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Evaluation of piezoelectricity in rat cortical bone

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1. Introduction

The low-intensity pulsed ultrasound (LIPUS) technique is known to shorten the healing time of bone fracture. However, the initial mechanism of bone healing is still unknown. We have then focused on bone piezoelectricity and tried to investigate its contribution to bone fracture healing. The piezoelectricity of bone seems to result from collagen, one of the main components of bone.[1]

In previous studies, ultrasonically induced electrical potentials were observed using large bovine cortical bones.[2] For future clinical studies, we next focused on a small rat bone. We fabricated a bone transducer using a small rat leg bone to check the piezoelectricity in the MHz range.

2. Materials and methods

The left and right femora of a Sprague-Dawley rat (12-week, male, CLEA Japan, Inc.) were polished to fabricate a thin specimen (thickness about 0.6 mm) as shown in **Fig. 1**. This sample was approximately 12 mm long and 5 mm wide. Using this bone specimen as a piezoelectric material, a bone ultrasound transducer was fabricated. The capacitance of the bone transducer was 23.6 pF. A PVDF transducer (Focus type, Toray Engineering, Curvature radius : 40 mm) and a bone transducer were used as the transmitter and receiver in degassed water at 24.9°C. The distance between the transmitter and receiver was 40 mm. Using a function generator and a power amplifier, a burst signal of 10 sinusoidal waves (70 Vp-p) was applied to the transmitter. The sound pressure at the focal point on the receiver surface was 7.4 $\mathrm{kPa}_{\mathrm{p\text{-}p}}$. The output of the bone transducer was amplified 40 dB and observed by an oscilloscope (Fig.2).

First, ultrasonic waves in the range from 1 to 2.5 MHz were irradiated, and the received waveforms by the bone transducer were observed

Next, we measured the distribution of induced potentials by changing the ultrasound irradiation positions in the bone transducer. The spot diameter of the focusing transducer used in this study was 1.6 mm (Fig.3). The diameter was measured by a needle type transducer (ONDA, HNR-1000).

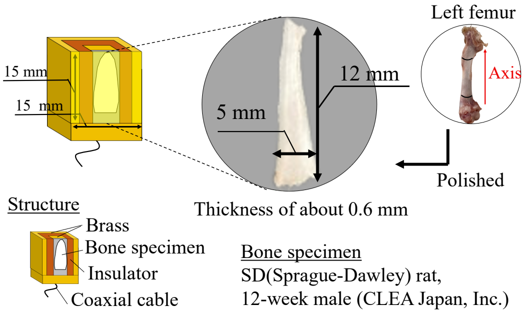


Fig. 1 A rat bone specimen.

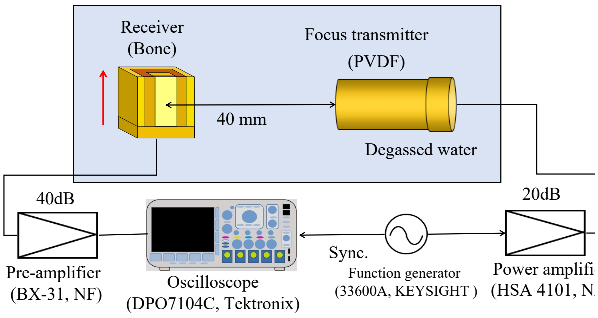
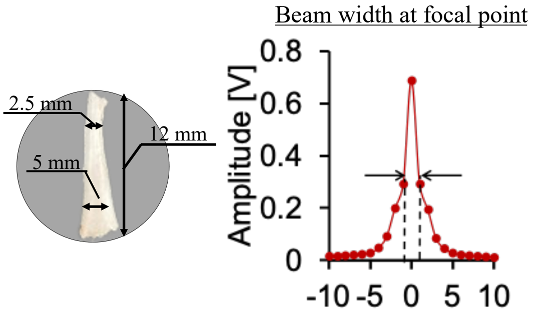


Fig. 2 The experimental set up.



Spot Diameter : about 1.6 mm

Fig. 3 Bone sample size and spot diameter of focused transducer.

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3. Results and discussion

Figure 4 shows an example of the observed waveform of the electrical potentials. The peak to peak value was about 1.3 mV. The peak to peak values were derived from the average of the five peaks in the middle part of the waveform after excluding the effect of high frequency noise.

The ultrasonically induced electrical potentials were next observed as a function of the frequency. The maximum output was observed at 1.6 MHz. This frequency is reasonable because it is near the 1/4 wavelength resonance in the bone thickness direction, considering the wave velocity (3600 m/s) and thickness of the bone specimen.

Next, the induced electrical potentials were measured by changing the irradiating area of the bone transducer. **Figure 5** shows the distribution of induced potentials. The potentials clearly changed depending on the position of irradiating area. One reason seems to come from the small size of the rat bone. The area where the highest potentials were observed was approximately 5 mm (widest), while the area with the lowest potentials were observed was about 2.5 mm (thinnest). Although they were larger than the spot diameter, we should be careful of the small size of the rat bone.

In this study, the rat used was 12-week-old, which corresponds to 11 years old in humans. It was young and the bone was small. In this experiment, the spot diameter of the ultrasound was comparatively small, but focusing ultrasound on the very small bone seems difficult. For future clinical studies, we should carefully select the appropriate age of rat with enough size for ultrasound irradiation in the MHz range.

4. Conclusion

Regarding a rat cortical bone as a piezoelectric material, we fabricated a bone ultrasound transducer. We succeeded in observing the ultrasonically induced electrical potentials in the rat bone transducer. Although the rat cortical bone specimen was very thin and small, we could confirm the existence of piezoelectricity.

However, the observed electrical potentials depended on the measured area. One reason seems to be the small size of the bone, which should be carefully checked in the case of clinical studies.

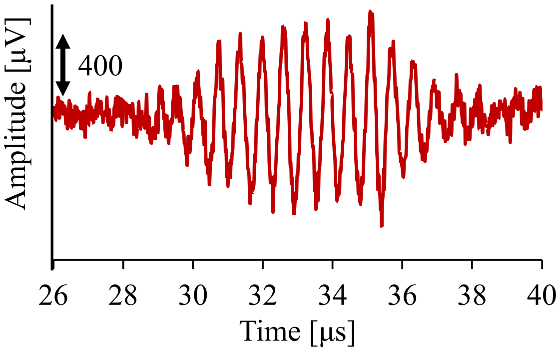

Fig. 4 Observed waveform (1.6 MHz).

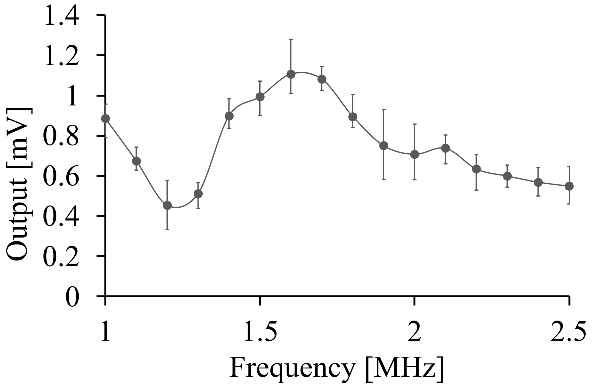

Fig. 5 Frequency characteristics.

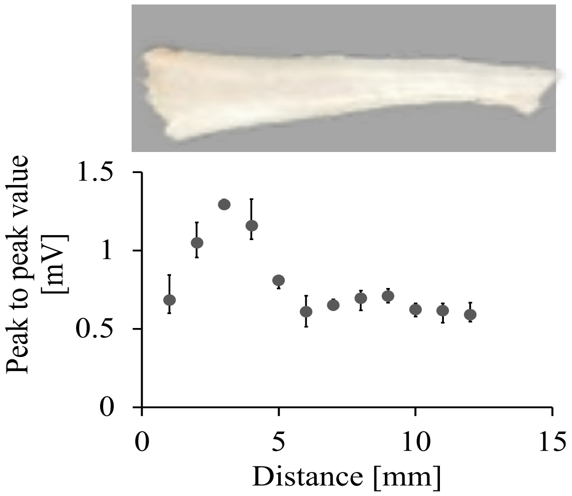

Fig. 6 Output of electrical potentials as a function of position.

Acknowledgment

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References

1. Y. Zhang et al.: IEEE Trans Dielectr Electr Insul. (2012).
2. M. Okino et al.: Appl. Phys. Lett. **103** (2013) 103701.