1P5-1

Effect of Pore Fluid on Piezoelectric Signal Generated in Cancellous Bone by Ultrasound Irradiation

超音波照射によって海綿骨で生じる圧電信号における間隙流体の影響

Atsushi Hosokawa[1†] and Ikumi Kabeshita ([1]Dept. Electr. & Comp. Eng., NIT, Akashi College; [2]Sci. & Tech., NAIST)
細川篤 [1†]，壁下育弥 [2] ([1]明石高専 電気情報, [2]奈良先端大 先端科学)

1. Introduction

Bone formation can be driven by mechanical loads[1], which is considered to be accompanied to the piezoelectric effect in the bone.[2] Therefore, the piezoelectric effect under ultrasound irradiation should be elucidated to realize effective healing of bone fracture using low-intensity pulsed ultrasound (LIPUS).[3,4] However, the piezoelectric properties at ultrasound frequencies in bone, particularly, in cancellous bone having a complicated porous structure, are not yet well investigated. In our studies, the experimental observations of the piezoelectric signals generated in cancellous bone by ultrasound irradiation has been performed using a piezoelectric cell (PE-cell), which can correspond to an ultrasound receiver.[5–7]

In the PE-cell used in our previous study, the pore spaces of the cancellous bone specimen were saturated with air. However, the real bone was saturated with bone marrow, which is not a gas. In this study, to investigate the effect of the pore fluid in the bone, the piezoelectric signals were observed in two cases of the air- and water-saturated bone specimens.

2. Method

The piezoelectric signals generated in bovine cancellous bone were experimentally observed using the PE-cell. The schematic drawing of the PE-cell[5] is shown in **Fig. 1**. The PE-cell is an ultrasound receiver, in which the bone specimen is used as a piezoelectric oscillator. In the PE-cell, two aluminum (Al) electrodes were attached on the front and back surfaces of the bone specimen using conductive tapes. The bone specimen was electrically shielded by the front Al electrode and the surrounding brass plates. The Al electrodes were conducted to a BNC connector, from which the piezoelectric signal generated in the bone specimen was outputted.

The bone specimen was cut from a bovine femur. The porosity was approximately 0.65 (65%), and the orientation of the trabecular network tended to be parallel to the thickness direction. The pore spaces in the bone specimen were saturated with air or water. Then, the back of the bone specimen in the PE-cell was filled with the same fluid.

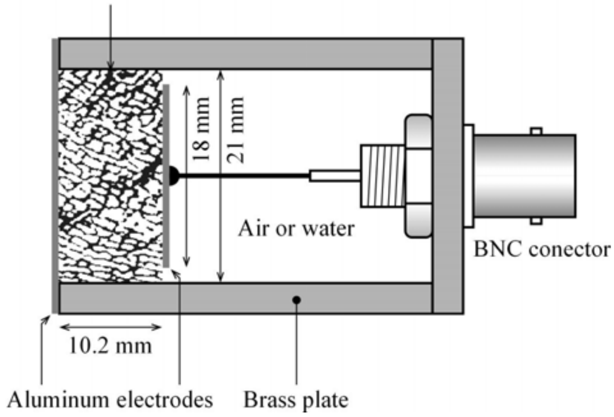


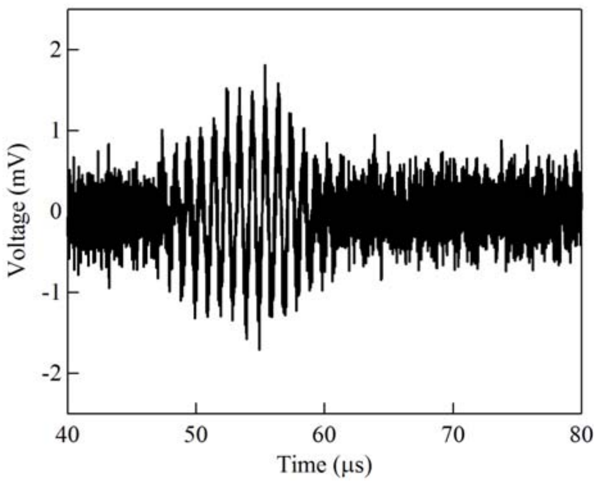
Fig. 1 Schematic drawing of a piezoelectric cell of cancellous bone.

In the experiments, the PE-cell and a Pb(Zr,Ti)O_3 (PZT) ultrasound transmitter were coaxially mounted with a distance of approximately 70 mm in water at room temperature. A burst ultrasound wave at 1 MHz radiated from the PZT transmitter was received by the PE-cell, and the output signal from the PE-cell, that is the piezoelectric signal generated in the bone specimen, was displayed on a digital oscilloscope. Two piezoelectric signals in the cases that the bone specimen was saturated with air and water were observed. The ultrasound waveform irradiated to the bone specimens was observed using a poly(vinylidene fluoride) (PVDF) ultrasound receiver.

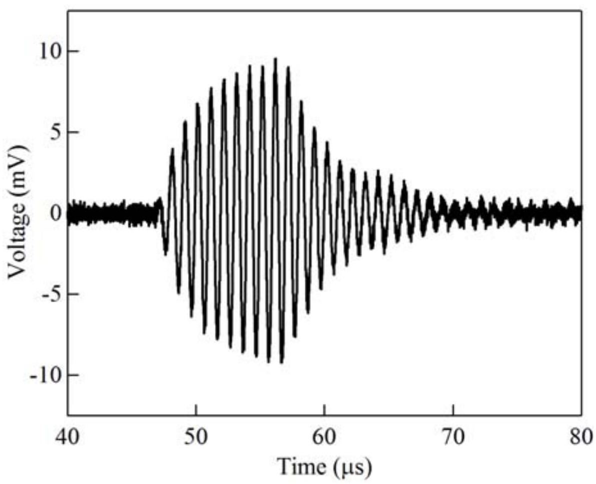
3. Results and Discussion

The observed waveforms of the piezoelectric signals in cancellous bone are shown in **Fig. 2**, in which (a) and (b) show the signals in air- and water-saturated bone specimens, respectively. The observed

hosokawa@akashi.ac.jp



(a)



(b)

Fig. 2 Observed waveforms of piezoelectric signals generated in (a) air- and (b) water-saturated cancellous bone specimens by ultrasound irradiation.

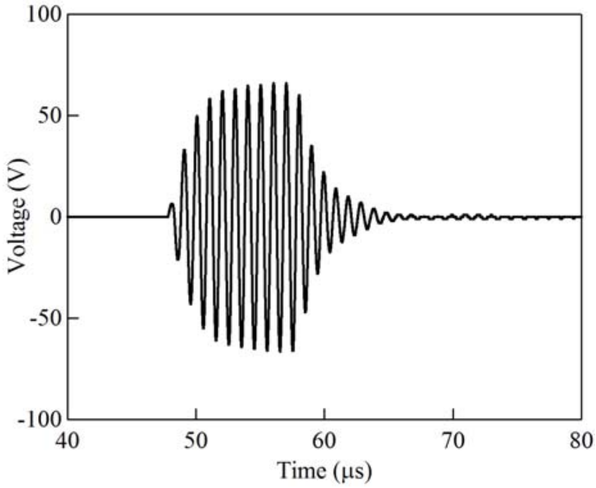


Fig. 3 Ultrasound waveform irradiated to the cancellous bone specimens, which was observed using a PVDF ultrasound receiver.

ultrasound waveform is shown in **Fig. 3**.

Compared between the piezoelectric waveforms in Figs. 2(a) and 2(b), the wave amplitude in the case of the water-saturated bone specimen was much larger than that in the case of the air-saturated bone specimen. This was considered to be because the degree of ultrasound transmission in the water-saturated bone was larger than that in the air-saturated bone. Moreover, the wave amplitude in the case of the water-saturated bone specimen gently varied with time, and the piezoelectric waveform was similar to the ultrasound waveform in Fig. 3 (note that the rise and fall times of the former were slightly longer than those of the latter). However, the amplitude in the case of the air-saturated bone specimen randomly varied with time, although the detail was unclear because of the low signal to noise ratio. This was considered to be because the degree of ultrasound scattering at the air-filled pores in the bone specimen was larger than that at the water-filled pores.

It was concluded from the experimental results that the piezoelectric properties at an ultrasound frequency in cancellous bone could be largely affected by the ultrasound properties.

4. Conclusions

In this study, the piezoelectric signals generated in air- and water-saturated cancellous bone by ultrasound irradiation were experimentally observed. The results showed that the piezoelectric signal could be affected by the pore fluid in the bone, which was considered to be due to the ultrasound properties. In a future work, the dependence of the ultrasound properties on the piezoelectric properties should be investigated.

Acknowledgment
This study was supported by the Japan Society for the Promotion of Science through a Grant-in-Aid for Scientific Research (C) (Grant No. 17K06479).

References

1. A. M. Parfitt, J. Cell. Biochem. **55**, 273 (1994).
2. M. H. Shamos and L. S. Lavine, Clin. Orthp. **35**, 177 (1964).
3. L. R. Duarte, Arch. Orthop. Trauma Surg. **101**, 153 (1983).
4. S. Mitragotri, Nat. Rev. Drug Discovery **4**, 255 (2005).
5. A. Hosokawa, J. Acoust Soc. Am. **140**, EL441 (2016).
6. A. Hosokawa, Proc. Mtgs. Acoust. **32**, 020001 (2017).
7. A. Hosokawa, Jpn. J. Appl. Phys. **57**, 07LF06 (2018).