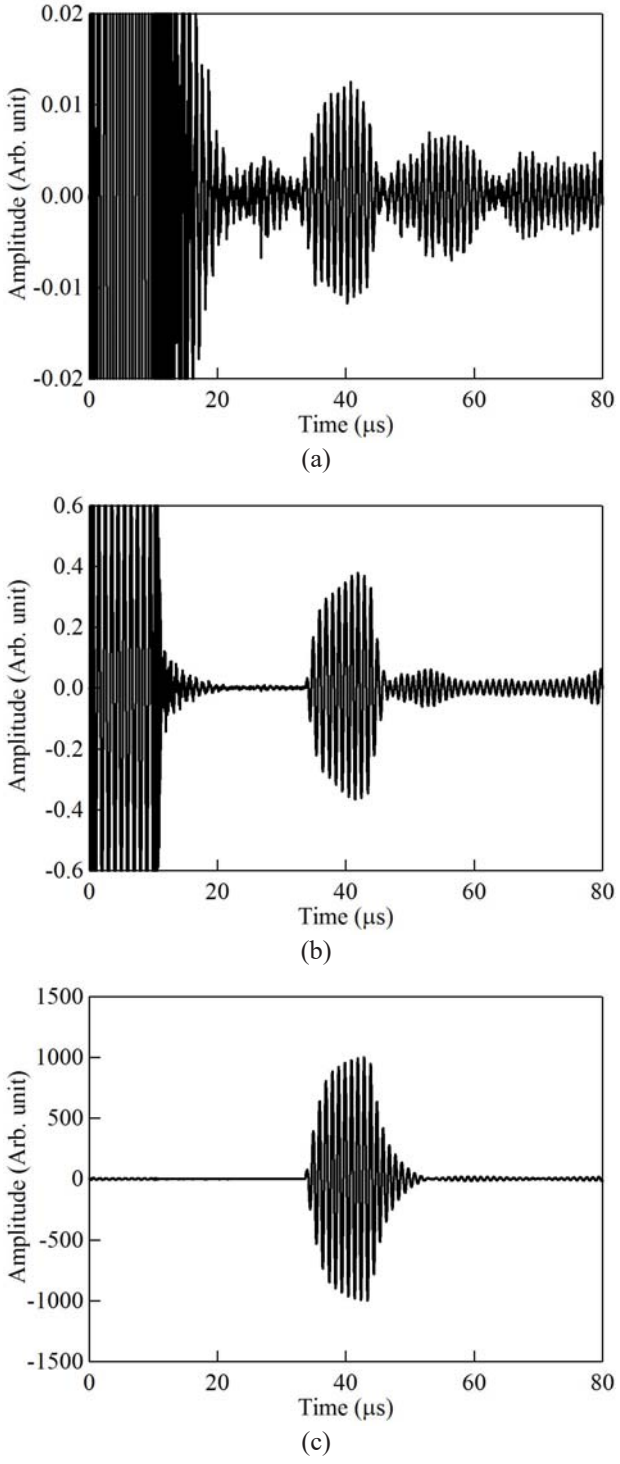

Fig. 2 Ultrasound waveforms received by (a) a PE-cell of cancellous bone, (b) a PE-cell of cortical bone, and a PVDF ultrasound transducer.

4. Experimental Results and Discussion

Figure 2 shows the experimentally observed ultrasound waveforms; (a)–(c) show the waveforms received by the PE-cell of cancellous bone, the PE-cell of cortical bone, and the PVDF ultrasound transducer, respectively. As the active areas of these receivers were different, the waveform amplitudes were normalized by the respective areas. In all figures, the burst waves were observed at 33–45 μs. These waves could be regarded as ultrasound signals transmitted from the PZT ultrasound transducer. On the other hand, the large waves observed at 0–20 μs in Figs. 2(a) and 2(b) could correspond to electromagnetic noises. Moreover, the other waves after 45 μs in Fig. 2(a) could be considered to be multi-reflected ultrasound waves between both surfaces of the cancellous bone specimen.

As shown in Fig. 2(a), the ultrasound wave could be received by the PE-cell of cancellous bone. Thus, the experimental observation of the piezoelectric effect in cancellous bone under ultrasound irradiation could be succeeded. To the best of author's knowledge, it is the first successful observation in the world. Compared Fig. 2(a) with Figs. 2(b) and 2(c), the ultrasound sensitivity of cancellous bone was estimated to be approximately 1/30 and 1/80000 of cortical bone and PVDF, respectively. Therefore, sufficiently prevention of electromagnetic noise is required to experimentally observe the piezoelectric signal generated in cancellous bone.

Trabecular structure in cancellous bone is anisotropic and inhomogeneous, which can largely affect ultrasound behaviors in the bone. It is therefore considered that the piezoelectric effect under ultrasound irradiation can depend on the trabecular structure. It is a subject of further study to investigate the effect of the trabecular structure on the piezoelectric properties in cancellous bone or the relationship between the ultrasound propagation properties and the piezoelectric properties caused by the ultrasound propagation.

5. Conclusions

Using the experimentally produced PE-cell of bovine cancellous bone, the piezoelectric effect under ultrasound irradiation could be clearly observed. The estimated ultrasound sensitivity of cancellous bone at 1.0 MHz was approximately 1/30 and 1/80000 of cortical bone and PVDF, respectively.

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