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# Evaluation of piezoelectricity in bone by ultrasound irradiation

# 超音波照射による骨の圧電特性の評価

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## 1. Introduction

It is known that bone growth is promoted by ultrasound irradiation [1]. Recently, Low intensity pulse ultrasound (LIPUS) technique is used for the healing of bone fractures. The ultrasound stimulates bone cells and promotes the healing of bone fracture. However, the primal mechanism of LIPUS is not fully understood.

In 1953, Fukada and Yasuda have reported that the mechanical stress at low frequencies induces electrical potentials in bone [1]. One expected mechanism of this induced potential is the piezoelectricity of collagen or hydroxyapatite in the bone matrix. However, piezoelectricity was only observed in the low frequency ranges up to several kHz, which is much lower than the frequency range of LIPUS (MHz range). To evaluate the stress induced electrical potentials in the MHz range, we have fabricated ultrasound transducers using bone as piezoelectric devices and could observe ultrasound waves by the bone transducer [2, 3].

The hard and dense cortical bone shows strong elastic anisotropy [4]. In this study, bovine cortical bone from the mid-shaft of femur was processed into a cylindrical shape similar to human long bone. We focus on the effect of bone anisotropy and investigate the relationships between the stress induced electrical potentials and ultrasound irradiation directions on the bone sample.

## 2. Material and Methods

**Figure 1** shows the preparation method of the sample. A cortical bone sample was extracted from the anterior part of the mid-femoral shaft of a 30 month-old bovine. It was finally processed into the cylindrical sample which has electrodes on the inside and the outside surfaces. The inner and outer diameters of this sample were 10 and 14 mm, respectively. The length was 13.00 ± 0.01 mm. The sample size was similar to the shaft of human radius bone. Using this sample, a cylindrical transducer was fabricated.

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A PVDF focus transducer (diameter, 20 mm; focal length, 40 mm; custom made by Toray) was used as a transmitter and a cylindrical bone transducer was used as a receiver. The transmitter and the receiver were set to be crossed at right angles in degassed water as shown in **Fig. 2 (a)**. A function generator (33250A; Agilent Technologies) delivered electrical pulse (a step signal of 70 V) to the transmitter, which was converted into a short ultrasound pulse. The pulse was irradiated to the side surface of bone of the transducer so that the induced potentials were generated. The received signal was amplified 20 dB by a pre-amplifier (BX-31A; NF, Yokohama, Japan) and observed in an oscilloscope (DPO3054; Tektronix, Beaverton, OR). The measurements were performed at each rotation angle $\theta$ or $\Phi$ of 10° from -60° to 60° as shown in **Figs. 2 (b) and (c)**. Ultrasound irradiation directions were changed by rotating the transmitter. The side surface of bone sample was 40 mm from the transmitter.

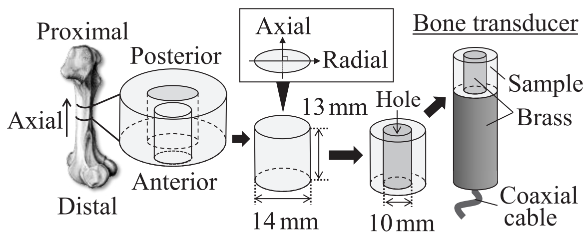



Fig. 1 Preparation of sample.

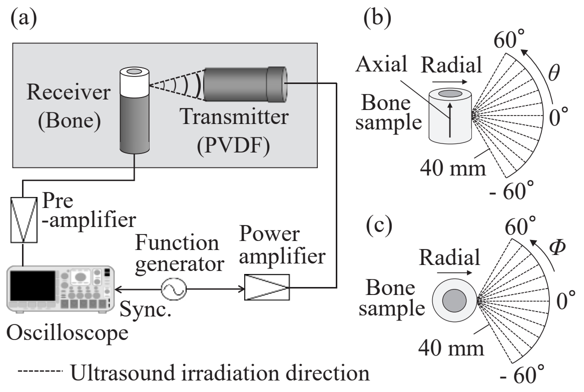



Fig. 2 (a) Experimental system. (b) and (c); Ultrasound irradiation directions of two pattern (0° is radial direction).

## 3. Results and Discussion

When the bone transducer was at the focal point of the transmitter, the transmitted ultrasound pressure at the measurement point was around 7.4 $kPa_{p\text{-}p}$. **Figure 3** shows observed waveforms measured by the bone transducer when ultrasound irradiation directions were $\theta = \pm 45°$ (pattern (b)). The p-p value of the stress induced electrical potentials was 21 μV at $\theta = -45°$ and 20 μV at $\theta = 45°$. The polarity of the wave front (arrows) showed differences due to the ultrasound irradiation directions on the bone sample. Anderson has reported that the piezoelectric constants of $d_{12}$ and $d_{13}$ bone at low frequencies are 0.037 pC/N and -0.083 pC/N, respectively, showing the change in polarity [5]. Our ultrasonic results also indicate the polarity change due to the irradiation direction. This indicates changes in polarity by ultrasound irradiation direction as healing of bone fracture using LIPUS.

Next, we measured the waves by rotating the transmitter at each 10°. $\theta = 0°$ and $\Phi = 0°$ indicate the radial direction. **Figures 4 (a) and (b)** show the relationships between the p-p values of the stress induced electrical potentials as a function of ultrasound irradiation directions. The p-p values of the stress induced electrical potentials were defined as the amplitude difference between second positive (or negative) and third negative (or positive). In **Fig. 4 (a)**, the polarity and the p-p value of the stress induced electrical potentials changed due to ultrasound irradiation direction on the bone sample. The values showed maximum around $\theta = \pm 50°$ and minimum around $\theta = 0°$. Furthermore, the polarity of the waves was plus from -60° to -10°, and was minus from 0° to 60°. In **Fig. 4 (b)**, the amplitudes showed maximum at $\Phi = 0°$. Error bars are the p-p value of noise. Therefore, the p-p value of the stress induced electrical potential is the largest when ultrasound irradiation directions are $\theta = \pm 50°$ and $\Phi = 0°$.

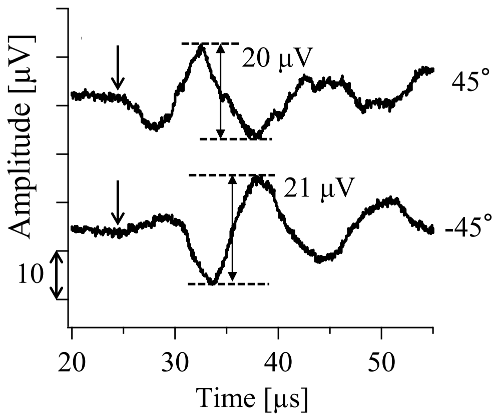
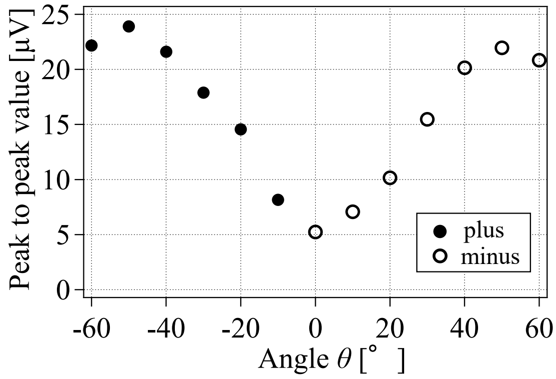
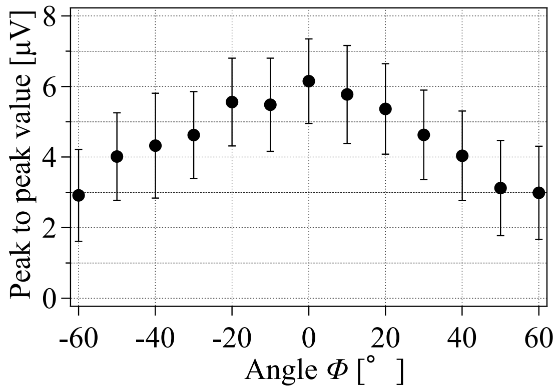


Fig. 3 Observed waves by a bone transducer.



(a) Ultrasound irradiation directions (pattern (b)).



(b) Ultrasound irradiation directions (pattern (c)).

Fig. 4 A relationship between the stress induced electrical potentials and ultrasound irradiation directions.

## 4. Conclusion

In this study, we investigated the relationship on the stress induced electric potentials and ultrasound irradiation directions using a cylindrical bone imitating human radius bone. Consequently, the stress induced electrical potentials became largest when ultrasound was irradiated with the angles of $\theta = \pm 50°$ and $\Phi = 0°$. This result possibly indicates that there is an optimal ultrasound radiation direction to induce electrical potentials in vivo.

## References

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