Characteristics of electromechanical response of bone in the MHz range

MHz 域における骨の電気機械変換特性

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1. Introduction

Bone piezoelectricity was first discovered by Yasuda in 1953. He noticed that bone generates electricity when submitted to mechanical stress. Following the idea, Yasuda derived the anisotropic piezoelectric constants of bone with Fukada.[1] Frequencies used in these studies were less than 10 kHz and few studies in the MHz range have been reported. Only mechanical methods have been used to measure bone piezoelectricity.

In recent years, healing of bone fractures has been studied extensively. In particular, a clinical method using low intensity ultrasound has been attracting attention. It is believed that the electromechanical phenomenon occurs in bone under the mechanical stress induced by ultrasound in the MHz range, and the resulting electric stimulation may enhance the healing of fractures. However, the physical and biological mechanisms of fracture healing by ultrasound in the MHz range are not clear yet.

Our study is then the first approach to investigate the electromechanical phenomenon in bone in the MHz range using ultrasound irradiation. Similar approach has been reported by Singh in 1986, but the obtained results do not seem to be reasonable for the actual bone properties. Here, we fabricated bone ultrasound transducer following the usual fabrication process of PVDF transducers, and observed the electromechanical response of the transducer in the MHz range.
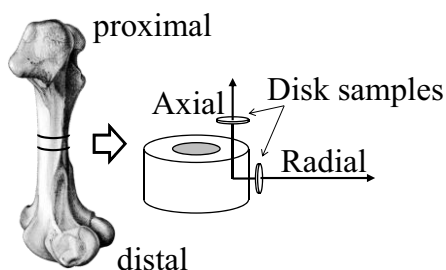
2. Material and Methods

Ten cortical bone samples were extracted from the anterior part of the mid shaft of the left femur obtained from a 29 to 31-month old bovine. These samples showed brick like plexiform structure. They were cut into thin disks (10.0 mm in diameter and 1.00 ± 0.01 mm thick). Six disk samples have circular-surfaces normal to the bone axis, other disk samples have surfaces normal to the radial direction (Fig. 1). Each of them was glued to a brass cylinder (backing material) and used as a transducer. A gold electrode was evaporated on the front surface of the transducer. A bone transducer is shown in Fig. 2.

We also checked the orientation of hydroxyapatite (HAp) crystallites by an X-ray diffraction (XRD) method before the assembly of bone transducers. Actually, the amount of HAp, which orients perpendicular to the circular disk surface, was measured as (0002) peak intensity by an XRD system (X'pert PRO; PANalytical).

A PVDF film transducer[2] (film thickness; 40 μm, Kureha) was also fabricated for comparison to bone transducers.

During ultrasonic experiments, a PVDF focused transducer (diameter; 20 mm, focal length; 40 mm, custom-made by Toray) was used as a transmitter and handmade bone or PVDF transducers were used as receivers. The transmitter and receiver were mounted coaxially with a distance of 30 mm in degassed water at about 24 °C. A function gener-

Fig. 1 Sample preparation.

Fig. 2 An example of bone transducer.

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ator (33250A; Agilent Technologies) generated burst wave with 10-20 sinusoidal cycles of 0.7-2.0 MHz, which was amplified to 70 V_{pp} by a bipolar power supply (HAS 4101; NF). Generated electrical signal was converted to ultrasonic waves by the transmitter and emitted to the water. 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 on the oscilloscope (DPO3054; Tektronix).

3. Results

In our experiments, transmitted sound wave pressure was about 10 kPa. Fig. 3 shows typically observed waveforms. The wave obtained by the PVDF transducer had amplitude of about 50 mV_{pp}, whereas the amplitudes of waves obtained by bone transducers were about 20 μV_{pp}. It was very small but we could confirm the output signal from the bone transducers.

Next, we estimated the sensitivity of bone transducers. Here, we adopted peak-to-peak value of wave amplitude at the 5th cycle of the received wave. We used a PVDF transducer for comparison. The PVDF transducer has already been calibrated by the reciprocal calibration method. This is then a comparative calibration of bone transducer. The results are shown in Fig. 4 for a transducer with an axial disk sample. The sensitivity of bone transducers were about 0.70~4.6 nV/Pa. It was about 66 dB less than that of the PVDF transducer.

We were able to observe the electrical signals from all axial and radial bone transducers.

4. Discussion and Conclusion

Here, we estimated the comparative sensitivity of homemade transducers using axial and radial bone samples in the MHz range. We then confirmed
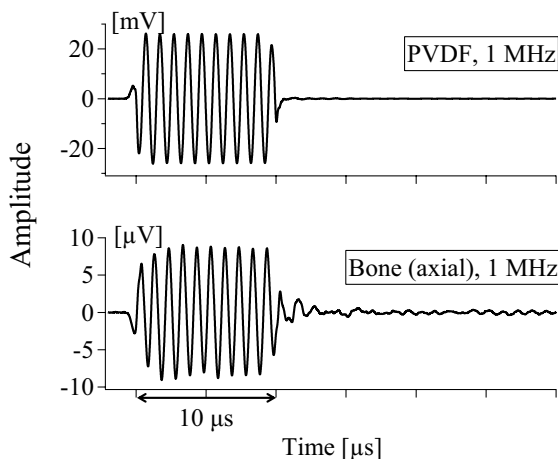

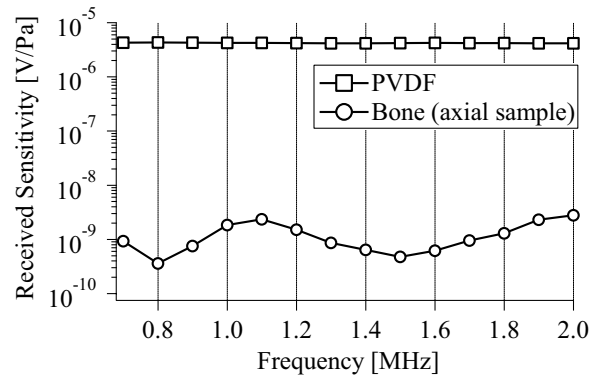
Fig. 3 Observed waveforms.

Fig. 4 Frequency characteristics of sensitivity.

the electromechanical behavior of bone samples. It is well known that cortical bone have strong elastic anisotropy, which is also measured as velocity anisotropy. This anisotropy results from the alignment of HAp crystals included.[3] Our present results indicate electromechanical response of bone in both axial and radial directions. The electromechanical response of radial samples shows that the HAp crystals, which are not vertically orientated in this direction, might have very little participation in the electromechanical phenomenon. In the past studies, at low frequency range less than 100 Hz, bone piezoelectricity was reported to depend on collagen not HAp. Following the idea, Anderson has reported piezoelectric constants d_{33} and d_{11}.[4] Our results also tell that the cause of the electromechanical conversion phenomenon is possibly collagen rather than HAp as Anderson showed at low frequencies.

References

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