치의학석사 학위논문

The relationship between primary implant stability by impact response frequency and 3D bone parameters

Impact response frequency 에 의한 일차적

임플란트안정성과

3D bone parameter 들과의 관계

2015 년 **8** 월

서울대학교 대학원

치의과학과 구강악안면방사선학 전공

복 성 철

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지도교수 이 원 진

이 논문을 치의학석사 학위논문으로 제출함

2015년 4월

서울대학교 대학원

치의과학과 구강악안면방사선학 전공

복 성 철

복성철의 치의학석사 학위논문을 인준함

2015 년 7 월

위 원 장 ______________________ (인)

부위원장 ______________________ (인)

위 원 ______________________ (인)

Abstract

The relationship between primary implant stability by impact response frequency and 3D bone parameters

Sung-Chul Bok, DDS

Department of Oral and Maxillofacial Radiology,

Graduate School, Seoul National University

(Directed by Prof. Won-Jin Lee, MSD, PhD)

Purpose: This study is designed to investigate the relationship between stability by impact response frequency (SPF) and 3D bone micro parameters.

Materials and methods: The developed stability measurement method using analog inductive sensor was utilized to acquire the movement of implant models. 23 dental implantation models using pig rib bone samples were used. The SPF results from implantation models were compared with 3D micro parameters from micro-CT images. The data were analyzed by the SPSS program for linear regression.

Results: Our analysis clearly revealed that a strong positive correlation between SPF values and bone microstructure parameters including BV/TV, BV, BS, IS, BSD, Tb.Th, and Tb.N. On the other hand, there was a negative correlation between SPF values and bone microstructure parameters including BD/BW and Tb.Sp.

Conclusion: This work reported the primary implant stability by impact response frequency and 3D bone parameters using pig rib bone.The results indicate that SPF strongly correlates with bone parameters. Based on the present results, further studies should be conducted to identify the correlation between SPF and histological parameters of bone in human samples including more specimens.

Keywords: Implant stability; impact response frequency (SPF); Inductive sensor; Micro-CT; Bone microstructure parameters

Student Number: 2013-23540

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Sung-Chul Bok, DDS

Department of Oral and Maxillofacial Radiology,

Graduate School, Seoul National University

(Directed by Prof. Won-Jin Lee, MSD,PhD)

CONTENTS

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]. A poor primary stability is one of the major causes of implant failure [2] other related causes of implant failure include inflammation, bone loss, and biomechanical overloading [1, 3]. Primary stability is influenced by various factors, including bone quality and quantity, implant geometry, and cortical bone thickness [4-6]. It has been reported that the primary stability is affected by cortical bone thickness and trabecular bone density [7].

Meredith *et al*. [6] monitored that the successful implant placement and osseointegration. They explained that implant stability is considered to play a major role in the success of osseointegration. Primary implant stability at placement is a mechanical phenomenon that is related to the local bone quality and quantity, the type of implant and placement technique used. As a conclusion, quantitative methods, including resonance frequency analysis, can yield valuable information.

Ilser *et al*. [8] determined the local bone density in dental implant recipient sites using computerized tomography (CT) and to investigate the influence of local bone density on implant stability parameters and implant success. And they revealed that CT is a useful tool to determine the bone density in the implant recipient sites, and the local bone density has a prevailing influence on primary implant stability, which is an important determinant for implant success.

Song *et al.*[9] examined that the relationship between bone quality, as evaluated by cone-beam computerized tomography (CBCT), and implant primary stability, as measured by resonance frequency analysis (RFA). They suggested that CT scanning would be effective for evaluating bone quality and predicting initial implant stability.

Julie *et al.* [10] confirmed the possible correlation between bone microarchitecture and primary implant stability. In this case, the bone structure was analyzed by microcomputed tomography (CT). Bone histomorphometrical parameters were calculated and correlated to primary implant stability. According to the result, implant stability quotients (ISQ) ranged from 50 to 70% depending on the specimens and sites. Histomorphometry indicated differences in the bone microstructures of the specimens. However, ISQ values were not related to trabecular bone histomorphometrical parameters. The sole correlation was found between ISQ values and cortical bone thickness. They suggested that the thickness of cortical bone can be assessed using a standard clinical CT.

Isoda *et al.* [11] valuated the variations in bone quality in implant recipient sites using density value recordings with CBCT, insertion torque during implant placement, and RF analysis immediately after implant placement and to explore possible correlations among these three parameters. Resonance frequency, which represented a quantitative unit called the implant stability quotient (ISQ), was measured using an Osstells Mentor immediately after the implant placement. Spearman's correlation coefficient was calculated to evaluate the correlations among density values, insertion torques, and ISQs at implant placement. As a result, the bone quality evaluated by specific CBCT showed a high correlation with the primary stability of the implants. Hence, preoperative density value estimations by CBCT may allow clinicians to predict implant stability.

Hsu *et al*. [12] investigated the effects of bone stiffness (elastic modulus) and the three-dimensional 3D) bone-to-implant contact ratio (BIC %) on the primary stabilities of dental implants using micro-computed tomography (micro-CT) and resonance frequency analyses. Artificial sawbones models with five values of elastic modulus 137, 123, 47.5, 22, and 12.4 MPa) comprising two types of trabecular structure (solid-rigid and cellular-rigid) were investigated for initial implant stability quotient (ISQ), this was measured using the wireless Osstell resonance frequency analyzer. Each bone specimen with an implant was subjected to micro-CT scanning to calculate the 3D BIC% values. The regression correlation coefficient was 0.96 for correlations of the ISQ with the elasticity of cancellous bone and with the 3D

BIC%. The initial implant stability was moderately positively correlated with the elasticity of cancellous bone and with the 3D BIC%.

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 [13, 14]. 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 [15]. Several noninvasive methods adequate for repeated measurements have been developed for the long-term observation of implant stability [16-19]. The Periotest (Siemens, Bensheim, Germany) and the Osstell Mentor system (Integration Diagnostics AB, Gote-borgsvagen, 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) [20]. 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 [15]. 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 [7], 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 [21-25]. In addition, previously developed a method for measuring implant stability using an inductive sensor [26]. 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 [26].

Bone quality is the one of the essential factors in predicting the success rate of implant installation [9, 27]. Mechanical competence of bone is constituted by bone mass, structural properties (macro-and micro-architecture), and material properties. This is referred to as bone quality [28, 29]. Dental implants are mainly in contact with trabecular bone rather than cortical bone, which directly contributes to implant stability [27, 30]. Therefore, the evaluation of the trabecular microarchitecture would provide useful information for implant installation. Also, clinicians generally observe a poor degree of bone mineralization or limited bone resistance by tactile assessment while drilling [31, 32]. This low density of bone is called “soft bone” [33, 34]. It is often difficult to obtain optimum primary stability in soft bone and implant therapy failure rates are therefore higher [35-37]. Accordingly, preoperative examination of the host bone is important for treatment predictability. Clinically, computed tomography (CT) is currently the only diagnostic imaging technique that allows for a rough determination of the structure and density of the jawbones [5, 38]. It is also an excellent tool for assessing the relative distribution of cortical and cancellous bone [39, 40]. In recent years, microcomputed tomography (μCT) has been the prevalent method of measuring the three dimensional (3D) bone structure of small animals because of its relative rapidity compared with conventional histology, its non-invasiveness, and its high spatial resolution [41-44]. The development of image analysis techniques for the characterization of the 3D-trabecular bone structure remains a privileged research field [45].The main requirement of a structural parameter is its correspondence with the density of bone, and indirectly with the fraction of solid bone volume/total volume (BV/TV). Furthermore, the definition of a predictive analytical model linking trabecular bone structure parameter to mechanical properties, could be useful for the practical use of such parameter [46] .Thus in addition to bone mineral density, the complementary role of an *in vivo* evaluation of the trabecular bone structure for understanding the age related skeletal changes or the role and mechanism therapeutic interventions, would be invaluable [45].

In the past two decades, μCT has been extensively used in the study of bone tissue [47-55]. Except for the densitometry parameters (volumetric BMD), the geometric parameters of bone can be precisely detected using μCT;

for example, total cross-sectional area (TtAr), cortical area (CtAr), cortical bone area fraction (CtAr/TtAr), and cortical thickness (CtTh) can be detected [56]. Furthermore, μCT can provide detailed information on the trabecular bone, such as percent bone volume (BV/TV), bone spcific surface (BS/BV), trabecular thickness (TbTh), trabecular bone separation (TbSp), and mean trabecular bone number (TbN) [56]. Therefore, μCT can be considered the gold standard for evaluating trabecular bone structure. However, μCT cannot be applied on humans because of the small scanning range [57].

The present study aimed to test the primary implant stability by impact response frequency and 3D bone parameters. To this end, for the primary stability of the implant and the bone correlations were quantified as peak frequency via inductive sensors. In addition, by μCT analysis, the 3D implant bone structure was observed to evaluate the correlation between bone factors and implant stability peak frequency (SPF) using pig rib bone.

Materials and methods

Stability measurement method utilized an analog inductive sensor (SUNGJIN Corporation, Busan, Korea), a movement amplification adaptor and a signal processing circuit [20, 26]. The inductive sensor detected movement of dental implant without physical contact. The coil and oscillator of the sensor create a magnetic field in the sensing surface. The target object also generated a magnetic field by induced eddy current which arose from the current in the coil. The interaction between these two magnetic fields generates an output signal corresponding to the distance between the implant and the sensor. A dedicated cube-shaped aluminum adaptor (13mm × 13mm × 13mm) was designed to amplify the small implant movement signal by increasing the current flowing through the induction loop in the electromagnetic induction system. The signal acquired from the sensor was high-pass filtered to remove noise and digitized at a 1 kHz-sampling rate.

Altogether 23 dental implantation models using pig rib bone samples (20mm × 20mm × 20mm) that comprised of trabecular bones without cortical bone layers were made. The samples were obtained from a slaughter house and stored in formaldehyde. SSII SA fixture that is used to cut production at the company Osstem implant diameter4.5 length that was used in11.5mm height. Using the implant for engines from Osstem placement was carried out drilling of 1200rpm Torque has to 30Ncm.Implant placement and the thread was locked and only to the extent completely controlled areas in the gingival height until the cuff was placed in the 23sample.BoneTrimming made to enforce a uniform sample size was performed, and a micro-CT was taken to analyze the bone parameter. Each sample was fixed on both sides by 5cm screws while the experiments were conducted.

The amplification adaptor was firmly screwed into the implant and taped with Periotest (Simens, Bensheim, Germany), and used as a source of excitation force. The signal of adaptor-implant body movement was recorded by the inductive sensor for each implantation model (Fig. 1). We acquired sequential impact responses and calculated the power spectrum of each response using fast Fourier transform (FFT). The peak frequency of the spectrum was used as the criterion for the implant stability. Ten peak frequencies for each condition were averaged and used for statistical analyses.

For micro-CT investigations the μ-CT scanner (SkyScan 1172, 100 kVp, 0.1 mA, 18 min, 12.97 μm isotropic voxel size, Kontich, Belgium) was used. The resulting bmp image files were exported to CTAn software (v1.14, SkyScan) for bone microstructure evaluations. Histomorphometric variables including bone volume fraction (BV/TV), bone volume (BV), intersection surface (IS), trabecular thickness (Tb.Th), trabecular number (Tb.N), and trabecular separation (Tb.Sp) were calculated.

The data were analyzed using SPSS statistics 21 (SPSS Inc., IL, USA) with a 5% significance level. The relationship between SPF and bone microstructure parameters was evaluated using linear regression analysis and Pearson's correlation analysis.

Results

Examples of the impact responses and their power spectra are shown in Fig. 2. Using these series of impact responses, the stabilities, as measured by peak frequency (SPF) were calculated. Table 1 shows the mean of the peak frequencies from the spectrum analysis for the experiment conditions and the histomorphometrical parameters for bone structure calculated by micro-CT imaging at 23 different pig rib bone samples.

A linear regression analysis was performed to statistically analyze the relationship between the bone microstructure parameters and the peak frequency. The SPF increased when calculating at the radius of 0.88 mm or 1.76 mm from implant center (Table 2). Especially, BV/TV, BV, BS, IS, bone surface/volume ratio (BS/BV), bone surface density (BSD), Tb.Th, Tb.Sp, Tb.N showed a high degree of relationship with SPF values. The regression model also indicated significantly high R^2 measure of goodness of fit ($P < 0.01$ for all). The regression analysis indicated a highly linear relationship between SPF and BV/TV and BV when calculating at the radius of 0.88 mm. BV/TV and IS showed highly linear relationship with SPF when calculating at the radius of 1.76 mm.

The Pearson correlation parameters between SPF values and microstructure parameters were calculated. As shown in Table 3, microstructure parameters were significantly correlated with implant SPF values (*P*< 0.01). BV/TV, BV, BS, IS, BSD, Tb.Th, and Tb.N have positive correlation with SPF values (Pearson correlation = 0.85, 0.86, 0.61, 0.73, 0.65, 0.64, and 0.54, respectively) when calculating at the radius of 0.88 mm. On the other hand, BS/BV and Tb.Sp showed negative correlation with SPF values (Pearson correlation = -0.71 and -0.66, respectively). The correlation graphs are shown in Fig. 3.In case of calculating at the radius of 1.76mm, the bone parameters were also considerably correlated with the SPF values (P<0.01). BV/TV, BV, BS, IS, BSD, Tb.Th, and Tb.N have positive correlation with SPF values (Pearson correlation = 0.82, 0.76, 0.66, 0.77, 0.74, 0.57, and 0.71, respectively). On the other hand, BS/BV and Tb.Sp showed negative correlation with SPF values (Pearson correlation = -0.63and -0.56, respectively). Fig. 4 shows the correlation graphs in 1.76mm of measuring area.

Discussion

The primary stability of an implant is affected by several clinical and mechanical parameters. Several methods are used to determine the stability of a dental implant including insertion torque, PTV, RFA, SPF [26] and ISQ [12] after implantation, it is easy to measure primary implant stability as given by the ISQ value. Therefore, previous study was focused only on the correlation between the bone parameters and ISQ values for the implant stability, nevertheless, only a few researches have tried to correlate the primary implant stability by ISQ values and bone microstructure [24, 27, 41, 58]. However, Roze*et al*. [10] explained that there was no correlation between ISQ values and the histomorphometric parameters of the trabecular bone such BV/TV, Tb.Pf, Tb.N, and Tb.Th. Similarly, Huwiler*et al*. [23] explained that there was no significant correlation between ISQ values and histological parameters such as bone volume density and bone trabecular connectivity. Ribeiro-Rotta*et al*. [59] found that the association between ISQ values and BV/TV, SMI, BS/BV, TV, BV, and BS showed tendency to positive correlation and also between ISQ values and TbPf, Tb.Th, Tb.N, and Tb.Sp showed tendency to negative correlation. However, there were no significant relationships to each other found the primary implant stability.

Previous studies demonstrated artificial bone blocks were useful to simulate cortical and trabecular bone condition in controlled manner [12, 60, 61]. This ensured that our previous study which was finding the relationship between different bone densities and thicknesses would enable simulation of various bone conditions at implantation [20]. This study was examined under artificial implantation conditions [20]. As successor, in the present study, we examined the primary implant stability by the peak frequency from impact response and 3D bone parameters using pig rib bone in realistic conditions with different human bone thicknesses and parameters. Pig rib bone is more similar to the human bone sample than other artificial models. Thus, this model has been widely applied in studying implant [62].

There was no previous study that evaluated the correlation between the 3D bone parameters and SPF values. The parameters identified were architecture, density, bulk and spacing: (1) architecture – variables affecting 3D trabecular bone configuration and organization, (2) density – variables relating to surface/volume ratios and volume/volume ratios. They correspond to the volume density of the examined VOI, (3) bulk – variables relating to the amount of bone and (4) spacing – variable related to the distance between trabeculae, determining the quantity and the organization of marrow spaces [59]. BV/TV, structure model index (SMI) and BS/BV belong to density group and trabecular pattern factor (Tb.Pf), Tb.Th and Tb.N correspond to architecture factors. TV, BV and BS belong to the bulk group and Tb.Sp is the spacing parameter [59]. We considered BV/TV parameter as representing the density of pig rib samples and analyzed the relationship between SPF and BV/TV. We also calculated the other 3D morphological parameters and studied the correlation between these parameters and SPF value.

Our analysis clearly revealed that a strong positive correlation between SPF values and bone microstructure parameters including BV/TV, BV, BS, IS, BSD, Tb.Th, and Tb.N. On the other hand, there were negative correlation between SPF values and bone microstructure parameters including BS/BV and Tb.Sp (Table 3). This result was in agreement with Kim *et al.* [20], who revealed that ISQ values showed poor differentiability with implant stability change, whereas, SPF showed good consistency with the tendency of implant stability in various implantation conditions. The SPF value increased consistently as the trabecular bone density increased. This result indicates that the SPF from the impact response can be an appropriate parameter to clinically measure implant stability at various times [20]. Similarly, in this study, the SPF values increased as BV/TV increased. This result suggests that SPF values from impact response of real pig ribs can be a proper parameter to implant stability in respect of bone microstructure parameter. BV, BS, BSD and IS are the amount of the bone portion so that these parameters have correlation with SPF similar to BV/TV. However, BS and BV increased as the amount of the bone portion increased, but the increases of BV were relatively larger than that of BS. In this regard, there was negative correlation between the SPF values and BS/BV.

Tb.Th and Tb.N are parameters for characterizing the shape of a complex bone structure and these are architecture parameters. In our study, the SPF values correlated with Tb.Th and Tb.N and this result indicates that the SPF also had relationship with morphological parameters. To estimate the bone strength, the architecture parameters are important as well as bone density. In this regard, the fact that the SPF is associated with bone structure parameters can be seen as meaning that the SPF could be a more accurate implant stability evaluation means. The parameter Tb.Sp represents the spacing data of bone structure by measuring the distance between trabecular bone patterns. In this regard, as increase of the amount of the bone portion, the gap of bone patterns decreased. Therefore, there was negative correlation between the SPF values and Tb.Sp.

Some limitations of this study should be considered. Pig rib bone was used in this study because of the difficulty of obtaining human samples. However, these pig rib bone samples were very consistent, which might have reduced the experimental error. During acquisition of impact response of pig rib bone, we were unable to fix the rib samples with same force in every process, so it would have affected the result.

Conclusion

This work reported the primary implant stability by impact response frequency and 3D bone parameters using pig rib bone. The results indicate that the SPF has a strong correlation with bone parameters. Based on the present results, further studies should be conducted to identify the correlation between SPF and histological parameters of bone in human samples and include more specimens.

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Tables

Table 1 Stability as measured by peak frequencies (Hz) and bone microstructure parameters for 23 dental implantation models using pig rib samples.

	SPF	BV/TV	TV	BV	TS	BS	IS	BS/BV	BSD	Tb.Th	Tb.Sp	Tb.N	Conn	Conn.Dn
SA1	223.92 ± 11.24	19.70	35.68	7.03	180.95	336.32	30.11	47.86	9.43	0.09	0.23	2.30	5643.00	158.17
SA2	342.80 ± 9.76	27.33	34.66	9.48	168.97	358.51	38.46	37.84	10.34	0.11	0.21	2.42	5733.00	165.39
SA3	292.97 ± 5.42	24.90	34.44	8.57	168.59	364.16	35.13	42.47	10.57	0.10	0.20	2.53	6310.00	183.23
SA4	310.87 ± 8.74	26.01	35.10	9.13	174.73	405.60	38.09	44.43	11.56	0.09	0.19	2.81	7333.00	208.93
SA5	321.46 ± 9.42	26.19	35.17	9.21	174.94	415.08	39.69	45.05	11.80	0.09	0.19	2.83	8785.00	249.78
SA6	362.94 ± 10.15	29.04	35.48	10.30	181.78	440.99	44.21	42.80	12.43	0.09	0.17	3.10	8245.00	232.37
SA7	360.36 ± 10.44	29.81	34.98	10.43	171.06	465.42	44.57	44.64	13.31	0.09	0.17	3.35	9324.00	266.57
SA8	306.01 ± 8.75	28.08	36.37	10.21	185.99	445.31	43.65	43.61	12.24	0.09	0.18	3.06	8292.00	227.99
SA9	302.48 ± 9.65	23.85	35.41	8.44	173.27	418.36	35.98	49.54	11.82	0.08	0.19	2.84	9686.00	273.57
SA10	351.84 ± 8.88	26.61	35.31	9.39	175.18	409.01	38.86	43.54	11.58	0.10	0.19	2.75	7884.00	223.30
SA11	303.69 ± 10.12	28.76	34.89	10.04	172.63	419.80	41.47	41.83	12.03	0.10	0.18	2.99	7217.00	206.87
SA12	337.88 ± 8.14	29.47	35.01	10.32	175.38	405.18	43.22	39.27	11.57	0.10	0.19	2.83	6818.00	194.76
SA13	237.74 ± 9.44	18.43	34.87	6.43	179.53	331.07	28.88	51.52	9.50	0.08	0.22	2.34	5898.00	169.17
SA14	290.93 ± 12.11	25.45	34.97	8.90	171.11	399.01	38.93	44.84	11.41	0.09	0.20	2.82	7569.00	216.46
SA15	329.15 ± 7.49	27.20	34.93	9.50	173.25	429.28	42.90	45.18	12.29	0.09	0.18	3.05	7907.00	226.37
SA16	329.26 ± 9.36	27.37	33.12	9.06	165.08	390.43	44.72	43.08	11.79	0.09	0.19	2.92	6998.00	211.31
SA17	306.62 ± 11.15	28.82	33.81	9.74	173.81	410.53	45.93	42.14	12.14	0.09	0.18	3.04	7399.00	218.86
SA18	348.56 ± 10.73	33.26	33.56	11.16	166.63	422.08	54.25	37.81	12.58	0.11	0.17	3.16	6858.00	204.35
SA19	325.47 ± 9.56	29.35	33.87	9.94	167.24	426.43	48.17	42.90	12.59	0.09	0.18	3.18	7517.00	221.93
SA20	307.12 ± 8.33	25.69	33.57	8.62	172.28	366.15	39.42	42.46	10.91	0.10	0.20	2.67	6153.00	183.31
SA21	374.87 ± 11.31	31.24	34.09	10.65	168.59	389.51	48.19	36.57	11.43	0.12	0.19	2.62	6017.00	176.49
SA22	330.78 ± 10.12	30.32	33.65	10.21	166.37	422.73	46.93	41.42	12.56	0.10	0.18	3.18	7042.00	209.25
SA23	265.10 ± 8.67	24.56	34.11	8.38	173.02	395.97	40.63	47.25	11.61	0.09	0.19	2.83	7916.00	232.04

Table 2 Linear regression analyses between SPF and bone microstructure parameters at 0.88mm and 1.76mm of measuring areas (P<0.01).

	0.88mm		**1.76mm**	
	R^2 value	F value	R^2 value	F value
BV/TV	0.72	52.79	0.68	44.53
BV	0.73	57.37	0.58	29.46
BS	0.37	12.16	0.43	16.13
IS	0.53	23.37	0.60	31.03
BS/BV	0.50	21.30	0.39	13.65
BSD	0.43	15.70	0.55	25.80
Tb.Th	0.42	14.90	0.33	10.29
Tb.Sp	0.43	15.87	0.31	9.60
Tb.N	0.29	8.41	0.50	21.02

Table 3 Pearson correlation values between SPF and bone microstructure parameters at 0.88mm and 1.76mm of measuring areas ($p<0.01$).

	0.88mm	**1.76mm**
BV/TV	0.85	0.82
BV	0.86	0.76
BS	0.61	0.66
IS	0.73	0.77
BS/BV	-0.71	-0.63
BSD	0.65	0.74
Tb.Th	0.64	0.57
Tb.Sp	-0.66	-0.56
Tb.N	0.54	0.71

Figures

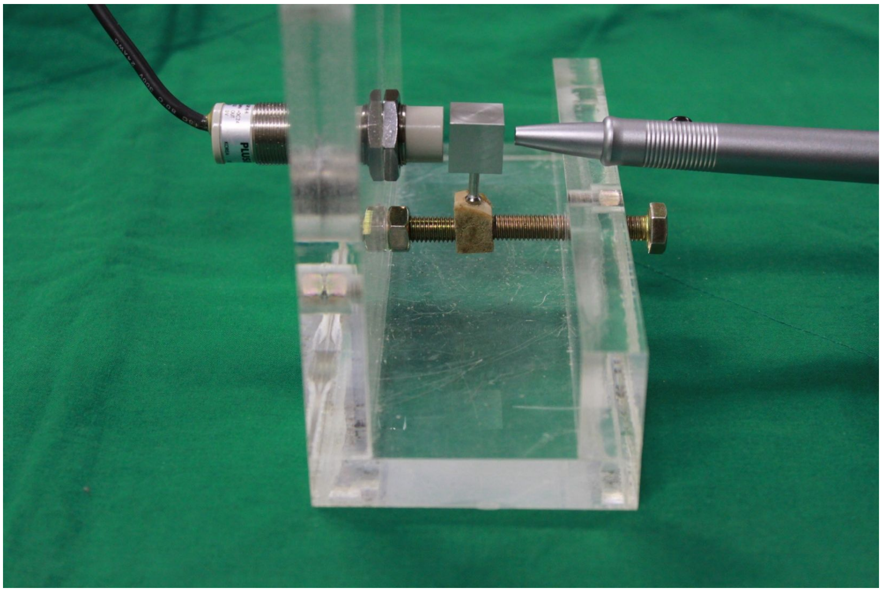

Figure 1 The signal of adaptor-implant body movement was recorded by the inductive sensor for each implantation model.

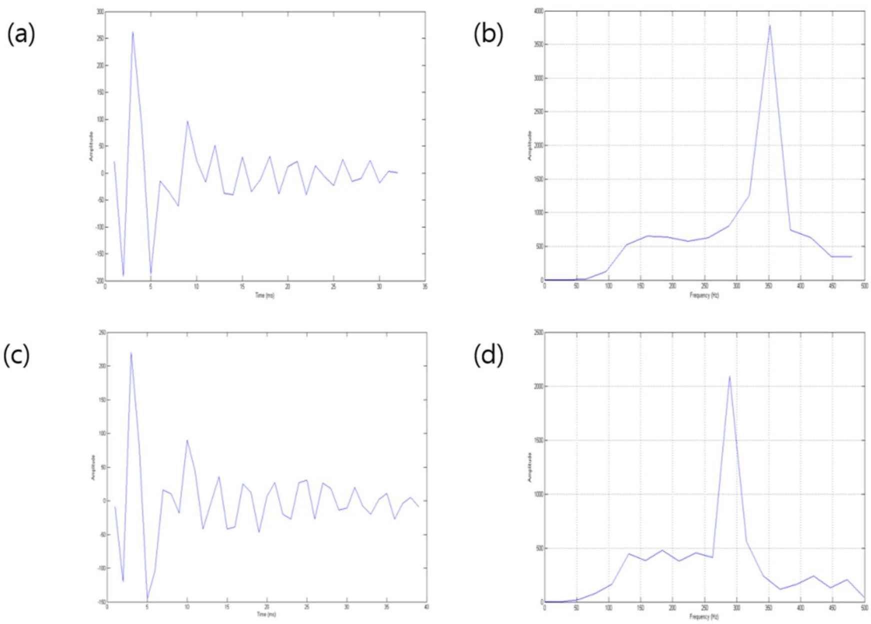

Figure 2 Examples of the impulse response signals (a, c) and their power spectra (b, d) with different pig rib samples. Upper is for sample 13 and lower is for sample 24.

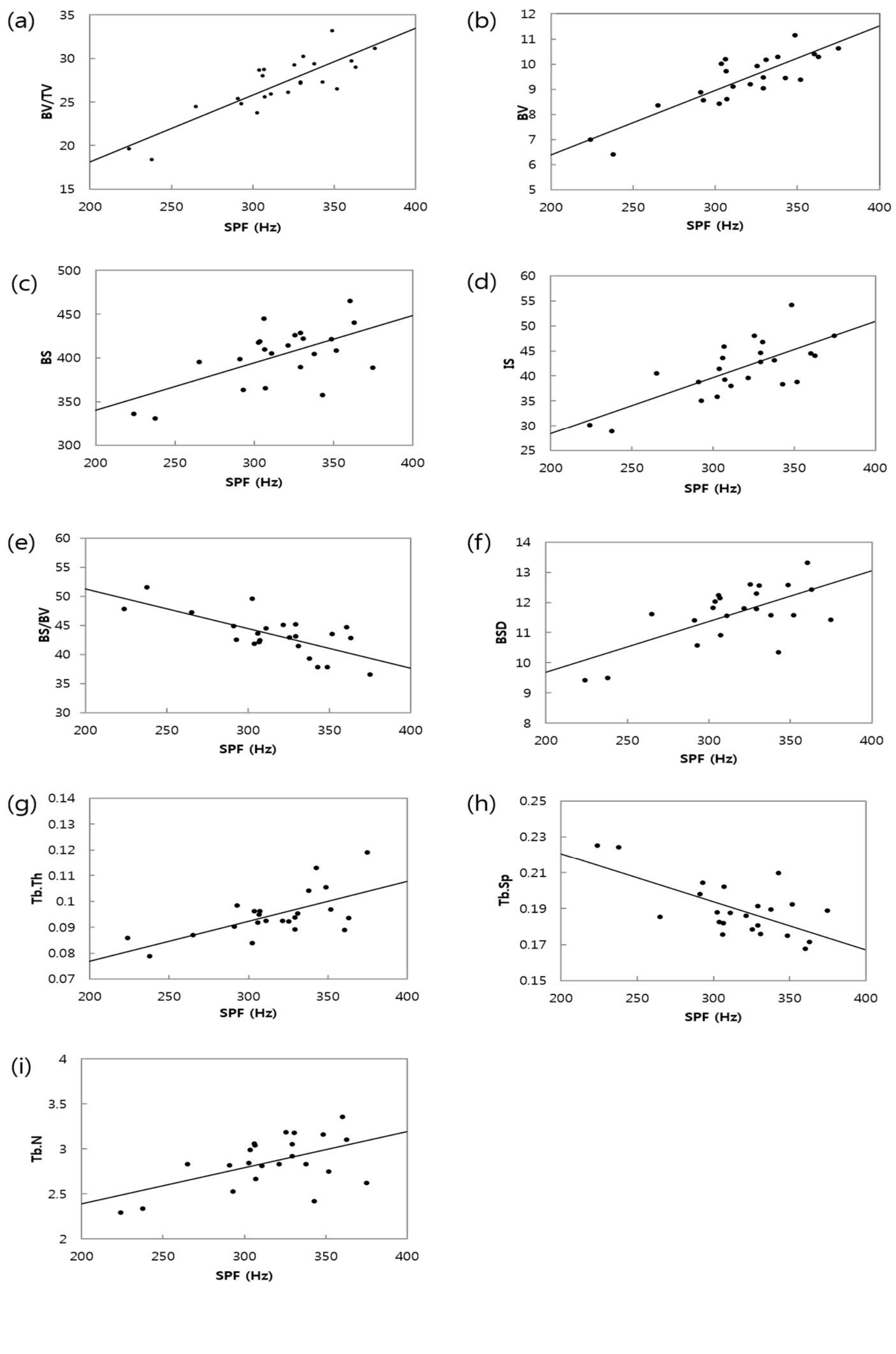

Figure 3 Correlations between SPF and bone parameters ((a) BV/TV, (b) BV, (c) BS, (d) IS, (e) BS/BV, (f) BSD, (g) Tb.Th, (h) Tb.Sp, and (i)Tb.N) with 0.88mm of measuring areas ($p<0.01$).

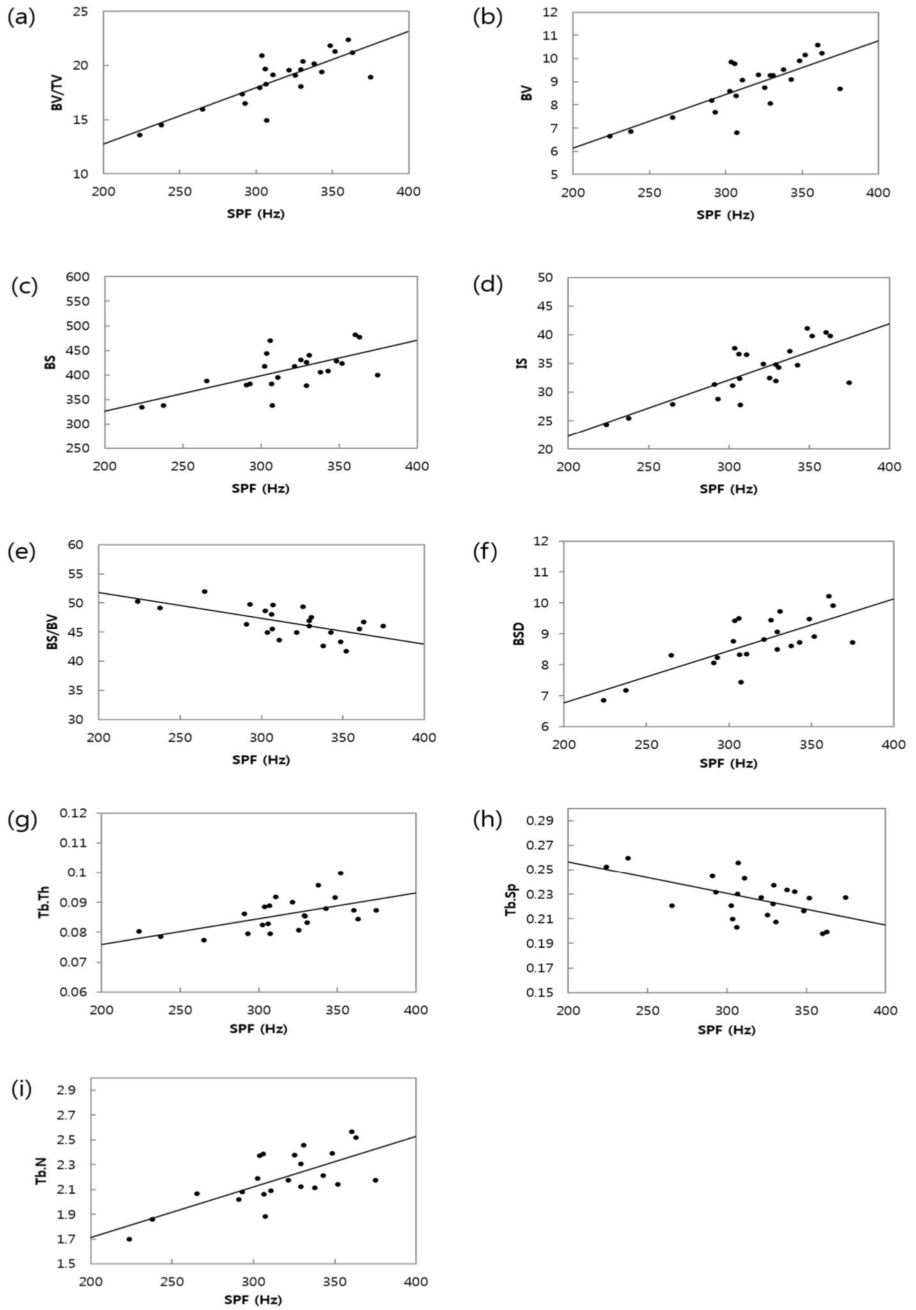

Figure 4 Correlations between SPF and bone parameters ((a) BV/TV, (b) BV, (c) BS, (d) IS, (e) BS/BV, (f) BSD, (g) Tb.Th, (h) Tb.Sp, and (i)Tb.N) with 1.76 mm of measuring areas (p<0.01).

국문초록

Impact response frequency 에 의한 일차적 임플란트안정성과 3D bone parameter 들과의 관계

복 성철

서울대학교 대학원 치의과학과 구강악안면방사선학 전공

(지도교수: 이원진)

1. 목 적: 임플란트 식립에 있어서 초기 안정성은 임플란트 성공에 있어서 중요한 요인 중 하나이다. 초기안정성을 평가하는데 있어서 비 침습적인 기구인 Periotest나 Osstell Mentor system에 대해서는 많은 논문들이 보고되고 있다. 이와는 다르게 우리는 이전 논문에서 아날로그 인덕티브 센서를 이용한 임플란트 안정성을 평가하는 시스템을 개발했다. peak frequency를 이용한 이 방법은

이전의 ISQ값보다 더 넓은 동적 범위와 좋은 해상도를 나타내주고 있다. 이전에 발표된 논문에서는 artificial bone을 이용해서 resonance frequency analysis 와 impact response를 통한 implant stabilities가 보고되었다.

이번 연구에서는 인공이 아닌 실제 돼지 늑골을 이용했다. 이때, 여러 샘플들의 cortical bone layers를 일정하게 유지하기 힘들었으므로 cortical bone layers가 없는 돼지늑골을 먼저 이용해서 실험해 보기로 했다. 늑골을 이용하여 임플란트를 동일조건에서 식립하였고, 그때의 초기 임플란트의 안정성과 3D bone microstructure parameter의 상관관계를 확인하고자 하였다. 그래서 임플란트와 뼈의 초기 안정성의 상관관계를 인덕티브 센서를 통한 peak frequency로 수치화하였고 SPF로 표현하였다. 그리고 마이크로 CT를 이용하여 3D bone parameter를 분석하였다. 결과적으로, 이렇게 얻은 parameter들의 상관관계를 분석하고자 하였다.

2. 방 법: 먼저 아날로그 인덕티브 센서(SUNGJIN Corporation, Busan, Korea)와 움직임을 증폭시키는 어댑터, 그리고 신호 처리회로로 구성된 안정성 평가 시스템을 이용하여 임플란트의 안정성을 평가했다. 이 안정성 평가 시스템은 이전 논문에서 개발된 시스템이다. 인덕티브 센서는 물리적인 접촉 없이 임플란트의 움직임을 감지할 수 있다. 따라서, 움직임을 증폭시키는 어댑터를 임플란트에 결합하여, 임플란트의 움직임을 증폭시킨 뒤, 그 신호를 인덕티브 센서를 통해 획득하였다. 실험의 샘플로는 23개의 임플란트를 돼지 늑골에 식립하여 정형화(2cm X 2cm X 2cm)시켰다. 샘플들은 cortical bone layers가 없는 trabecular bones으로 구성된 bone들만 이용했다. Osstem implant 회사에서 생산되고 있는 SSII SA fixture를 이용하여 직경 4.5mm에 길이는 11.5mm인 것을 이용했다. 오스템에서 나온 임플란트 식립용 엔진을 이용해서 1200rpm의 드릴링을 시행했으며 식립토크는 30Ncm로 했다. 그리고 임플란트 thread가 완전히 잠길 정도까지만 식립했으며 gingival height가 있는 cuff부위 전까지 식립될 수 있도록 조절하면서 23개의 sample에 식립했다. 각각의 샘플은 5cm 길이의 나사로 고정시켜 놓은 상태에서 실험을 시행하였다.

또한 마이크로 CT를 이용하여 23개의 샘플에 대한 bone microstructure parameter의 정보를 얻었다. 샘플들은 마이크로 CT(SkyScan 1172, 100 kVp, 0.1 mA, 18 min, 12.97 m isotropic voxel size, Kontich, Belgium)로 스캔되었다. 스캔 된 영상은 bmp image file로 저장되어 CTAn software (v1.14, SkyScan)에서 3D bone parameter를 계산하는데 사용되었다. bone volume fraction (BV/TV), bone volume (BV), intersection surface (IS), trabecular thickness (Tb.Th), trabecular number (Tb.N), 그리고 trabecular separation (Tb.Sp)등등의 histomorphometric variables을 수치화했다. 이때, parameter를 계산하는 영역의 범위를 반경 68픽셀과 136픽셀로 나누어서 데이터를 획득하였다. 이러한 parameters 들을 peak frequencies와 선형회귀분석을 통해 상관관계를 분석하였다.

3. 결 과: 선형회귀분석을 통해서 Bone microstructure parameters중 BV/TV, BV, IS, bone surface/volume ratio (BS/BV), bone surface density (BSD), Tb.Th, Tb.Sp, Tb.N이

Implant stability peak frequency(SPF)와 높은 연관성이 있는 것으로 나타났다(p<0.01). 또한, 모든 Pearson correlation값은 유의확률이 0.01수준에서 유의했으며, 반경 68픽셀을 이용해 측정한 BV/TV의 경우 0.85의 correlation값을 BV경우엔 0.86의 값을 보였다.

4. 결 론: 이번 연구에서는 아날로그 인덕티브 센서를 통해 얻은 SPF 값이 실제 돼지 늑골의 임플란트 안정성을 평가하는데 적절한지 실험하였다. 그리고, SPF 값이 마이크로 CT 에서 얻은 bone parameter 들과 큰 연관성을 가진다는 결과를 나타냈다. 따라서, SPF 가 임플란트 안정성을 평가하는데 적용이 가능할 것으로 보이고, 앞으로 실제 사람 뼈에서도 적용이 가능할 것으로 기대한다.

주요어: 임플란트 안정성; 인덕티브 센서; SPF; bone microstructure parameter; 마이크로 CT

학 번: 2013-23540