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Ultrasonically induced electric potentials in the cortical bone
皮質骨中における超音波誘発電位に関する検討

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1. Introduction

Healing of bone fracture with LIPUS (low intensity pulse ultrasound) has attracted attention in recent years. The ultrasound stimulates bone cells and promotes the healing of bone fracture. However, the mechanism of ultrasonic effects on bone has not yet been clearly understood.

In 1953, Fukada and Yasuda have reported that the mechanical stress at low frequencies induces electrical potentials in bone [1]. The stress-induced electrical potentials stimulate bone cell and promote bone remodeling. One expected mechanism is the piezoelectricity of collagen or hydroxyapatite (HAp) in bone matrix. However, the piezoelectricity of bone in the MHz range has been rarely investigated. To evaluate the stress induced electrical potentials in this frequency range, we have fabricated ultrasound transducers using bone as piezoelectric devices and could observe ultrasound waves by the bone transducer [2, 3].

Bone is composed of collagen and HAp. They are highly orientated in the direction of bone axis, which results in the strong anisotropy. Therefore the longitudinal velocities in the bone axis direction were always the highest of those in three orthogonal directions [4]. The purpose of this study is to investigate the effect of this bone anisotropy on the induced electric potentials.

2. Material and Methods

Cortical bone samples were extracted from the anterior part of the mid-femoral shafts of a 31 month-old bovine as shown Fig. 1. The diameter and thickness of these samples were 10.0 and 3.00 ± 0.01 mm, respectively. We fabricated ultrasound transducers using these samples.

Figure 2 shows the experiment system. A PVDF focus transducer (diameter, 20 mm; focal length, 40 mm; custom made by Toray) was used as a transmitter and a handmade bone transducer was used as a receiver. We set the transmitter and the receiver to be crossed at right angles in water. In this system, a function generator (33250A; Agilent Technologies) generated 1 cycle of square pulse wave at 10 kHz, which were amplified to 70 V_{pp} by a bipolar power supply (HAS 4101; NF). Ultrasound was irradiated to the side of bone sample. The received signal was amplified 40 dB by a pre-amplifier (BX-31A; NF) and observed in an oscilloscope (DPO3054; Tektronix). The bone transducer was rotated at each 10 degrees to observe the anisotropy.

3. Results and Discussion

Figure 3 shows an observed ultrasonic waveform obtained by the PVDF transducer (flat; diameter, 10 mm). The temporal difference between

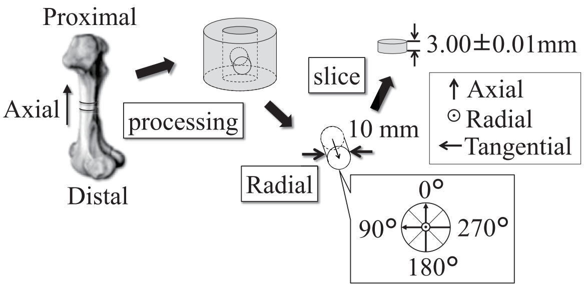

Fig. 1 Preparation of samples.

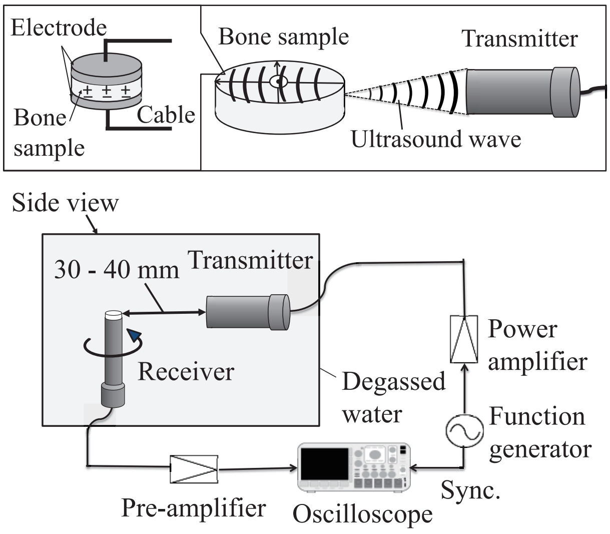

Fig. 2 Experiment system.

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the two extremes was 7 μs. The difference changed due to the diameter of the transducer. When we measured the wave rotating PVDF transducer around the sound axis, the waveforms did not change.

Figure 4 shows the observed waveforms obtained by the bone transducer. The polarity of the wave front showed differences due to the ultrasound propagation directions in the bone sample. Fukada and Yasuda have reported that the piezoelectric constants of bone at low frequencies are $d_{12}=0.11$ pC/N are $d_{13}=-0.25$ pC/N, showing the anisotropy [1]. Our ultrasonic results also indicate the polarity change due to the anisotropy at high frequencies. In addition, the stress-induced electrical potentials became largest when ultrasound propagated in the off axis direction.

Next, we measured the waves by rotating the bone transducer at each 10 degrees. Figure 5 shows a relationship between the piezoelectric polarity, and the amplitude of the stress-induced electrical potentials as a function of sound propagation direction. The amplitudes became maximum around 45, 135, 225 and 315 degrees, showing the clear polarity change.

We also measured HAp orientation in the bone sample by the X-ray diffraction technique. The orientation of HAp in the sample was inclined about 3 degrees from the bone axis. This phenomenon has already been reported by Yamato et al. Around 3 - 10 degrees, we can also find a dip of output potentials in Fig. 5. These data suggest that bone anisotropy due to HAp and collagen alignment has a clear effect on the induced electric potentials.

4. Conclusion

In this study, we investigated the effect of bone anisotropy on the induced electric potentials. The polarity and the amplitude of the stress-induced electrical potentials changed due to the sound propagation direction in the bone sample.

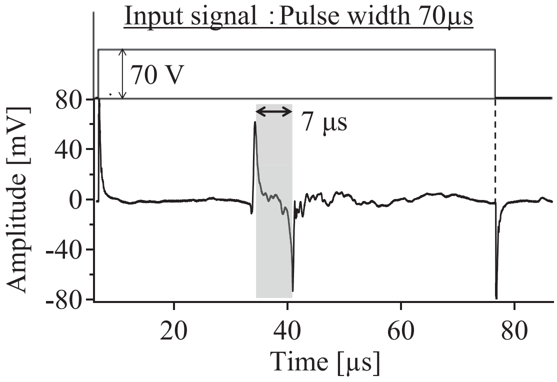

Fig. 3 Observed wave by a PVDF flat transducer.

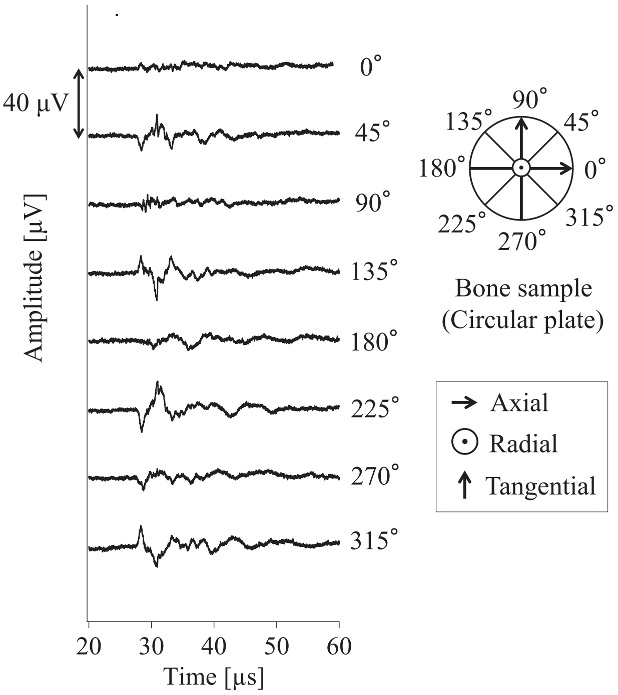

Fig. 4 Observed waves by a bone transducer.

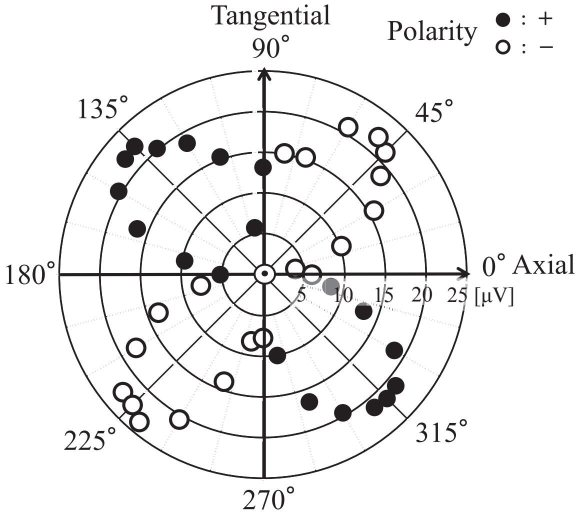

Fig. 5 Anisotropy of the induced electric potentials by ultrasound irradiation.

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