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Development of a Dental Implant Mobility Measurement System Using an Inductive Sensor

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Abstract— **Estimation of dental implant stability is an important factor for diagnosis of implant treatment. In this study, we have developed a new system for measuring dental implant mobility. Movement of the implant was measured by an inductive sensor and an amplification adaptor was developed to multiply movement of the implant. Impulse response signal of the implant was acquired and power spectrum analysis was applied for the signal. Various implant-tissue interfacial conditions were simulated in an in vitro experiment and average peak frequency of the power spectrum was calculated for each condition. Artificial implantation model of acryl was fabricated and holes of different levels of depth and diameter were drilled. Two types of impression materials were used to fix the dental implant into the hole. The peak frequency showed linear relationship (*P*-value<0.01) with the depth and the diameter of the hole. Differentiability of the system was evaluated by ANOVA test.**

I. Introduction

Dental implant stability appears to be an important factor for assessment of success of dental implantation. A quantitative measurement of the implant stability through the whole implant treatment becomes more essential. High implant stability implies successful osseointegration of the implant with surrounding bone and change in implant stability reflects the current status of the implant-tissue interface. However, currently, no standard tool for evaluating implant stability exists.

The needs for convenient tools to quantify the implant stability have been raised and various techniques were introduced. Histomorphometry [1], X-ray image examination [2], and reverse torque test [3] are intuitive methods to analyze the implant stability. However, histomorphometry and reverse torque test are destructive methods and X-ray image do not provide the clinician with high resolution good enough to detect subtle bone change. Cutting resistance analysis, which measures the energy required to cut off a unit volume of bone, cannot be used to acquire longitudinal implant stability [4]. Several noninvasive techniques were developed to overcome the limitation of previous method [5-9] and, among them, the Periotes and the Osstell Mentor are the most widely used tools for repeatable clinical assessment.

The Periotest (Siemens, Germany) was originally developed to measure the stability of the tooth. It was also applied to the dental implant mobility measurement. The Periotest calculated the interfacial damping characteristic between the tooth and the surrounding tissue by measuring contact time of the tapping rod with the tooth [10]. The mobility of the tooth and/or the implant is represented as a digital number, PT value, and PT value ranging from -8 to 0 represents clinically good ossesointegraion. However, PT value is reported to be strongly related to the orientation of excitation direction and tapping position [11].

The Osstell Mentor (Integration Diagnostics AB, Sweden) is based on resonance frequency analysis. This method is noninvasive and no direct contact to the implant is needed. The Osstell Mentor uses the implant stability quotient (ISQ) as measurement unit. Increase in ISQ value during long-term examination implies that the implant becomes more stable. It was reported that ISQ value was proportional to bone formation [12]. Although ISQ value might be useful for detecting tendency of implant stability, diagnostic criteria for failure of the implantation has not been clearly established [4].

In this study, we developed a dental implant mobility measurement system using an inductive sensor to evaluate the implant stability objectively and repeatedly for longitudinal assessment. An implant movement amplification adaptor was designed to detect subtle movement of the implant and impulse response of the implant was analyzed. Performance of the developed system was verified by simulation of various conditions of implant-tissue interface.

II. Procedure for Paper Submission

A. Hardware configuration of Dental Implant Mobility Measurement System

Dental implant mobility measurement system consisted of three parts; Movement sensing part, signal processing part, and communication part (Fig. 1).

Our system used an inductive sensor, which detected changes in distance between the sensor and a metal object and converted it into an electrical signal, to measure the dental implant mobility. The detected signal of distance between the sensor and the implant was measured at 1 KHz sampling frequency and amplified at the signal processing part. The signal was then filtered by a high pass filter with a 100 Hz

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cut-off frequency. The processed signal was transferred to the PC by UBS communication cable for further analysis.

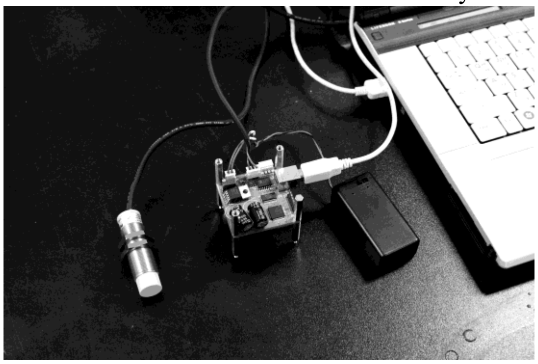

Fig. 1. Hardware configuration of the dental implant. mobility measurement system.

As the movement signal of the dental implant detected by the inductive sensor is small, we have developed an adaptor to amplify the movement signal of the implant (Fig 2). The adaptor was cube-shaped and made of aluminum. The rod of the amplification adaptor was firmly screwed into the implant so that the adaptor and the implant acted like one rigid body. The adaptor improved the detectability of the inductive sensor and small movement of the implant could be easily measured by the sensor. The signal acquired from the sensor was further magnified through the signal processing part. The magnification factor was carefully adjusted to enhance the original signal.

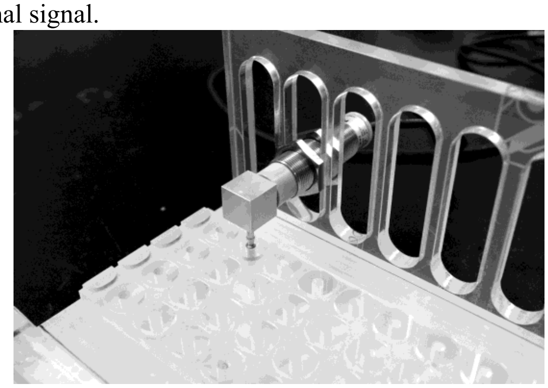

Fig. 2. An amplification adaptor is fastened to the dental implant to amplify the movement signal of the dental implant.

B. Simulation of dental implant-tissue interface condition

We designed artificial implantation model for simulation of various implant-tissue (soft and hard) interface to test our system. The experiment stand was made of acryl and holes of various depths and diameters were drilled to simulate the bone loss and different implant-tissue interfacial condition.

Gap between the hole and the implant were filled with different types of dental impression materials. Two dental impression materials were used; EXAMIXFINE (GC Corporation, Japan), Regisil Rigid (DENTSPLY Caulk, USA). The hardness of these materials was 75.84 HA (Regisil Rigid) and 44.62 HA (EXAMIXFINE) when tested with a Shore A- type hardness tester (Landtek, China). The difference in hardness of 2 impression materials represented degenerative changes of implant-tissue interface.

In our study, we used single type of dental implant which was 4.0 mm in diameter and 10 mm in length (OSSTEM IMPLANT, Korea). After filling the hole with the impression material, the implant was slowly inserted into the hole. Implantation guide tool was used to guarantee the implant to be placed in the center of the hole. The depth of the hold was divided into 4 steps and varied from 10 mm to 7 mm. The different levels of depth simulate the loss of alveolar bone supporting dental implant. The diameter of the hole was varied from 4.2 mm to 4.8 mm by 2 mm and represented changes in implant-tissue interfacial condition including extension of the periodontal ligament space.

C. Analysis of the Dental Implant Mobility

Periotest (Siemens, Germany) was used as an impact driving module for the implant. After fastening the adaptor to the implant, the head of adaptor was tapped by the tapping rod of the Periotest. And the series of vibration signal was transferred to the PC for the evaluation. The signal was composed of series of impulse response of the dental implant.

III. RESULTS

Sequential movement data of the implant was acquired and recorded (Fig. 3). For each implantation condition, five impulse responses were automatically extracted and analyzed.

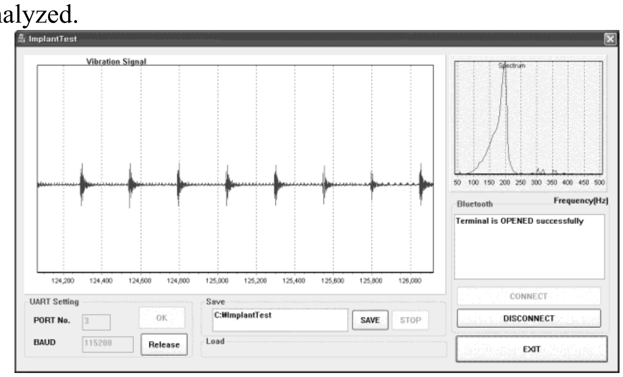

Fig. 3. Raw movement signal of the implant acquired from the mobility measurement system consists of sequential impulse responses.

We used power spectrum analysis to assess the implant mobility and calculated a peak frequency of the power spectrum (Fig. 4).

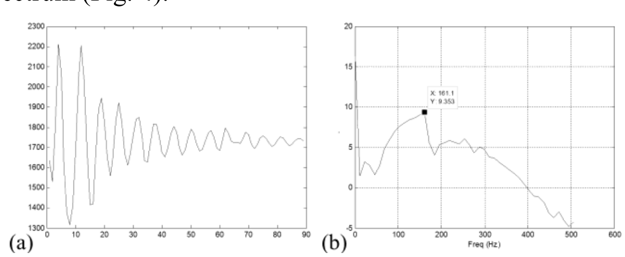

Fig. 4. (a) Impulse response signal of dental implant and (b) the result of power spectrum analysis.

A power spectrum was obtained by fast Fourier transformation and average peak frequency of five power spectrum was calculated. The results of the peak frequency calculation were shown in table 1 and 2.

Table 1. Result of peak frequency calculation (mean ± SD) for an experiment with EXAMIXFINE.

Diameter / Depth	7	8	9	10
4.2	135.57±3.74	154.53±1.95	180.17±5.44	189.07±1.42
4.4	118.38±2.14	138.87±1.92	158.60±5.31	179.44±1.93
4.6	111.59±1.81	129.82±3.01	145.08±2.75	157.64±2.27
4.8	99.12±4.73	117.045±0.75	132.69±5.06	138.78±3.39

Table 2. Result of peak frequency calculation (mean ± SD) for an experiment with Regisil Rigid.

Diameter / Depth	7	8	9	10
4.2	159.94±1.57	200.13±4.73	232.02±6.15	249.57±3.50
4.4	149.25±3.67	191.63±3.12	223.55±1.34	227.3±5.53
4.6	145.48±4.36	164.97±1.76	177.20±4.84	197.71±4.34
4.8	138.43±4.60	149.93±2.87	168.37±1.61	184.24±7.10

The peak frequency of the signal was increased along with the increase in stiffness of the impression materials and depth of the hole (Fig. 5). And the peak frequency of the impulse response increased as the diameter of the hole decreased (Fig. 6).

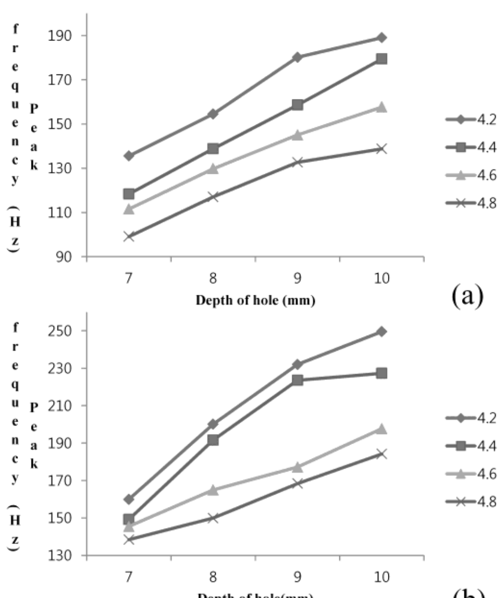

Fig. 5. Mean peak frequency versus depth of the hole for an experiment with EXAMIXFINE (a) and Regisil Rigid (b).

Linear regression was performed to statistically analyze the relationship between the parameters. When EXAMIXFINE was used as a filling material, the peak frequency of the power spectrum was linearly associated with the depth of the hole (R^2=0.443, *P*-value<0.01) and the diameter of the hole (R^2=0.396, *P*-value<0.01). When Regisil Rigid was used as a filling material, the peak frequency, also, showed linear relationship with the depth of the hole (R^2=0.555, *P*-value<0.01) and the diameter of the hole (R^2=0.350, *P*-value<0.01).

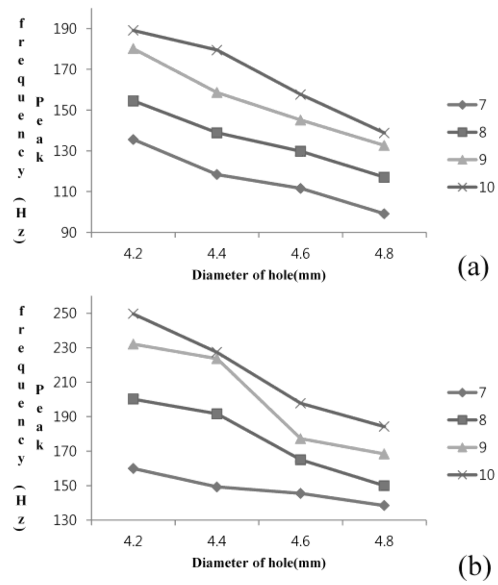

Fig. 6. Mean peak frequency versus depth of the hole for an experiment with EXAMIXFINE (a) and Regisil Rigid (b).

We performed one-way analysis of variance (ANOVA) to verify the ability of the system to differentiate between different conditions. A statistically significant difference (*P*-value<0.01) was found between all implantation conditions except one case for Regisil Rigid experiment. Under the same hole depth condition of 7mm, peak frequency of the hole diameter of 4.4mm and 4.6mm showed no statistical difference. However, other peak frequencies were differentiable from each other.

IV. DISCUSSION

In our study, a new system for measurement of dental implant was developed. The system was noninvasive and repeatedly usable, which was adequate for long-term clinical observation of implant stability.

Movement of the dental implant was detected by an inductive sensor at a high sampling rate of 1 KHz. A specially designed movement amplification adaptor was designed and attached to the implant to magnify the movement of the implant. The metallic amplification adaptor helped detect subtle vibrational movement of the implant, since the inductive sensor measure the distance between a metallic object and the sensor through electromagnetic principle. The amplified movement signal had sufficient amplitude to be analyzed compared to the original implant movement signal without attaching the adaptor. In previous studies, the mechanical movement of the implant was measured with piezoelectric sensor and the vibrational movement of the implant could not be amplified [6, 8, 9]. Impulse response signal of the dental implant was measured and power spectrum analysis was applied. Average of 5 peak frequency of the power spectrum was calculated for each implant.

The ability of the system was verified by in vitro experiment. Various implant-tissue conditions were simulated to evaluate the system. Statistically significant linear relationship between the peak frequency and implantation conditions (depth and diameter of hole) was found by regression analysis. The peak frequency was proportional to the depth of the hole and inversely proportional to the diameter of the hole. Previously, strong correlation was observed between the level of horizontal implant fixture exposure and implant stability measurement value (PT and ISQ value) [13]. The peak frequency was also increased when stiffness of the impression material was increased. Kaneko [14] reported that there was a theoretical relationship between the stiffness of the implant-bone system and the PT value. Differences between the average peak frequencies for each implantation condition were evaluated by ANOVA test to test the differentiability of the system. According to the results, the developed system was proved to be able to detect changes in the implantation conditions. Further investigation is required to clinically verify the ability of the system.

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