Medical Engineering & Physics 36 (2014) 715–720

Contents lists available at ScienceDirect

Medical Engineering & Physics

journal homepage: www.elsevier.com/locate/medengphy

Technical note

Comparison of dental implant stabilities by impact response and resonance frequencies using artificial bone

Dae-Seung Kim[a], Woo-Jin Lee[a], Soon-Chul Choi[b], Sam-Sun Lee[b], Min-Suk Heo[b], Kyung-Hoe Huh[b], Tae-Il Kim[c,∗∗], Won-Jin Yi[b,∗]

[a] *Interdisciplinary Program in Radiation, Applied Life Science Major, College of Medicine, BK21, and Dental Research Institute, Seoul National University, Republic of Korea*
[b] *Department of Oral and Maxillofacial Radiology, BK21, and Dental Research Institute, School of Dentistry, Seoul National University, Republic of Korea*
[c] *Department of Periodontology and Dental Research Institute, School of Dentistry, Seoul National University, Republic of Korea*

ARTICLE INFO

Article history:
Received 14 March 2013
Received in revised form
15 November 2013
Accepted 1 December 2013

Keywords:
Implant stability
Impact response
Peak frequency from power spectrum
Implant stability quotient
Resonance frequency analysis

ABSTRACT

Purpose: We compared implant stability as determined by the peak frequency from the impact response with the implant stability quotient (ISQ) by resonance frequency analysis (RFA) in various artificial bone conditions. The clinical bone conditions were simulated using an artificial bone material with different cortical thicknesses and trabecular densities.
Materials and methods: The artificial bone material was solid, rigid polyurethane. The polyurethane foam of 0.8 g/cm^3 density was used for the cortical bone layer, and that of 0.08, 0.16, 0.24, 0.32, and 0.48 g/cm^3 densities for the trabecular bone layer. The cortical bone material of 4 different thicknesses (1.4, 1.6, 1.8, and 2.0 mm) was attached to the trabecular bone with varying density. Two types of dental implants (10 and 13 mm lengths of 4.0 mm diameter) were placed into the artificial bone blocks. An inductive sensor was used to measure the vibration caused by tapping the adapter–implant assembly. The peak frequency of the power spectrum of the impact response was used as the criterion for implant stability. The ISQ value was also measured for the same conditions.
Results: The stability, as measured by peak frequency (SPF) and ISQ value, increased as the trabecular density and the cortical density increased in linear regression analysis. The SPF and ISQ values were highly correlated with each other when the trabecular bone density and cortical bone thickness changed (Pearson correlation = 0.90, $p < 0.01$). The linear regression of the SPF with the cortical bone thickness showed higher goodness of fit (R^2 measure) than the ISQ value with the cortical bone thickness. The SPF could differentiate implantation conditions as many as the ISQ value when the trabecular bone density and the cortical density changed. However, the ISQ value was not consistent with the general stability tendency in some conditions.
Conclusion: The SPF showed better consistency and differentiability with implant stability than the ISQ value by resonance frequency analysis in the various implantation conditions.

1. Introduction

Primary stability is one of the most important factors in the assessment of dental implantation success, and is considered a prerequisite for successful implantation [1]. Primary stability is influenced by various factors, including bone quality and quantity, implant geometry, and cortical bone thickness [2–4]. It has been reported that the primary stability is affected by cortical bone thickness and trabecular bone density [5]. The trabecular bone density in the mandibular region is typically higher than in the maxillary region [5], and the cortical bone is thinner in the posterior maxillary region [6]. Several studies have shown that implant survival rates are higher in the mandibular than in the maxillary region [7–9]. While primary stability is related to the mechanical relationship between the implant and the bone, secondary stability is related to bone regeneration and remodeling after implantation [10,11]. Changes in implant stability may depend on the degree of osseointegration, which is affected by various factors during the healing period. The quantification of implant stability at various times may provide significant information as to the individualized optimal healing time [12].

[∗] Corresponding author at: Department of Oral and Maxillofacial Radiology, BK21, and Dental Research Institute, School of Dentistry, Seoul National University, Seoul, Republic of Korea. Tel.: +822 2072 3049; fax: +822 744 3919.
[∗∗] Corresponding author at: Department of Periodontology and Dental Research Institute, School of Dentistry, Seoul National University, Seoul, Republic of Korea. Tel.: +822 2072 2642; fax: +822 744 0051.
E-mail addresses: periopf@snu.ac.kr (T.-I. Kim), wjyi@snu.ac.kr (W.-J. Yi).

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http://dx.doi.org/10.1016/j.medengphy.2013.12.004

Several noninvasive methods adequate for repeated measurements were developed for the long-term observation of implant stability [13–16]. The Periotest (Siemens, Bensheim, Germany) and the Osstell Mentor system (Integration Diagnostics AB, Goteborgsvagen, Sweden) are noninvasive diagnostic methods for the measurement of implant stability at various time points. The Periotest evaluates the interfacial damping characteristics between the tooth (implant) and the surrounding tissue by measuring the contact time of the tapping rod with the tooth (implant) [17]. The degree of stability is represented as a Periotest value (PTV). The prognostic accuracy of the PTV for implant stability has been criticized for its lack of resolution, poor sensitivity, and susceptibility to operator variability [12]. In comparison, the Osstell Mentor system is based on resonance frequency analysis (RFA), which measures the stability as an implant stability quotient (ISQ). Although RFA is considered to be an objective method to measure implant stability [5], several studies have shown discrepancies between RFA and other stability measurements such as insertion torque, removal torque, bone mineral density, and histological bone-implant contact [18–22]. In addition, we previously developed a method for measuring implant stability using an inductive sensor [23]. The peak frequency from the impact response showed a wider dynamic range and higher resolution than the ISQ value in determining dental implant stability in an *in vitro* model [23].

In this study, we simulated clinical bone conditions with different cortical thicknesses and trabecular densities using an artificial bone material, which enabled simulations of various bone conditions at implantation. Then, we compared implant stability, as determined by the peak frequency from the impact response, with the ISQ by RFA under various artificial bone conditions.

2. Materials and methods

The developed stability measurement method utilized an analog inductive sensor (SUNGJIN Corporation, Busan, Korea), a movement amplification adaptor, and a signal processing circuit [23]. The inductive sensor detected dental implant movement without direct contact through the interaction between the magnetic fields created by the sensor itself and the target object. The interaction between magnetic fields generated an output signal proportional to the continuous changes in distance between the sensor and the implant. A dedicated cube-shaped adaptor made of aluminum (13 mm × 13 mm × 13 mm) was designed to amplify small implant movements by increasing the current flowing through the induction loop in the electromagnetic induction system. The signal produced by the sensor was further amplified electrically. The signal was subsequently processed through a high-pass filter to remove noise, digitized at a 1 kHz sampling rate, and then transferred to a PC through a USB connection.

Clinical dental implantation conditions were simulated using artificial bone material blocks (170 mm × 116 mm × 30 mm) (Sawbones, Pacific Research Laboratories, Inc., Vashon, WA, USA). The artificial bone block used for the cortical and trabecular bones was made of solid rigid polyurethane foam, which was approved by the American Society for Testing and Materials for a standard material for testing orthopedic devices and instruments. The solid polyurethane foam of 0.8 g/cm^3 density was used for the cortical bone layer, and that of 0.08, 0.16, 0.24, 0.32, and 0.48 g/cm^3 densities for the trabecular bone layer. The cortical bone material was cut into 4 different thickness (1.4, 1.6, 1.8, and 2.0 mm) and attached to the trabecular bone with varying density. Two types of dental implants (10 and 13 mm lengths of 4.0 mm diameter) (US II Fixture, OSSTEM IMPLANT, Seoul, Korea) were placed into the artificial bone blocks. As recommended by the manufacturer, a hole of 3.8 mm diameter was drilled into the bone block. The drilling was performed by using a press drill to prevent discrepancies in direction or depth. Then, the implants were installed in the hole with consistent and reproducible alignment. A total of 40 dental implantation conditions were simulated in this study.

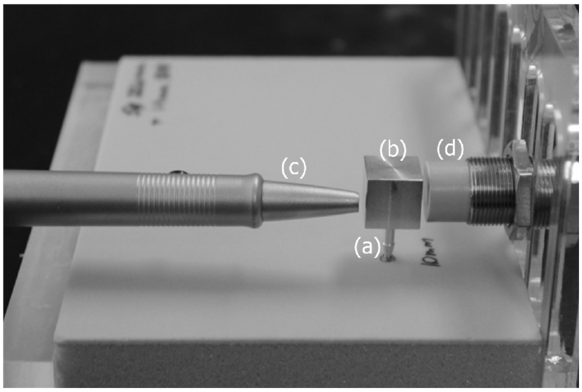

Fig. 1. Measurement of implant stability with an inductive sensor at different artificial implantation conditions. The implant (a) with an adaptor (b) was placed into the artificial bone block, and was tapped using the tapping rod of the Periotest (c). The vibration of the adapter–implant assembly was measured by an inductive sensor (d).

The amplification adaptor was tightly fastened to the implant, and the adapter was taped by the Periotest tapping rod of the Periotest (Siemens, Bensheim, Germany). The vibration of the adapter–implant assembly was measured by the inductive sensor for each implantation condition (Fig. 1). Sequential impact responses were acquired, and the power spectrum of each response was calculated using fast Fourier transform (FFT). The peak frequency of the spectrum was then used as the criterion for implant stability. Five peak frequencies for each condition were used for statistical analyses. Implant stability was also measured by resonance frequency analysis using an Osstell Mentor (Integration Diagnostics AB, Goteborgsvagen, Sweden) under the same conditions. The transducer (SmartPeg) was attached to the implant, and the implant stability quotient (ISQ) value was measured five times for each condition. The relationships between bone density and thickness and the implant stability parameters were evaluated using linear regression analysis. One-way analysis of variance (ANOVA) and Scheffe method as *post hoc* test were performed to analyze the differentiability of the stability parameters at different bone densities and thicknesses. Student's *t*-test was also performed to identify the difference in stability according to implant length.

3. Results

Examples of the impact response and its power spectrum are shown for two different conditions in Fig. 2. Table 1 shows the mean of the peak frequencies from the spectrum analyses at different implantation conditions. The relationship between the trabecular bone density and the peak frequency was evaluated using regression analysis. The stability, as measured by peak frequency (SPF), increased with trabecular bone density at the same cortical thickness ($p < 0.05$), and the regression model indicated significantly high R^2 measure of goodness of fit (Table 2). Using the same trabecular bone density, the SPF also increased according to the increase in the cortical bone thickness ($p < 0.05$). A significant linear relationship between the SPF and cortical bone thickness was found by linear regression analysis (Table 2). The ISQ value also showed a similar trend of stability when the trabecular bone density increased (Table 3). The regression analysis indicated a linear relationship between ISQ value and trabecular bone density (Table 4). However, the R^2 measure of goodness of fit between