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Study on photoacoustic properties of cortical bone and hydroxyapatite pellet

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1. Introduction

Bone is mainly composed of hydroxyapatite (HAp) and collagen [1]. National Institute of Health pointed that bone strength depended on bone mineral density (BMD) and bone quality [2]. While BMD is the density of minerals, bone quality includes several factors such as micro cracks, bone metabolic rotation, crystalline orientation, and microstructure. Bone quality is then related to the viscoelastic properties of bone and is often difficult to be diagnosed by X-ray techniques. Ultrasonic techniques which can give us information of viscoelasticity seem suitable for bone quality evaluation.

Recently, an increased risk of bone fractures due to the diabetes mellitus has been reported [3]. Saito reported the contribution of the abnormal cross-links in collagen molecules to the fragility [4]. They are different from the normal "physiological crosslinks". These different crosslinks may change and viscoelasticity and other material properties in bone. If changes of bone properties due to diabetes can be evaluated in vivo, we can expect the prevention of bone fracture.

In this study, an infrared photoacoustic (PA) method was applied to evaluate bone properties. In the photoacoustic method, ultrasonic waves are generated from thermal expansion and contraction due to light absorption in a material. One of the advantages of photoacoustic methods is the ability to select wavelengths of light at which the absorption spectrum of the material is high. It has been reported that light in the near-infrared region is easily absorbed by collagen [5].

Using bovine cortical bone and an artificially fabricated pellet of the HAp, an initial study was performed to know the possible contribution of collagen to PA properties.

2. Experiment method

One cortical bone plate sample (10×10×2.0 mm^3) was fabricated from a femur of a 28-month-old bovine. The bone axis was along the thickness direction of the sample. A pure HAp pellet sample (same size, HOYA Technosurgical) was used for comparison. These two samples were set together as shown in Fig.1.

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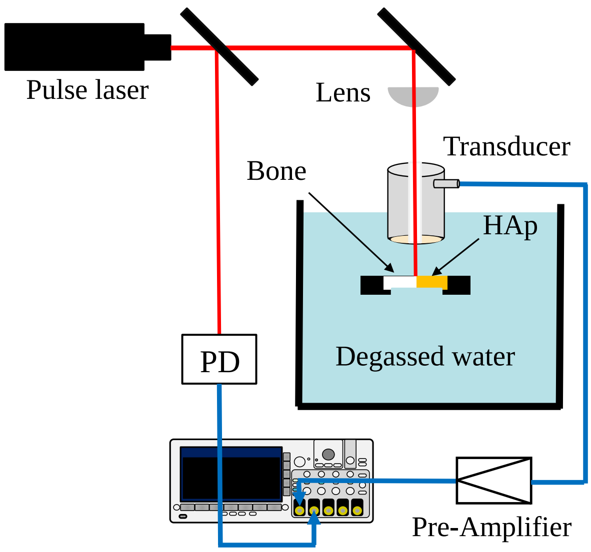

Fig.1 Experimental system.

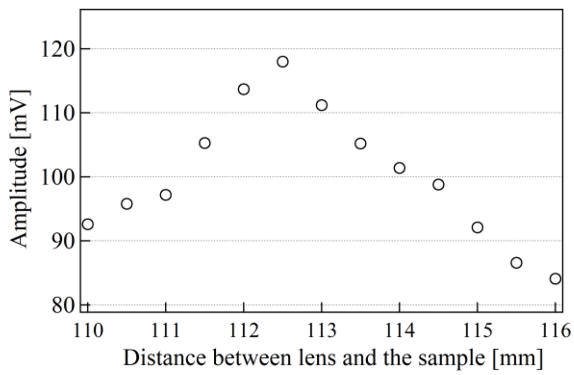

Fig.2 Observed amplitude as a function of the distance.

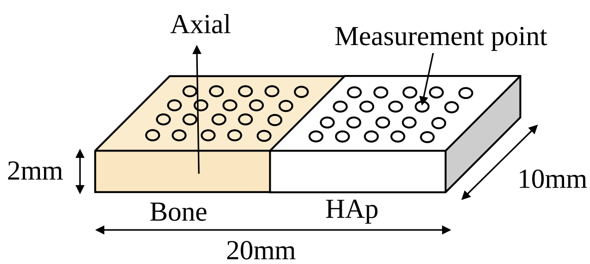

Fig.3 Samples.

Figure 1 shows the experimental setup near the sample. A hollow concave polyvinylidene difluoride (PVDF) transducer (diameter 20 mm, Custum made, Toray) was placed above the sample in degassed water to observe ultrasonic waves. A pulsed laser light (Cobolt Tor™ XS, HÜBNER PHOTONICS, wavelength 1064 nm, pulse width 2.5 ns) was focused on the top surface of the sample through the center of the transducer. Figure 2 shows the amplitudes of the observed signal by the PVDF transducer as a function of the distance between the lens and the sample. Figure 3 shows the measurement positions in the samples. 20 waves from different positions were observed from each sample by setting the two samples side by side. After amplification, the waves were observed by an oscilloscope (DPO7254C, Tektronix). The water temperature was 21.2°C and the incident light intensity was 49 mW near the sample. The intensity was measured by a power meter (PM100D, Thorlabs).

3. Experimental results and consideration

Figures 4 and 5 show observed waveforms by the PVDF transducer. The waves around 10 μs were ultrasonic waves generated by the photoacoustic effect. The waves from the bone sample changed due to the measurement positions, reflecting the heterogeneity of the cortical bone. On the other hand, the waves obtained from the HAp pellet were similar, due to the almost homogeneous character. In addition, we found that samples were not perfectly opaque for the infrared light. Small waves could be found after the initial pulse.

Figure 6 shows peak-to-peak (PP) values of observed waves with standard deviation (SD). They were normalized by the averaged PP values of waves from bone. From the HAp pellet, we found small waves with the normalized PP value of 0.29 with SD of 0.14, indicating a significant difference (*$p<0.01$) from the waves from bone. The big difference between bone and HAp is the existence of collagen. This result suggests that collagen may affect the PA properties.

4. Conclusion

A simple PA method with infrared light was applied to evaluate cortical bone and a HAp pellet. The results showed that the amplitude of the PA wave from HAp was smaller, with a significant difference from those of bone. This may indicate that the collagen in the bone affects the PA properties.

The relationship between collagen and PA properties should be investigated in detail to understand the effects of diabetes for the next step.

Acknowledgment

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References

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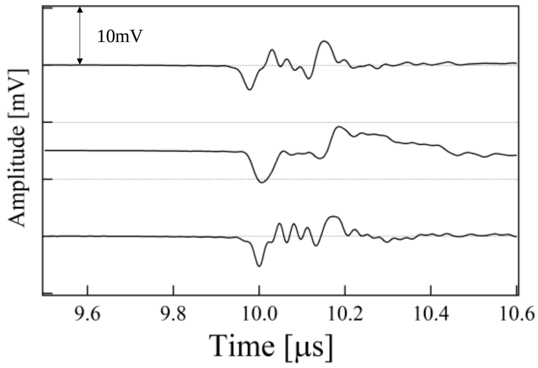

Fig.4 Photoacoustic waveforms from bone.

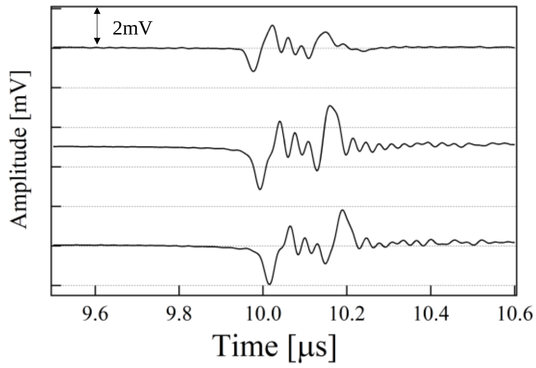

Fig.5 Photoacoustic waveforms from HAp.

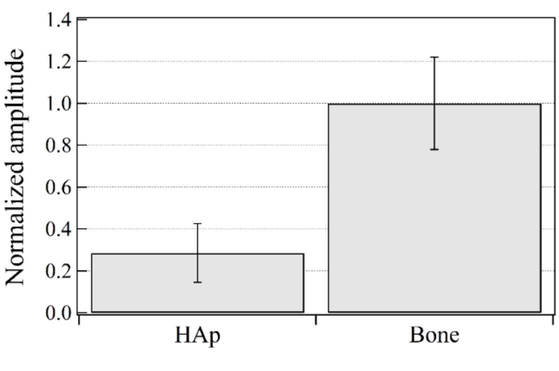

Fig.6 Normalized photoacoustic amplitudes.