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Effects of microstructure on bone piezoelectricity in the MHz range
骨の微細構造が超音波帯域の圧電性に与える影響

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1. Introduction

In 1953, Yasuda has reported that mechanical stress at low frequencies induces electrical potentials in bone [1]. Bone remodelling possibly has relations with the electrical potential because bone grows up in the same direction that stress is added to. One expected mechanism is the streaming potential caused by the interaction of liquid and solid phases in the complicated structure in wet bone [2]. The other is the piezoelectricity of collagen or hydroxyapatite (HAp). Unfortunately, there are few studies on the mechanism for the stress induced electric potential in the MHz range.

To evaluate the stress induced electrical potentials at high frequencies, we used cortical bone as a piezoelectric device [3]. We have then fabricated a bone transducer, to obtain output signals induced by ultrasound irradiation in the MHz range.

Cortical bone has a complicated structure from the microscopic to the macroscopic level. Bovine cortical bone can be classified into two main microstructures, plexiform and haversian. Fig. 1 shows the distribution of the microstructures in the midshaft of femur. Human cortical bone has only haversian structure [4].

In this study, we investigated the effect of microstructure on the piezoelectricity. We also tried to evaluate the polarity of piezoelectric properties in bone in the MHz range.

2. Material and Methods

36 circular plate cortical bone samples were extracted from the anterior part of the left and right mid-femoral shafts of 30- to 35-month-old bovines. The diameters were 10.0, 8.0 and 7.0 mm and thickness of these samples were 1.00±0.01 mm. We fabricated three types of circular plate samples: plexiform structure, haversian structure and mixed structure. We checked microstructures of the bone samples by a microscope (IX-7 , Olympus). Samples were used as piezoelectric materials in the ultrasound transducer. Fig. 1 shows the distribution of the microstructures on the surfaces of the ring-shaped samples obtained from the mid shafts.

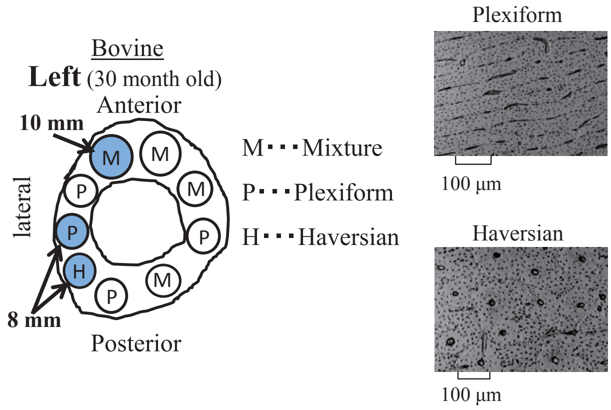

Fig. 1 Distribution of the microstructures in the midshaft of bovine femur.

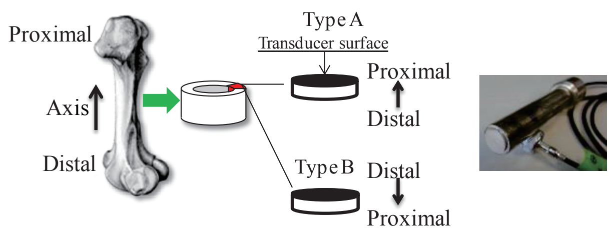

Fig. 2 Fabrication process of bone plate samples and bone transducer.

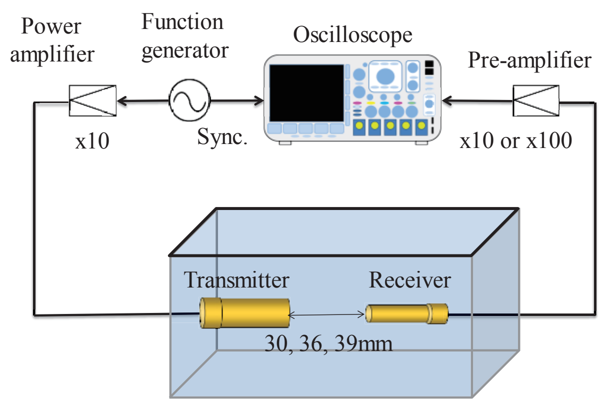

Fig. 3 Experimental setup.

The fabrication process of the bone transducer followed the method reported by Nakamura [5]. We fabricated two types of bone transducers as can be seen in Fig. 2: (Type A) transducer surface was proximal part and (Type B) transducer surface was the distal part.

Figure 3 shows the experimental setup. In the ultrasonic immersion experiments, a PVDF focused transducer (custom-made by Toray) was used as a transmitter and a handmade bone transducer or PVDF transducer were used as a receiver.

First, we estimated the sensitivity of the bone transducers. A function generator (33250A; Agilent Technologies) generated 12-28 cycles of sinusoidal wave at 0.7-1.5 MHz, which were amplified to 70 V_{pp} by a bipolar power supply (HAS 4101; NF). The ultrasonic waves were received and changed into electrical signals by the PVDF or bone transducer. The received signal was amplified 40 dB by a pre-amplifier (BX-31A; NF) and observed in an oscilloscope (DPO3054; Tektronix). The ultrasound pressure was about 10 kPa.

Next, we investigated the polarity of piezoelectric properties in bone in the MHz range. A function generator applied a square pulse to the transmitter. Ultrasound was transmitted at the initial rise and last decrease of the pulse. The ultrasonic waves were received by the bone transducer.

3.Result and Discussion

We measured sensitivity of eleven bone transducers (diameter = 8 mm, haversian structure type or plexiform structure type, from same bovine). Figure 4 shows sensitivity of bone transducers. The sensitivity of haversian bone was higher than that of plexiform bone, telling the effects of microstructure. Yamato has reported that the velocity and orientation of HAp crystallite in the cortical bone depends on the structure [4]. Bone piezoeletricity seems to depend on the structure.

Next, we investigated the polarity of piezoelectric properties in bone. Type A transducers were fabricated from the anterior part (diameter = 10 mm, mixture or plexiform structure) and posterior part (diameter = 8 mm, haversian structure). They showed clear initial rise for the positive ultrasound pressure (Fig. 5), whereas type B showed initial decrease. For the negative pressure both transducers showed opposite changes. However, other smaller transducers (mixture, plexiform and haversian) did not show clear rise because of the small amplitudes . Regardless of microstructure, when bone transducer received the positive ultrasound pressure, proximal part of bone generates minus electric potential and distal part of bone generated plus electric potential. Negative pressure showed opposite changes.

4. Conclusion

We investigated the effect of microstructure on the piezoelectricity. Sensitivity of haversian bone was higher than that of plexiform bone. The bone microstructure showed an effect on the bone piezoelectricity. When bone transducer received the positive ultrasound pressure, proximal part of bone generated minus electric potential and distal part of bone generated plus electric potential. Negative pressure showed opposite changes. The polarization in bone did not depend on the structure.

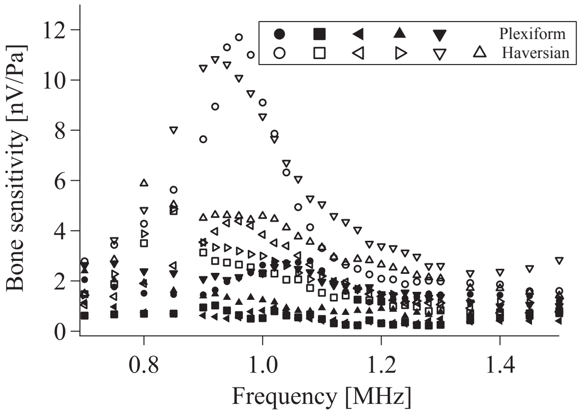

Fig. 4 Frequency characteristics of sensitivity.

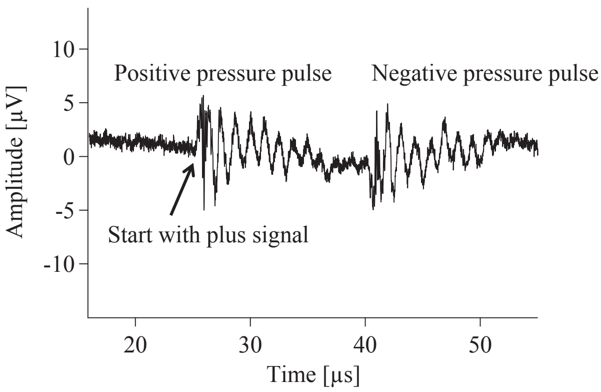

Fig. 5 Output of bone transducer (Type A).

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