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Ultrasonically induced electrical potentials in swine skull

ブタ頭蓋骨における超音波誘発電位

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1. Introduction

Piezoelectricity in bone is well known after Fukada and Yasuda's studies of induced electrical potentials by low frequency mechanical stress [1]. They have also reported that collagen may contributes to the piezoelectricity in bone. Okino et. al. have fabricated ultrasound transducers using bone of bovine femur as piezoelectric devices and succeeded in observing ultrasound waves as the output of the electrical potentials [2]. Moreover, Matsukawa et. al. observed the relationships between potentials and ultrasound irradiation directions, and its anisotropic character [3]. However, these are the results of loaded bone, and the piezoelectricity of unloaded bone, such as skull has not been reported. Compared to the loaded bone, the elasticity of skull shows weak anisotropy [4].

The aim of this study is to characterise piezoelectricity of skull bone by investigating the relationship between the induced electrical potentials and ultrasound propagation directions.

2. Material and Methods

Figure 1 shows the preparation of bone samples. Four kinds of circular plate outer cortical skull samples (plates are parallel to the skull surface) were extracted from the right frontal lobe (A), left frontal lobe (B), right occipital lobe (C), and left occipital lobe (D) of swine skull. The diameters were 10.5-11.0 mm and thicknesses were 3.00 ± 0.01 mm, respectively. Using these swine skull plates as piezoelectric materials, we fabricated bone transducers as ultrasound receivers.

For the experiments, a PVDF focus transducer (diameter, 20 mm; focal length, 40 mm; custom made by Toray) was used as a transmitter. The transmitter and the bone receiver were set to cross at right angles in degassed water as shown in Fig. 2. In this setup, a function generator (33250A; Agilent Technologies) generated a burst wave with 10 sinusoidal cycles (frequency; 1 MHz) which was amplified to 70 $V_{p\text{-}p}$ by a bipolar power supply (HAS 4101; NF). Ultrasound was focused to the side surface of bone transducer. The received signal was amplified 40 dB by a pre-amplifier (BX-31A; NF) and observed by an oscilloscope (DPO3054; Tektronix). The bone transducer was rotated at each 10 degree to check the anisotropy. Here, 0° means that the ultrasound propagates from the anterior side, 90° means from the left side, 180° means from the posterior side, and 270° means from the right side.

Subsequently, the longitudinal wave velocity was then measured. A PVDF focus transducer was used as the transmitter, and a flat PVDF transducer (diameter: 3 mm) was used as a receiver. Using a sinusoidal burst wave at 1 MHz as an input signal, the bone transducer set between the transmitter and the receiver was rotated every 10° for measurement.

The alignment of HAp crystallites in the samples were also observed using the X-ray diffraction technique. The c-axis (axis of symmetry) of the hexagonal HAp crystal is perpendicular to the (0002) plane, and the intensity of the (0002) measured at the plate surface was observed [5].

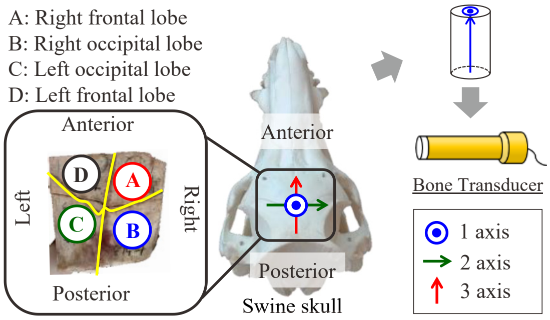

Fig. 1 Preparation of bone transducers.

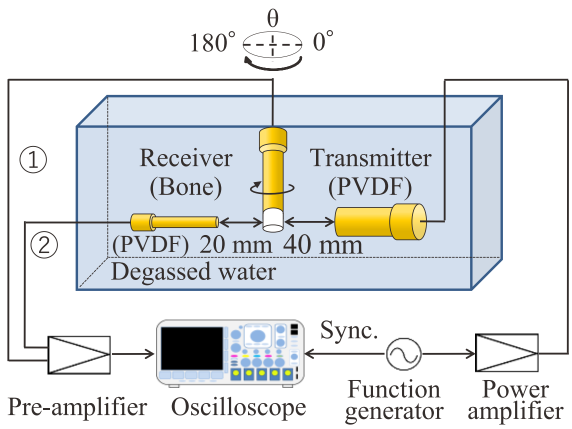

Fig. 2 Experimental system.
①measurement of induced potentials.
②measurement of velocity

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3. Results and Discussion

Figure 3 shows observed waveforms measured by a swine skull transducer (A). When the bone transducer was set at the focal point of the transmitter, the transmitted ultrasound pressure at the measurement point was around 7.4 $kPa_{p\text{-}p}$. The amplitudes of electrical potentials obtained by the swine skull transducers were about half of those of the bovine femur transducers [3].

Figure 4 shows relationships between amplitudes of induced electrical potentials and ultrasound irradiation direction. The amplitude of the electrical potential stayed almost constant in the range of 4~8 $\mu V_{p\text{-}p}$, and no significant change (anisotropy) in amplitudes was observed. The piezoelectric constant d_{12} corresponds to the electrical potentials at 90° and 270°, and d_{13} corresponds to the electrical potentials at 0° and 180°.

Here, the alignment of HAp crystallites in the samples were observed using the X-ray diffraction technique. If the HAp crystallites are aligned unidirectionally in a specific direction, then the summation of the poles that are diffracted by each crystallite forms a high concentration. As shown in Fig. 5, HAp crystallites did not show clear concentration. Figure 6 shows the wave velocity anisotropy. Longitudinal wave velocity almost showed isotropic character, which is consistent with XRD data. According to these data and former studies, the skull samples may have almost isotropic elastic property and piezoelectricity in plane.

4. Conclusion

The relationships between the induced electrical potentials and ultrasound irradiation directions in the swine skull was investigated. The amplitude of the stress-induced electrical potentials did not depend on the wave propagation direction in the skull cortical plate.

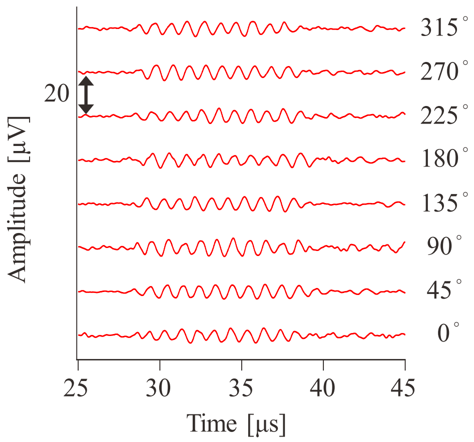

Fig. 3 Observed waveforms by the AP sample.

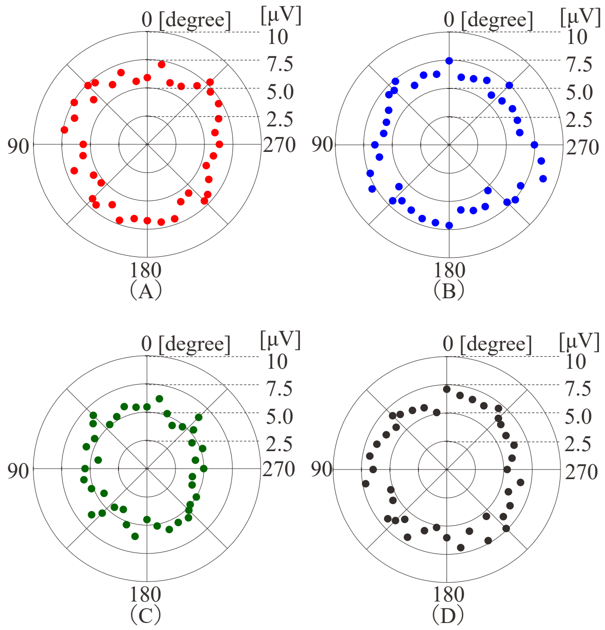

Fig. 4 Relationships between induced electrical potentials and ultrasound irradiation directions.

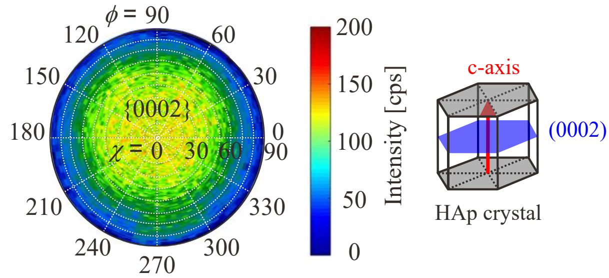

Fig. 5 HAp crystallites orientation in the skull plate (sample A).

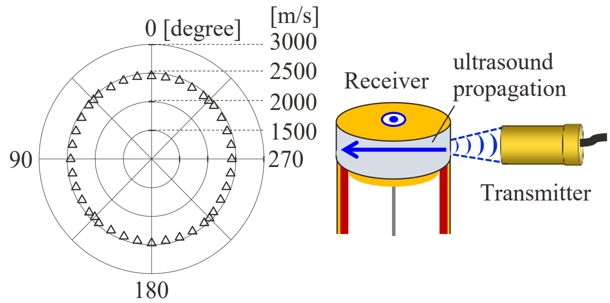

Fig. 6 Longitudinal wave velocity in the skull plate (sample A).

References

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