Correlation between bone quality evaluated by Cone-Beam Computerized Tomography and implant primary stability

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I. INTRODUCTION

Studies have shown that implants that are designed to osseointegration have a generally high success rate.[1,2] This success is considered to be influenced by both the volume (quantity) and density (quality) of available bone for implant placement. Therefore, emphasis has been placed on the bone quantity and quality as important prerequisites of predictable implant success. [3-6]

In the early introductory book on the osseo integration written by Brånemark et al.,[7] Lekholm and Zarb subjectively classified the radiographical bone density into 4 types based on the amount of cortical versus trabecular bone. Misch[8] charac terized the perception of bone quality during drilling procedures on the basis of this subjective classification. A method of obtaining objective measurements of the cutting resistance prior to the placement of implants was developed by Johansson and Strid.[9] Other methods for evaluating bone quality are histomorphometry of bone biopsies[10], densitometry[11], digital image analysis of microradiographs, and ultrasound.

Computerized tomography (CT) has been an established method to evaluate cross-sectional images of jaw bone before implant surgery.[12-14] It can also be used for the objective quantification of bone mineral densities. Quantitative CT (QCT) furnishes direct density measurements expressed in Hounsfield units (HU). But the X-ray dose absorbed by the patient during CT scanning may limit the use of this modality for a routine diagnosis or repeated surveys. Therefore, a new type of CT machine for the purpose of dental and maxillofacial imaging has been introduced.[15] This new CT machine uses a cone-shaped X-ray area detector and is termed cone-beam CT (CBCT). Like a conventional CT, quantitative bone density measurements can be retrieved (quantitative CBCT, QCBCT). The amount of radiation absorbed by the patient for each scan is reportedly 0.62 mGy.[16]

Recently, the immediate or early loading of implants with good initial stability has been widely accepted.[17] Since immediately loaded implant protocol mainly depends on a certain level of implant stability[18], it is advantageous to evaluate the anticipated implant stability before treatment is initiated rather than after treatment is initiated.

Meredith and coworkers[19] described a non-invasive method whereby bone formation around an implant could be evaluated by measuring the resonance frequency of a small transducer to an implant fixture. Resonance frequency analysis (RFA) is a steady-state and nondestructive technique. A new version of clinical instrument, Osstell™ *mentor* (Integration Diagnostics AB, Savedalen, Sweden) was developed to analyze resonance frequency by using a unit called implant stability quotient (ISQ).

The specific purpose of this study is to examine the relationship between the bone quality, ies; the CT numbers and the thickness of compact bone evaluated by CBCT and the implant primary stability measured by RFA.

II. MATERI ALS AND METHOD

A total of 20 patients who need more than 2 implants in a quadrant were included in this study. All the patients were healthy and had no uncontrolled systemic diseases. Patients who had guided bone regeneration before implant placement or who needed this procedure simultaneously were excluded.

After thorough diagnosis and treatment planning, the implant placement surgery has been performed. Under local anesthesia, full thickness flap was reflected and osteotomy was performed according to recommended sequences by the implant company. After the 2 mm twist drilling up to the exact depth of the planned implant, the gutta-percha bar (E&Q PLUS Gutta Percha Bar; Meta Biomed Co., Ltd, Chungbuk, Korea) with same diameter that was a couple of millimeters longer than the drilling depth was inserted into the osteotomy site and CT scan has been taken (Implagraphy; VATECH, Kyunggi-do, Korea). It took 24 seconds in normal mode. After taking CT scan, the rest of the implant surgery was continued. For the 5 mm wide diameter implant, the CT has been taken after 3 mm twist drilling procedure with gutta-percha bar placed in the osteotomy site. Since the self-tapping fixtures were used in this study, 3.3 mm diameter was the final osteotomy for 4 mm regular diameter implants and 4.3 mm diameter was the last for 5 mm wide diameter implants. Then, Avana USII fixtures (Osstem, Seoul, Korea) have been placed. These fixtures have biocompatible RBM (Resorbable Blasting Media) textured surface and an external hex which is same design as original Brånemark implant. These implants were positioned equicrestally, so the top of the implant platform was flushed with residual crest.

Before flap closure, implant stability has been measured with OsstellTM mentor (Integration Diagnostics AB, Savedalen, Sweden). The results have been expressed in implant stability quotient (ISQ). The corresponding SmartpegTM (Type I) was connected to the implant and the RFA was measured 4 times per an implant, twice from bucco-occlusal direction and twice from linguo-occlusal direction. After measuring RFA, suture was placed and the surgery has been finished.

The CT scan images taken with gutta-percha in the osteotomy sites were processed into two types of cross sectional images with Ezimplant (VATECH, Kyunggi-do, Korea); one perpendicular to jaw bone and the other parallel to it (Fig 1 and 2).

The images of gutta-percha were used as indicators of the exact position of the fixture. Ezimplant software calculated the average CT numbers in the "region of interest" (ROI) around the gutta-percha(Fig 3).

Fig 1. Cross sectional image perpendicular to the mandible.

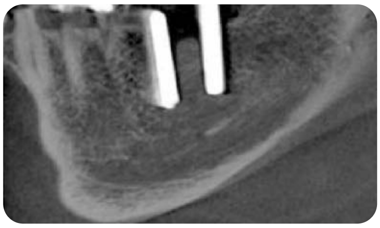

Fig 2. Cross sectional image parallel to the mandible.

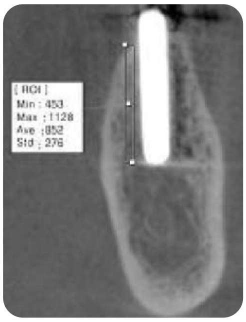

Fig 3. Real example of calculating the CT number.

In this study, the CT numbers of the surrounding bone were measured at a distance of 1 mm away from the outer surface of gutta-percha at all buccal, lingual, mesial, and distal sides with same length as an implant and these CT numbers were considered as the quality of the bone that threads of the self-tapping implant engaged. Also, using the same cross sectional images, the thickness of compact bone 1 mm away from the indicators was measured at the same 4 sides using measuring function of the software(Fig 4).

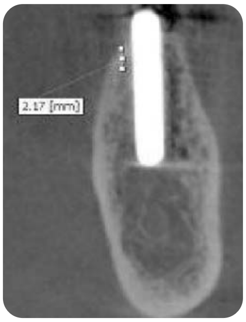

Fig 4. Real example of measuring compact bone thickness.

Therefore, each implant has (1) four CT numbers at buccal, lingual, mesial, and distal sides, (2) the thickness of compact bone at the same four sides, and (3) an average ISQ.

III. DATA ANALYSIS

The correlations between CT numbers and ISQ and between thickness of compact bone and ISQ were tested with Pearson's correlation coefficient. All the statistical analyses have been performed using SAS v8.2 (SAS Institute Inc., North Carolina, USA). P value less than .05 was considered statistically significant..

IV. RESULTS

A total of 61 implants from 20 patients were examined. The patients' ages at surgery were 57.15 ± 11.9 years-old (24Y3M to 71Y4M). In Table 1, implant dimensions were expressed as diameter x length in millimeters. The average CT numbers obtained by CBCT are shown. Mesial and distal sides showed lower CT numbers than buccal and lingual sides because of the shadow effect. The average thickness of compact bone and the average ISQs were listed as well. The four RFA values of the implant did not show large differences.

There were correlations between CT numbers at all four sides and implant primary stability at a level of significance of 0.025 (Table 2). Even though CT numbers at mesial and distal sides showed lower measurements due to the hollow effect, they did demonstrate correlations with RFA. Statistically significant correlation coefficients were observed for the relationships between the thickness of compact bone and ISQs at a level of significance of 0.001 (Table 3).

■ Table 1. The implant sizes, average CT numbers, thickness of compact bone, and ISQs.

Implant serial No.	Implant size	Average CT number of buccal and lingual	Average CT number	Average thickness of compact bone	Average ISQ
1	4 × 13	840.0	703.25	2.23	84.50
2	4 × 13	861.0	679.50	2.45	79.50
3	4 × 13	863.0	719.75	2.72	88.00
4	4 × 13	805.5	722.50	2.55	82.00
5	4 × 10	629.0	501.25	2.34	80.00
6	4 × 10	733.5	555.75	2.84	80.00
7	4 × 10	707.5	541.50	2.20	73.75
8	4 × 10	391.0	312.75	1.08	70.00
9	4 × 10	399.0	345.75	0.98	68.00
10	4 × 13	392.5	365.25	1.46	72.25
11	4 × 11.5	475.5	424.25	0.71	74.50
12	5 × 10	388.0	369.25	1.34	75.00
13	4 × 11.5	799.0	469.00	3.36	82.50
14	4 × 11.5	833.0	515.00	3.88	85.50
15	4 × 11.5	655.0	464.00	1.69	75.25
16	5 × 11.5	678.5	473.00	1.79	76.75
17	5 × 11.5	663.5	446.25	1.31	70.00
18	4 × 13	903.0	777.25	2.23	85.50
19	4 × 11.5	514.5	423.50	2.69	78.75
20	4 × 10	679.5	560.25	2.25	84.50
21	4 × 13	657.5	544.25	3.12	84.75
22	4 × 13	769.0	617.00	3.61	82.25
23	4 × 13	751.0	611.00	3.37	81.50
24	4 × 13	688.0	563.25	3.23	77.00
25	4 × 10	574.0	516.25	2.32	58.00
26	5 × 13	834.0	494.75	2.42	87.00
27	5 × 11.5	841.5	524.75	2.77	87.50
28	4 × 11.5	760.0	631.25	2.80	75.25
29	4 × 10	629.5	451.25	2.58	76.00
30	4 × 10	660.0	485.25	3.57	84.25

Implant serial No.	Implant size	Average CT number of buccal and lingual	Average CT number	Average thickness of compact bone	Average ISQ
31	5 × 10	527.5	388.50	1.33	71.00
32	5 × 10	512.5	356.25	1.06	67.00
33	4 × 10	748.5	581.50	2.98	81.00
34	4 × 10	767.0	589.75	3.17	81.50
35	5 × 11.5	814.5	561.75	3.47	83.25
36	5 × 11.5	784.5	533.50	3.55	80.75
37	5 × 11.5	611.0	456.75	3.29	80.50
38	5 × 10	604.5	450.50	3.24	80.50
39	5 × 13	731.0	497.00	3.43	84.00
40	5 × 11.5	716.0	512.00	3.38	82.50
41	4 × 11.5	322.5	238.00	0.80	63.50
42	4 × 11.5	319.0	240.00	0.75	63.50
43	4 × 11.5	319.0	242.50	0.82	65.50
44	4 × 11.5	323.5	240.25	0.80	64.00
45	4 × 11.5	517.0	422.25	1.18	68.50
46	5 × 10	503.0	409.50	0.92	66.25
47	5 × 10	482.0	451.75	0.78	59.00
48	5 × 11.5	639.0	553.25	2.89	74.00
49	5 × 11.5	644.5	533.75	2.87	75.50
50	4 × 11.5	712.5	545.25	1.96	66.00
51	5 × 11.5	758.5	537.75	2.50	74.50
52	5 × 10	750.5	562.75	2.60	72.50
53	4 × 13	714.0	567.25	2.35	72.00
54	4 × 13	700.5	553.25	2.25	70.75
55	4 × 10	722.0	595.75	3.23	76.75
56	4 × 10	741.0	629.75	3.17	77.25
57	4 × 13	865.5	693.00	3.69	81.25
58	4 × 13	869.5	698.25	3.76	83.25
59	4 × 13	861.0	688.25	3.65	82.00
60	4 × 10	768.0	604.75	3.36	77.75
61	4 × 10	773.5	610.00	3.38	79.00

■ Table 2. The correlation coefficient and p−value between CT numbers and ISQs

Dependent variable \ Independent variable		Buccal CT numbers	Lingual CT numbers	Mesial CT numbers s	Distal CT numbers
RFA	Correlation coefficient	0.7525	0.6986	0.2887	0.3116
	p−value	<0.0001	<0.0001	0.0241	0.0145

■ Table 3. The correlation coefficient and p−value between thickness of compact bone and ISQs

Dependent variable \ Independent variable		Thickness of compact bone at buccal	Thickness of compact bone at lingual	Thickness of compact bone at mesial	Thickness of compact bone at distal
RFA	Correlation coefficient	0.6632	0.6551	0.7072	0.7552
	p−value	<0.0001	<0.0001	<0.0001	<0.0001

Ⅴ. DISCUSSION

Accurate information on bone quality will help the surgeon to identify suitable implant sites, thereby improving the possibility of success. Information on bone quality can be obtained by an adequate radiographic examination.

The Hounsfield unit is a standardized and acceped scale for reporting and displaying reconstructed CT values.[20,21] This unit is based on a linear scale defined only by two points, the attenuation of dry air, set at 1,000 HU, and the attenuation of pure water at 25 ℃, set at 0 HU. Bone quality can be measured with CBCT as well. However, for the CBCT, the standard unit of displaying bone density (HU) is not used but the term 'CT number' should be used. Few studies have reported on the use of QCBCT relating to oral implants. Norton and Gamble[22] used 32 reformatted CTs and the recorded mean measurements ranged from 77 to 1421. In the study of Shapurian et al.[21], these measurements ranged from −240 to 1159. In this study, the highest number was 904 while the lowest was 107. The mesial and distal sides of the radiopaque indicators show dark hollow images due to the shadow effect of the CBCT.[23] Therefore, CT numbers of these areas may not indicate the actual bone quality.

The thickness of the compact bone around the implants varied greatly according to the sites. Usually the anterior mandible shows the thickest compact bone. Also, the buccal side of the posterior mandible revealed a greater than average thickness. Contrary to expectation, in a few cases, the compact bone could not be identified.

In this study, CT was taken in the middle of surgery in order to locate exact site where the implants placed. Therefore, the correlations between bone quality and implant stability could be examined. However, in the clinical situation, CT doesn't have to be taken during the surgery.

The use of RFA allows clinicians to measure implant stability. Recent findings with this technique suggest that it may be used as a diagnostic tool. Moreover, since measurements can be repeated over time, changes in implant stability during loading can be monitored. In the present study, ISQs showed relatively higher numbers. Except for very few implants, the ISQ values were over 70, which indicates very good implant stability. According to the study by Sennerby and Meredith[24], ISQ values above 65 are regarded as optimal. Measurements conducted twice from one direction show similar ISQs with only minor differences, indicating that RFA has repeatable and reliable characteristics.

In this preliminary study, the bone quality evaluated by CBCT has a very strong correlation with the primary stability of the implants.

Therefore, the preoperative evaluation of CT numbers and thickness of compact bone using CBCT allows one to predict the implant stability after installation and the possibility of immediate or early loading. For this reason, bone quality as well as bone quantity should be considered during treatment planning..

Ⅵ. CONCLUSION

The present study has shown that bone quality evaluated by CBCT has correlations with primary implant stability. This suggests that bone quality is one of the factors that require evaluation before implant surgery.

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Abstract

Cone-beam 컴퓨터 단층촬영으로 평가된 골질과 임프란트 초기 고정성 간의 관계

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술 전 cone-beam 컴퓨터 단층촬영으로 평가된 골질과 임프란트 식립 직후의 일차 고정성 간의 관계를 알아보고자 본 연구를 시행하였다. 골질의 평가는 cone-beam CT에서 측정된 CT number와 치밀골의 두께를 측정하였고, 임프란트의 일차 고정성은 공명 진동 분석으로 평가하였다.

총 20명의 환자의 61개의 임프란트를 조사하였다. 4 mm 지름의 임프란트 식립을 위하여 치조골에 직경 2 mm 골 삭제 후 같은 지름의 거터퍼쳐를 골 삭제 부위에 넣고 cone-beam 컴퓨터 단층촬영을 시행하였고 5 mm 지름의 임프란트의 경우에는 직경 3 mm 골 삭제 후 거터퍼쳐를 넣고 단층촬영을 하였다. 그리고 임프란트 식립 후 봉합 전에 공명 진동 분석으로 임프란트의 일차 안정성을 측정하였다. 단층촬영한 악골의 단면 영상을 이용하여 거터퍼쳐에서 1 mm 떨어진 협측, 설측, 근심측과 원심측의 CT number를 측정하였고, 같은 위치의 치밀골 두께를 측정하였다. 그리하여, CT number와 임프란트 일차 고정성 그리고 치밀골 두께와 임프란트 일차 고정성 간의 상관관계를 알아보았다.

CT number와 임프란트 일차 고정성의 상관관계를 분석한 결과, 협, 설측에서는 매우 강한 상관관계를 보였으며($p < 0.01$), 근심과 원심에서도 유의한 상관관계를 보였다 ($p < 0.025$). 치밀골 두께와 임프란트 일차 고정성 간의 관계에서는 4곳 모두 강한 상관관계를 나타내었다 ($p < 0.01$).

Cone-beam 컴퓨터 단층촬영을 이용한 술 전 골질의 평가는 임프란트 일차 고정성을 예측하는데 유용하게 사용될 수 있으며 이를 근거로 술 전 컴퓨터 단층 촬영은 골양의 평가 뿐 아니라 골질의 평가를 통한 임프란트 치료 계획과 치료 기간을 결정하는데 중요한 수단으로 고려될 수 있다고 사료된다.