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Electrical Potential on Boundary of Osseointegrated Implant and Bone

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***Abstract*—Osseointegration could be described as the modality for stable fixation of titanium implant to bone structure. The OI has become a realized phenomenon of importance in the dental and rehabilitation sciences since recently developed dentures and artificial limbs are directly attached to human skeleton by using osseointegrated (OI) implants. Previously, the electricity-generating capability of bone had been investigated when it is subjected to mechanical loads. This is related to static and dynamic capability of bone, so-called linear piezoelectric and streaming potential effect respectively. Streaming potential or bone strain generated potential (SGP) is an electrical potential and considered to be generated by fluid flow in bone. Bone Piezoelectric potential (PZP) is an electrical potential and considered to be generated by deformation in bone. Since changes in boundaries on bone-implant affect deformations of bone matrix and interstitial bone fluid flow, it could be postulated that SGPZP could be used as a parameter to examine the amount of osseointegration on bone-implant interface. Since no study was performed to understand effects of loading rate changes on behavior of SGPZP for the bone-implant composite, rate dependent behavior of SGPZP was investigated in this study. Magnitude of SGPZP was found to be significantly increased as the rate increased for OI bone-implant composite. In contrast, the time duration of SGPZP was decreased as the rate increased. These results could imply that the temporal SGPZP behavior of bone-implant composite is significantly affected by the loading rate.**

***Index Terms*—bone strain generated potential, bone piezoelectric potential, osseointegration, bone-implant composite, rate dependent behavior, bioelectromechanics.**

I. INTRODUCTION

Bone is a solid porous material saturated with viscous fluids. Materials having this structure are usually called fluid filled porous medium or quite often namely biphasic material. The structural characteristics of these materials mutually depend on the infiltrated fluid and solid properties. When a time-dependent nonuniform mechanical load is applied to the fluid-filled bone, the interstitial fluid flow occurs through the interconnected pore space in bone. Then, the interstitial fluid flow in bone will lead the movement of the charged layer of fluid. This causes an electrical field in bone tissue. This phenomenon is called as bone strain generated streaming potential (SGP).

While studying fracture repair in bone, the another electricity-generating capability of bone had been investigated when it is subjected to mechanical loads. This capability are called bone piezoelectrical potential (PZP). Representative characteristics of bone are having direct piezoelectric effect (when piezoelectric material is loaded by the external force, the electric polarization is generated). As a result, there are two distinctive electrical potential generation mechanisms. The combined one, we could call it as the bone electrical potential (SGPZP).

It has been suggested that SGPZP is closely related to bone remodeling processes [1]. The intensity of SGPZP in bone tissue decreases when there is a lesion, and remarkable SGPZP occurs when bone tissue is formed again in a fractured part. In addition, negative potential increases in the epiphyseal growth plate when bone tissue grows faster. Ultimately, SGPZP is known to control the activity of osteoblasts and, stimulates osteogenesis on the negative pole, and promotes bone resorption on the positive pole [2], [3].

Boundary conditions of osseointegrated (OI) implant in bone affect the characteristics of interstitial bone fluid and interfacial surface potential of the bone matrix. Thus, changes in boundary on OI implant could induce changes SGP and PZP when a load is applied to the bone OI implant composite. It is hypothesis that differences of interstitial fluid flow and bone matrix deformation rates of OI bone-implant composite, which are considered by changes of loading rate, could cause different temporal behavior of SGPZP. However, there is no research to understand effects of loading rate on SGPZP behavior of OI bone-implant composite. The purpose of this study is to understand effects of loading rate changes on SGPZP behavior of OI bone-implant composite.

II. MATERIALS AND METHODS

Eight experimental white New Zealand rabbits underwent pure titanium implant insertion surgery to tibia after amputation (Fig. 1). It was carried out implanting operation into the medularly cavity of tibia of the right hinder limb. At the end of the 5 weeks, all experimental animals were euthanized and the amputated tibia-implants were harvested as in Fig. 2. Then, digital plane radiographs were taken to examine OI. It was determined that four tibia-implants showed OI. As a result, a total of

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four specimens were used in this study. In experiment, we put the tibia-implants in physiological saline under the room temperature in the laboratory for an hour, and then attached electrodes and measured SGPZP.

Figure 1. Implant of pure titanium and a mature rabbit with the implant inserted.

Figure 2. Amputated tibia with implant for measuring SGPZP.

The SGPZP was measured using probe type electrodes in this study. As in Fig. 3, holes 0.5mm in diameter were made on the tissue of the rabbit's tibia and titanium electrodes 0.16mm in diameter were inserted to the holes, and then SGP was measured. As in Fig. 4, an electrode on the left side (section AA') is the base electrode for differential amplification. The resulting relative electrical potential difference measured between the electrodes in section AA' and BB' is SGPZP. Fig. 5 shows the structure of the SGP measuring system.

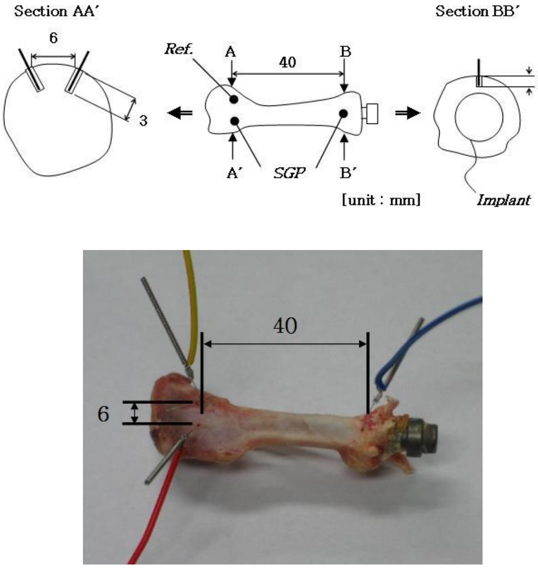

Figure 3. Positions of probe type electrodes.

In order to apply a load, the section AA' of the tibia-implants was fixed using a clamp as in Fig. 5. The other end of the tibia-implants was set upon the crosshead of a servo testing machine (Kyungsung, Korea). In order to minimize noises, insulations are applied to the contact surfaces of the clamp and the load cell. The load was measured in the process of compression, and the strain was 1.54 % for the length of the tibia-implants. To remove noises, we used a bandstop (15Hz~100Hz) filter, commercial software for noise filtering (LabView, National Instrument, USA). In addition, we used amplifier AD620 model (ANALOG DEVICE, USA). Measured SGP was saved in PC through BNC-2120 (National Instrument, USA). In such method, four different displacement rates, 100, 200, 500, and 1000 mm per minute were applied to the bone-implant composites.

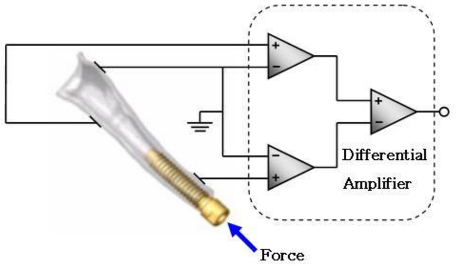

Figure 4. Schematic diagram of experiment upon bone tissue using an animal model.

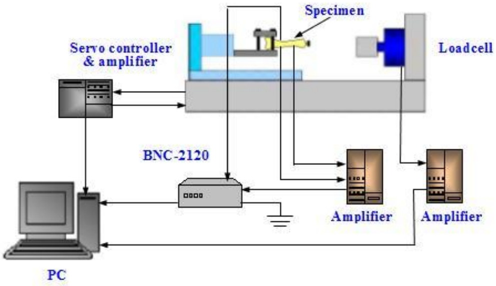

Figure 5. Structure of SGPZP measuring system.

III. RESULTS

Measured results (mean SGPZP for four specimens) are shown in Fig. 6. SGPZP was found to be significantly increased as the rate increased. The peak amplitudes of SGPZP for four different rates were statistically different based on ANOVA (p < 0.001). ANOVA showed that the time at the peak SGPZP was significantly shortened as the rate increased ($p < 0.001$).

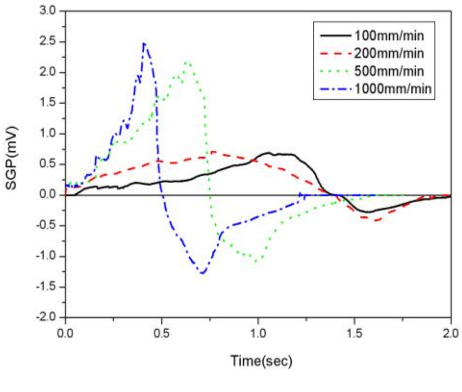

Figure 6. Rate dependent behavior of SGPZP.

IV. DISCUSSION

Based on the theory of poroelasticity, an external loading to fluid-saturated bone causes interstitial fluid pressure gradient [4]. The interstitial fluid pressure generation characteristics in bone are functions of its poroelastic properties and boundary conditions. The mostly important factors governing the interstitial fluid flow are the fluid and loading boundary condition. In addition, by the porous-piezoelectricity an external loading to fluid-saturated bone causes electroviscous interstitial fluid flow [5]. As a result, PZP by the external load on bone matrix complexly interacts with SGP. As describing the meaning of the fluid flow and piezo-effect boundary, OI implant-bone composite formed an undrained fluid and fused boundary at the interface between bone and the surface of implant. As a result, a significant SGPZP generation for OI implant-bone composites was found but not for non-OI ones that did not form an untrained and infused boundary at the bone-implant interface even in a quasi-static loading condition.

Changes of displacement rate on OI specimens in this study means varying loading boundary condition. The previous research [6] indicates that increase of loading rate causes a significant increase of interstitial or intraosseous fluid pressure in bone. Thus, the faster displacement rate could cause the higher intraosseous fluid pressure near the bone-implant interface. As a result, the higher SGPZP s due to the faster intraosseous fluid flow were measured when the faster displacement rates were applied. A theoretical study is required for further understanding of SGPZP behavior in OI implant bone composite.

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