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First Human Experience with Acoustically Stimulated Electromagnetic (ASEM) Signal Measurement of Bone

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1. Introduction

Bone is principally composed of hydroxyapatite, which is responsible for its strength, and collagen fiber, which is responsible for its flexibility. In current clinical practice, simple X-rays are mainly used for morphological diagnosis, and bone mass is quantified by dual-energy X-ray absorptiometry (DXA).
However, the assessment tool for collagen fiber has not yet been fully-developed for practical use although the importance of this has been highlighted in recent years. For example, in healthy cortical bone, collagen is aligned along the bone axis, but this orientation is reported to be disorganized in osteoporosis [1]. Moreover, no evidence has been reported to date on the changes in collagen structure in healing process of the fractured bone.

This study targeted on the piezoelectricity of bone, which is reported to be mainly derived from collagen. Piezoelectricity of bone was first discovered in dehydrated femoral cortex suggesting a link between bone collagen orientation and piezoelectricity [2]. However, at this moment, the assessment tool for piezoelectricity of biological material is limited to the excised specimens by means of tensile testing or nanometer probe microscopy. The practical potential for medical use of piezoelectric measurement is greatly enhanced by applying this evaluation to living humans.

Recently, we have demonstrated a unique method to measure the stress-induced electric polarization of biological tissues [3]. The principle of this technique is based on the generation and detection of acoustically stimulated electromagnetic (ASEM) response through electro- or magneto-mechanical coupling of materials. We have reported the ASEM signal from excised cortical bone from animals suggesting the ability to detect polarization induced by ultrasound [3]. This paper provides experimental evidence that human bone in a living state exhibit ASEM response.

2. Materials and Methods

2.1. Acoustically induced polarization

Assuming that the acoustically induced polarization of biological tissue is attributed to piezoelectricity as observed in inorganic crystals with uniaxial symmetry, the detected signal has rotational symmetry around the orientation direction.

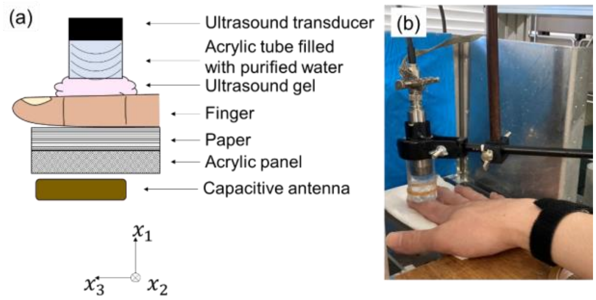

Fig.1 (a) Schematic illustration of the geometric position of the capacitive antenna and ultrasound transducer, (b) Photograph of the experimental setup.

of the piezoelectric tensor with uniaxial symmetry material, d_{14} and d_{3j} ($j = 1,2,3$) components theoretically contain values ("non-zero component") whereas most of the components are theoretically close to zero ("zero component"). Indeed, the previous report from excised cortical bone confirmed the ASEM response from the d_{14} and d_{31} components while negligibly small response was observed from the d_{21} component [3].

2.2. Experimental Setup

Basically, the configuration can be divided into two sections: ultrasound transmission to the subject and ASEM signal detection through the capacitive antenna. The system utilizes a 3.5-MHz planer transducer (KGK Co., LTD, Japan) with the aperture of 7 mm and a 6-dB bandwidth of 4.4 MHz. Deionized water in an acrylic tube was used for the ultrasound coupler to keep a certain amount of distance from the subject. An appropriate distance between the sample and the transducer (approximately 35 mm in this experiment) allows us to distinguish the pulsed ASEM response from the electro-magnetic noise generated by the transducer temporally. Opposite end of the ultrasound coupler was sealed with polyvinylidene chloride (PVC) film with approximately 110-µm thickness. A sufficient amount of ultrasound gel was applied on the boundary between the ultrasound coupler and finger.

The ASEM signal was detected by a circular-shaped resonant capacitive antenna (Cu circular plate with the diameter of 15 mm) tuned to the frequency of the ultrasound signals. The antenna was

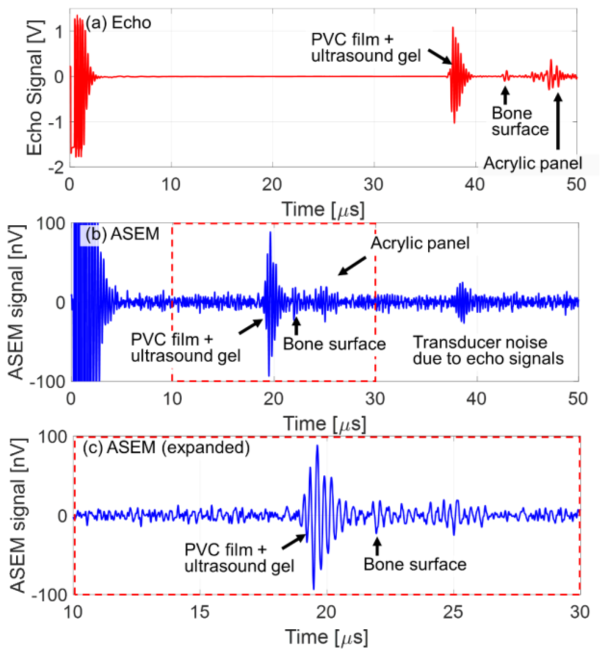

Fig. 2 Typical time traces of (a) Echo signal (b) corresponding ASEM signal, and (c) expanded ASEM signal.

placed under the finger (i.e. opposite side from the ultrasound transducer). The detected ASEM signals were amplified by 92 dB and averaged over 5.0×10^4 pulses at a repetition frequency of 1 kHz. Both ultrasound radio-frequency (RF) signals and ASEM signals were digitized with the sampling frequency of 100 MHz.

This paper pursued to observe the non-zero component based on the above-mentioned theory and experimental evidence [3]. Since the subject was required to remain stationary for at least several seconds during the measurement, this experiment prioritized the configuration that allowed the subject to maintain a stable posture. In this experiment, ultrasound was irradiated in an orientation perpendicular to the bone axis, and the capacitive antenna was placed under the finger (Fig.1 (a)).

The one-dimensional signal data was acquired from the right-pointing finger of a healthy volunteer aged the 20s. The finger was placed on the acrylic panel in a relaxed state to avoid shaking during sequential data acquisition (Fig. 1 (b)). Institutional Review Board (IRB)/Ethics Committee approval was obtained from Tokyo University of Agriculture and Technology, Japan. All subjects enrolled in this study signed a written consent form before initiation of the study-specific procedures.

3. Results

Figure 2 shows the time traces of the ASEM signals and the corresponding ultrasound echo signal. The ASEM response from human bone was observed. Because the ASEM response was generated at half the echo delay time, the signal observed at 22.0 μs and 23.0 μs was identified as the target ASEM response from the bone surface (i.e. around cortical bone). The signal prior to the target ASEM response was at 19.6 μs identified as the electrical charge from PVC film. The amplitude of the ASEM response from the bone surface was approximately 20.7 nV.

4. Discussion

This paper demonstrated the first human experience of the ASEM signal measurement from bone. ASEM response was above the detection sensitivity. This matches well with the *ex-vivo* study with the bovine cortical bone [4]. Further improvement of the detection sensitivity is expected by optimizing the measurement setup.

Regarding the amplitude of the ASEM response, signal from near the surface cortical bone was prominent. This trend matches with the previous report that the ASEM signal from the femur bone of rat was dominant around the cortical bone in the ultrasound irradiation plane [5].

In conclusion, this paper showed the first application of the measurement of the acoustically induced electric polarizations in a living human. This will contribute greatly to the development of diagnostic and therapeutic methods for musculoskeletal diseases that affect the quality of life of patients.

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