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Longitudinal Variation of Electrical Potential on Osseointegrated Bone

Hunhee Kim and Junghwa Hong
Korea University/Department of Control and Instrumentation Engineering, Sejong, Korea
Email: hoony220@korea.ac.kr, hongjh32@korea.ac.kr

***Abstract*—Osseointegration could be described as the modality for stable fixation of titanium implant to bone structure. 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 bone electrical potential (SGPZP) could be used as a parameter to examine the amount of osseointegration on bone-implant interface. For the purpose, nine electrodes including one reference were instrumented on the wet composite for the one-dimensional mapping of SGPZP during compression tests. The peak magnitudes of SGPZP were found to be significantly increased when the measurement position was approached for the interface of implant-bone. The results could indicate that the spatial SGPZP behavior of osseointegrated implant-bone composite could be caused by the interface of the implant-bone.**

***Index Terms*—bone strain generated potential, bone piezoelectric potential, osseointegration, bone-implant composite, longitudinal variation of sgpzt, 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].

Timothy *et al.* [4] proposed a model on the occurrence of SGPZP difference by the flow of bone marrow using the theory of poroelasticity. MacGinitie *et al.* [5] carried out a four-point bending experiment with specimens collected from the section of a cattle femur in order to explain the relation between the flow of fluid and SGPZP. Beck *et al.* [6] suggested the relation between stress and SGP by performing a compression and bending experiment with the ulna of turkeys. A research with the human body was performed by Gu *et al.* [7].

It was an experiment to measure SGPZP in consideration of orientation in the human lumbar vertebrae using a compression chamber. In this way, SGPZP occurs in bone tissue deformed by external force applied under various conditions and it is known to be closely related to bone growth or remodeling. All previous basic researches explained that SGPZP generation is closely related to interstitial fluid flow in bone. Furthermore, it could be one of important factor inducing bone remodeling processes.

Recently, there was an attempt to use SGPZP as a tool for assessment of osseointegration (OI) to check the mechanobiological firmness at the interface implant-bone. Thus, SGP could be a useful parameter for nondestructive evaluation to check the degree of OI for implant-bone composite. For more understanding, investigations for the spatial SGP behavior of osseointegrated (OI) implant-bone composite are required. In this study, it was hypothesis that differences of interstitial fluid pressure along the OI implant-bone composite could cause different spatial behavior of SGPZP.

II. MATERIALS AND METHODS

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Eight experimental white New Zealand rabbits underwent pure titanium implant insertion surgery to tibia after amputation. 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. 1. Then, digital plane radiographs were taken to examine OI. It was determined that four tibia-implants showed OI. As a result, a total of 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.

The SGPZP was measured using probe type electrodes in this study. As in Fig. 2, 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 SGPZP was measured. The probe array was a regular 7mm inter-electrode spacing for 8 electrodes spanning a total distance of 49mm.

Fig. 3 shows the structure of the SGPZP measuring system. In order to apply a load, the section AA' of the tibia-implants was fixed using a clamp as in Fig. 3. 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 SGPZP was saved in PC through BNC-2120 (National Instrument, USA).

Figure 1. Amputated tibia with implant for measuring SGPZP.

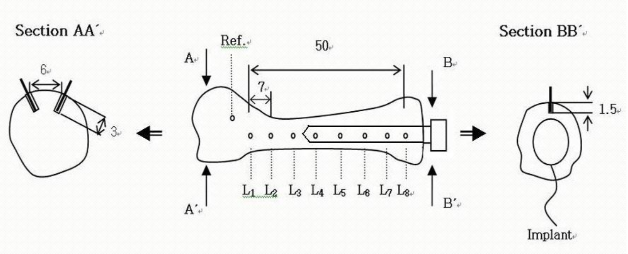
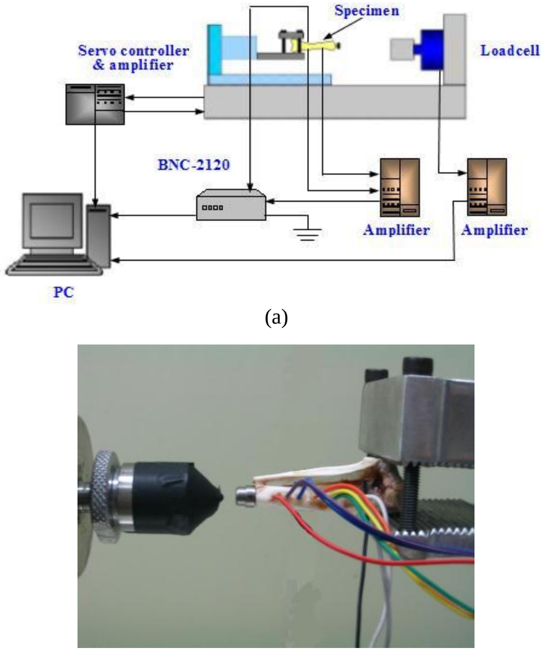


Figure 2. Positions of probe type electrodes.



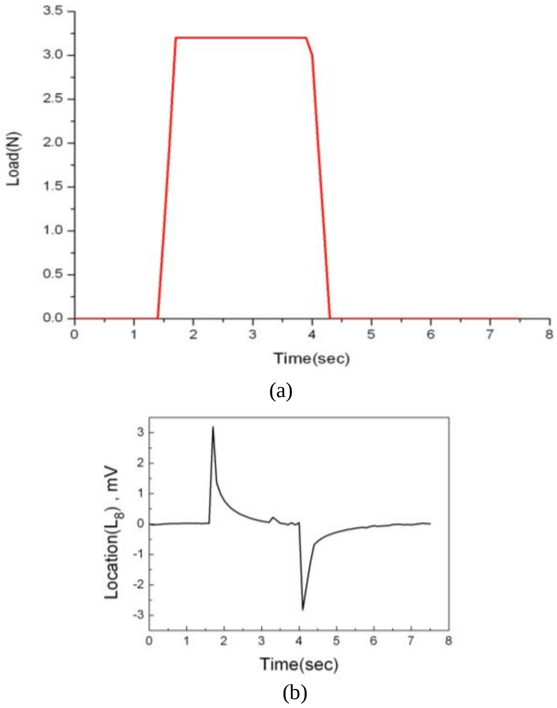
(a)

(b)

Figure 3. Positions of probe type electrodes.

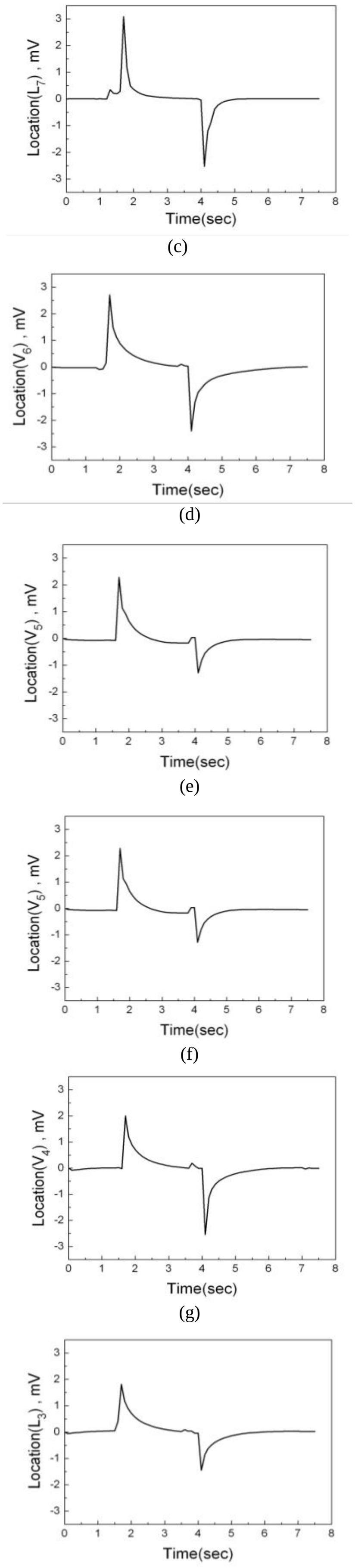
III. RESULTS

Mean SGPZPs from four specimens for each location are shown in Fig. 4 ((b), (c), (d), (e), (f), (h), and (i)). The applied rate of ramp loading was 16mm/sec with 3.2N of peak load. After maintaining the peak load for 2.5 second, the load was removed (Fig. 4 (a)). The peak magnitudes of SGPZP were found to be significantly increased when the measurement position was approached for the interface region of implant-bone, as indicated in Fig. 5.



(a)

(b)



(c)

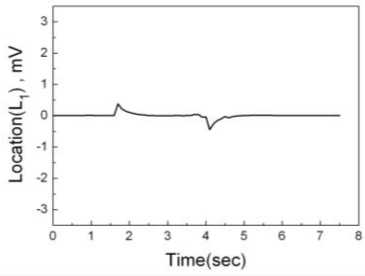
(d)

(e)

(f)

(g)

(h)



(i)

Figure 4. SGPZP behaviors depending on the location changes of measurement.

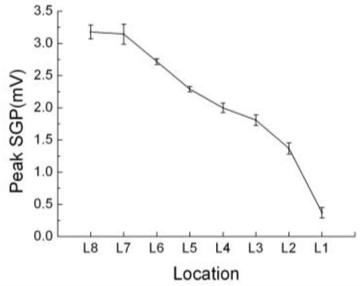


Figure 5. Spatial peak voltage distribution of SGPZP with standard deviation error bars.

IV. DISCUSSION

Based on the theory of poroelasticity, an external loading to fluid-saturated bone causes interstitial fluid pressure gradient [8]. 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. 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 undrained boundary at the implant-bone interface even in a quasi-static loading condition. In this study, the obtained experimental results support the importance of fluid boundary condition in OI implant-bone composite. The significantly high SGPZP values in implant-bone interface region of the OI composite mean that significant generation of intraosseous fluid pressure occurred at the OI implant-bone interface. In contrast, SGPZP values were dramatically decreased when the measurement position was gone away from the interface. More study is required for further understanding of relationships between SGPZP behavior and intraosseous fluid pressure in OI implant bone composite.

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Junghwa Hong Professor Junghwa Hong received B.S. and M.S. degrees in Mechanical Engineering (1988) at Korea University, Republic of Korea, and in Engineering Mechanics (1993) at University of Wisconsin-Madison, USA, respectively. He received a Ph.D. degree in Biomedical Engineering (1996) at the Marquette University, USA. Following the Senior Researcher for the safety in the automobile industry (Technical Center, General Motors, USA), he went to Rehabilitation Engineering Research Center, Republic of Korea as a Principal Research Director for the biomechatronic researches for the disables and elderly in 2000. Currently, he is a professor of the Department of Control and Instrumentation Engineering, Korea University in charge of various research projects related to biomechatronics, biosystem control, and rehabilitation engineering.

Hunhee Kim Hunhee Kim received B.S. (2008) and M.S. (2010) degrees in Control and Instrumentation Engineering at the Korea University, Republic of Korea. Currently, he is a Ph.D. candidate.