Assessment of Correlation Between Computerized Tomography Values of the Bone and Cutting Torque Values at Implant Placement: A Clinical Study

Noriharu Ikumi, DDS[1]/Sadami Tsutsumi, PhD[2]

Purpose: *The relationship between computerized tomography (CT) values of bone surrounding endosseous implants and the cutting torque values required for self-tapping during implant placement was examined for the purpose of predicting the initial stability (bone quality) during implant placement by presurgical CT scan examinations and determining whether it can be quantified.* ***Materials and Methods:*** *The study sample consisted of 13 subjects with 56 implants. Sites for implant placement were determined based on CT data using implant planning software. The average CT values of the bone surrounding the simulated implants were calculated by the software. Using a stereolithographic drill guide, implants were placed at the locations indicated by the protocol. The cutting torque values required for self-tapping were measured during implant placement. The resulting CT values and cutting torque values were analyzed statistically for correlation.* ***Results:*** *The correlation was considered significant at a level of .01 or less, and the correlation coefficient was 0.77.* ***Discussion:*** *There was a strong correlation between CT values and cutting torque values in the clinical cases evaluated. These results indicate that it may be possible to predict and quantify initial implant stability and bone quality from presurgical CT diagnosis and implant simulation.* ***Conclusion:*** *Presurgical CT examination may be an effective technique for predicting initial stability of the implant and bone quality.* INT J ORAL MAXILLOFAC IMPLANTS 2005;20:253–260

Key words: *bone quality, computerized tomography, dental implants, torque*

The predictability of dental implant integration has been improved by innovations in surface properties and surface materials. However, decreases over time in the survival rate of implants placed in the maxillary molar region have been reported extensively in the literature.[1–3] In addition, the survival rate of implants functionally loaded immediately after placement has been reported to be lower in maxillary situations than in mandibular ones.[4] This is thought to be the result of bone conditions around the implant, eg, the tendency for there to be less existing bone capable of allowing implant placement in the maxilla. The cortical bone in this area is thin and consists of fibrous bone; it is less dense than that found in the mandible.

In cases of extremely low bone density, initial stability of the implant immediately after placement is usually low. Osseointegration may not be established during the healing period.[5–7] In addition, the implant's ability to support loads once it is functional is considered to be affected by the density of the bone surrounding the implant. Consequently, if it were possible to predict initial implant stability and bone quality during the presurgical assessment of the implant site, it might be possible to propose an

[1]Researcher, Department of Medical Simulation Engineering, Institute for Frontier Medical Sciences, Kyoto University, Kyoto, Japan.
[2]Professor, Department of Medical Simulation Engineering, Institute for Frontier Medical Sciences, Kyoto University, Kyoto, Japan.

Correspondence to: Dr Noriharu Ikumi, Department of Medical Simulation Engineering, Institute for Frontier Medical Sciences, Kyoto University, 53 Shogoinkawara-machi, Sakyou-ku, Kyoto-city, Kyoto 606-8397, Japan. Fax: 81 27 361 1346. E-mail: noriharu@cic-implant.jp

Fig 1 CT scanning was performed with a radiographic template in place with barium sulfate and gutta-percha markers.

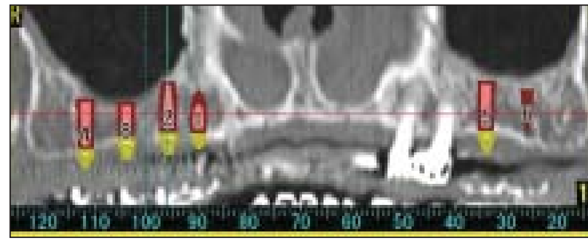

Fig 2 Implant placement simulation was performed using the SimPlant software. Optimal implant sites and implant sizes were determined presurgically.

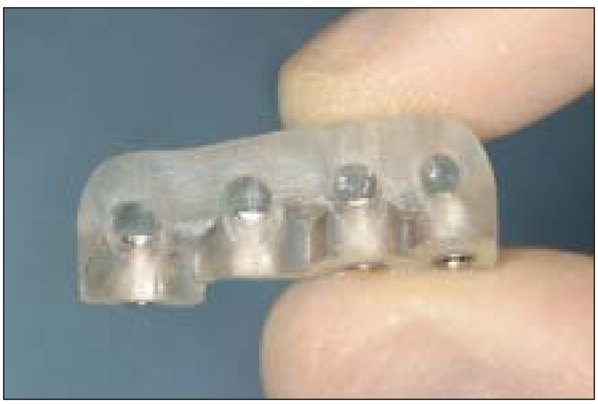

Fig 3 The stereolithographic surgical guide was fabricated by Materialise based on the simulation data of SimPlant to permit implant placement in the simulation sites. The design incorporated stainless steel tubes as drilling guide holes.

Fig 4 Bone drilling was performed using the stereolithographic surgical guide, which was set on the bone.

implant treatment protocol offering higher predictability.

Although there have been numerous reports on the usefulness of computerized tomography (CT) for the purpose of assessing bone volume and morphology,[8–10] there have been few reports on the relationship between CT values and initial implant stability at sites where implants have been placed in actual patients. In this study, the correlation between CT values of the bone and cutting torque values during implant placement were examined.

MATERIALS AND METHODS

Implants

The implants used in this study consisted of 56 TiUnite Mk III implants (Nobel Biocare, Göteborg, Sweden) with diameters of 3.75 mm and lengths of 10.0 mm, 11.5 mm, 13.0 mm, and 15.0 mm placed in maxillary and mandibular bone. These implants were placed according to the following procedure: *(1)* A CT scan was performed with a radiographic template precisely set on the ridge of the patient (Fig 1). *(2)* Placement of the implant was simulated using SimPlant software (Materialise, Leuven, Belgium) (Fig 2). *(3)* The SurgiGuide, a custom-made stereolithographic drill guide, was fabricated by Materialise based on the simulation data of SimPlant, so as to allow drilling of the bone at the simulated location (Fig 3). *(4)* A hole was drilled at the implant placement site using a 3.0-mm-wide twist drill and the SurgiGuide (Fig 4). *(5)* The implant was placed by self-tapping using the OsseoCare DEC600 surgical motor system (Nobel Biocare), which measured cutting torque value during implant placement.[11]

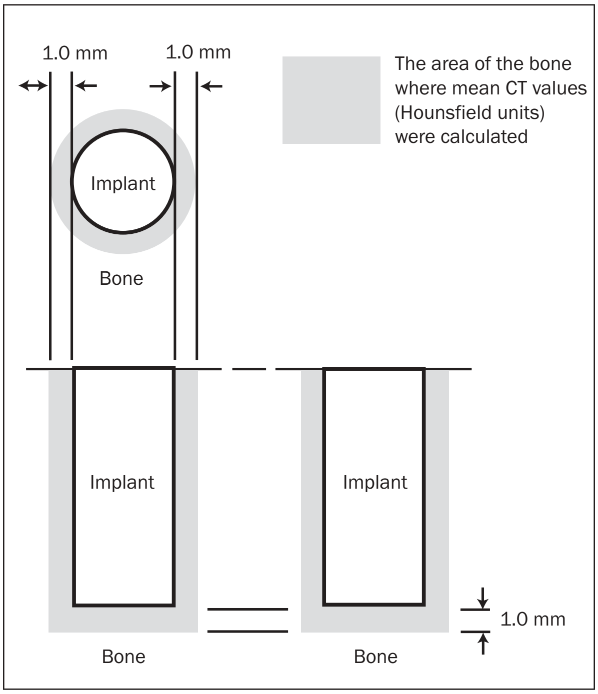

Fig 5 The average CT values (Hounsfield units) of the surrounding bone to a distance of 1.0 mm from the surfaces of the simulated implants were measured using the CT value measurement function of the software.

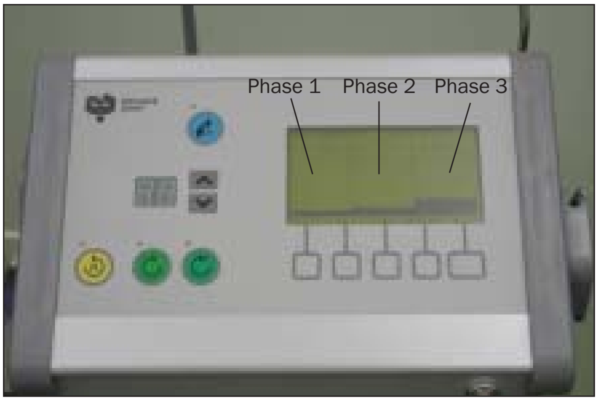

Fig 6 Implant placement was performed by self-tapping using the OsseoCare system, which has a torque measurement function.

Measurement Methods

Measurement of CT Values. CT scanning (Aquilion Multi TSX-101/4A; Toshiba Medical Systems, Tokyo, Japan) of the maxilla or mandible was done after positioning a radiographic template in the form of the definitive prosthesis under the following conditions: 120 kV, 100 mA, scan time of 1.0 sec, reconstruction algorithm FC30, slice thickness of 1.0 mm, table increment of 1.0 mm. SimPlant images were processed with ImageMaster 101 (Columbia Scientific, Columbia, MD) from CT imaging data. The images of the barium sulfate and gutta-percha markers within the template, which appeared in the SimPlant images, were used as indicators of the center position and external shape of the respective teeth. The locations and directions thought to be optimum for each implant on SimPlant images were determined and tested using implant placement simulation (Fig 2). SimPlant software calculates the average CT value in the thin "cup" surrounding the simulated implant and graphically displays the CT values in thin rings along the simulated implant's length. The width of the rings and the thickness of the cup are adjustable.[12] In this study, the average CT values (ie, Hounsfield units) of the surrounding bone were measured to a distance of 1 mm from the simulated implants (Fig 5), and these CT values were used as CT values of the bone surrounding the implants.

Measurement of Cutting Torque Values. The cutting torque required for placement was measured using the torque measurement function of the OsseoCare system during placement of the implants by self-tapping (Fig 6). To carry out cutting torque measurements, "Measure Mode" was selected, and the implant was rotated into the prepared site. Although this system displays the respective average cutting torque value by dividing the number of revolutions required from the start of implant placement until the motor stops automatically as a result of having reached the specified torque in 3 phases (phases 1, 2, and 3) (Fig 7), in this study, the average of the cutting torque values of phase 1 and phase 2 was used as the average cutting torque value (Ncm).

Examination of Correlation. The presence of a correlation between CT values and cutting torque values was tested with Pearson's correlation coefficient.

Figure 8 shows a schematic representation of the study design.

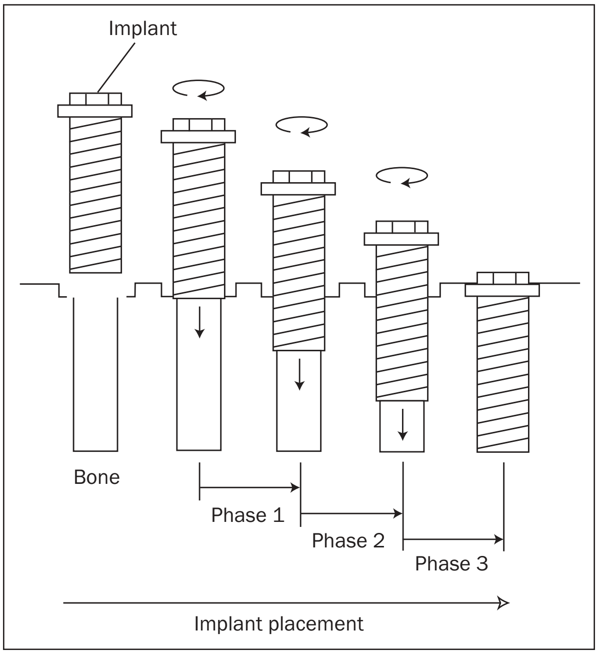

Fig 7 The implant placement process can be divided into 3 components (phases 1, 2, and 3). In this study, the average torque value of phases 1 and 2, measured in Ncm, was used as the cutting torque value.

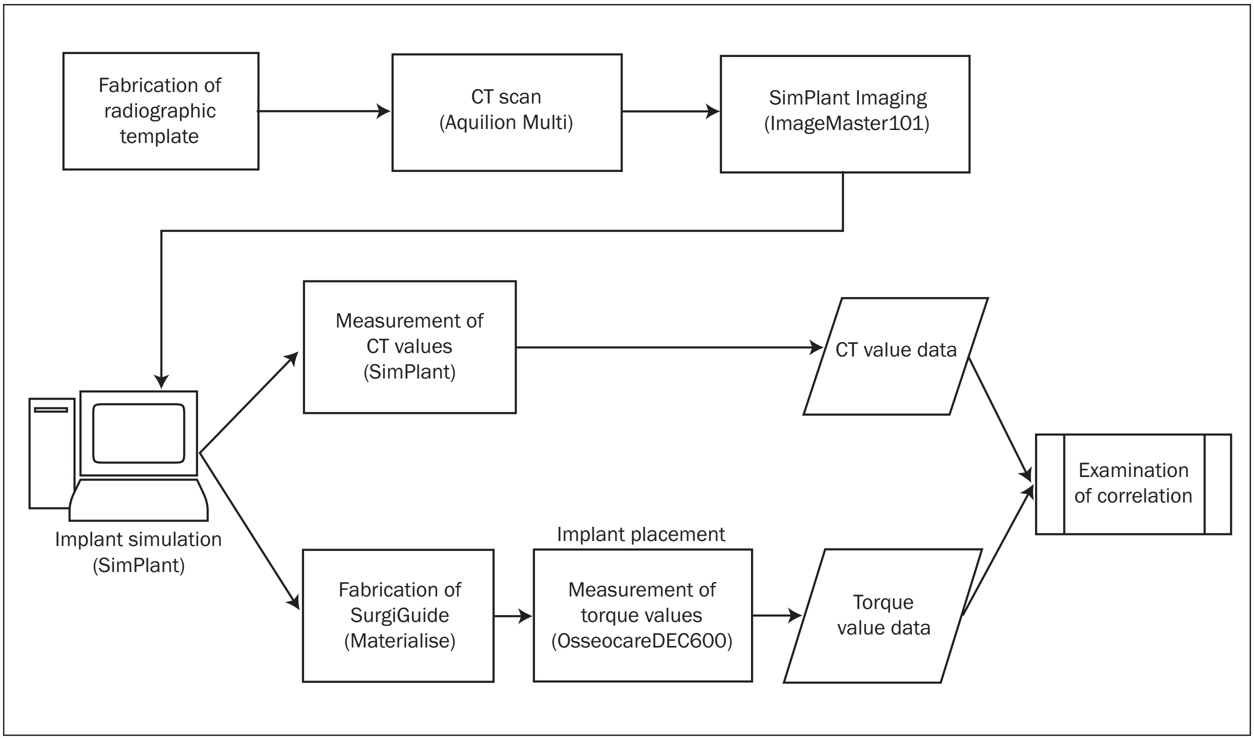

Fig 8 A schematic diagram of the study design.

RESULTS

The measured CT values and cutting torque values comprising the raw data of the 13 patients are shown in Table 1. There was significant correlation between CT values and cutting torque values during implant placement at a level of significance of .01, and the correlation coefficient was 0.77. A regression graph of the correlation is shown in Fig 9.

Table 1 CT Values and Torque Values of Implants

Patient	Gender	Implant location	Implant length (mm)	CT value (Hounsfield unit)	Torque value (Ncm)
A	F	10 (22)	13.0	927	6.0
		9 (21)	13.0	791	5.0
		8 (11)	13.0	768	6.5
		7 (12)	13.0	841	7.5
B	M	12 (24)	11.5	847	3.5
		11 (23)	13.0	869	5.0
		10 (22)	13.0	865	6.5
		9 (21)	13.0	813	5.0
C	F	11 (23)	13.0	538	3.5
		8 (11)	13.0	428	1.5
		6 (13)	13.0	428	3.0
		5 (14)	13.0	538	4.5
		4 (15)	13.0	507	2.5
D	M	13 (25)	15.0	868	5.0
		12 (24)	15.0	906	8.5
		11 (23)	13.0	1,020	4.5
		6 (13)	13.0	1,004	10.5
E	M	10 (22)	11.5	480	4.0
		9 (21)	11.5	425	4.0
		8 (11)	11.5	568	3.0
		7 (12)	11.5	523	3.5
F	M	9 (21)	10.0	472	5.5
		10 (22)	10.0	699	7.0
G	F	13 (25)	10.0	338	2.0
		10 (22)	13.0	597	6.0
		8 (11)	13.0	505	1.5
		6 (13)	13.0	458	4.5
H	F	14 (26)	13.0	330	1.5
		12 (24)	13.0	413	2.5
		5 (14)	13.0	408	1.5
		3 (16)	13.0	218	1.0
I	F	15 (27)	11.5	446	3.5
		13 (25)	10.0	256	0.5
		7 (12)	13.0	550	2.5
		5 (14)	13.0	416	1.5
		4 (15)	10.0	373	1.5
		3 (16)	10.0	208	1.0
		2 (17)	13.0	231	2.5
J	F	23 (32)	10.0	835	1.5
		22 (33)	10.0	851	2.0
		27 (43)	10.0	857	4.0
K	F	5 (14)	13.0	549	1.5
		4 (15)	10.0	316	2.0
		3 (16)	10.0	271	2.0
		2 (17)	10.0	296	0.5
		14 (26)	10.0	341	1.5
		15 (27)	10.0	389	1.0
L	M	23 (32)	10.0	1,034	8.0
		22 (33)	10.0	1,068	7.5
		26 (42)	10.0	1,059	7.0
		27 (43)	10.0	1,078	12.0
M	M	19 (36)	10.0	577	3.5
		18 (37)	10.0	652	2.5
		28 (44)	11.5	1,099	9.5
		29 (45)	10.0	896	3.0
		30 (46)	10.0	875	4.5
		2 (17)	10.0	725	5.5

Tooth names: Universal (FDI) system.

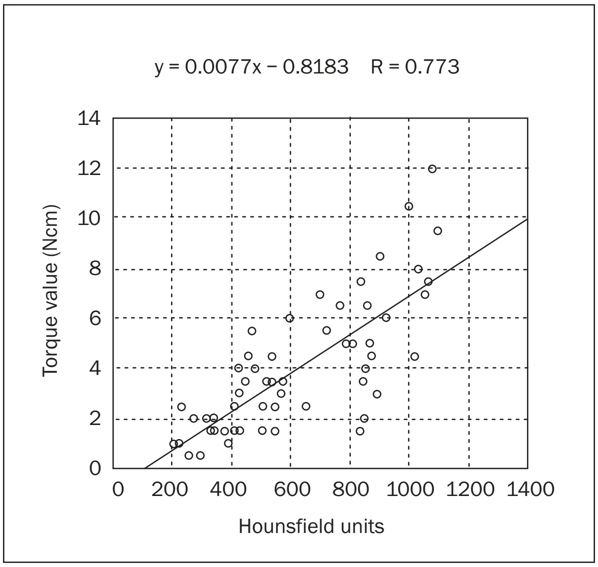

Fig 9 Regression graph of the correlation between CT values and cutting torque values during implant placement.

DISCUSSION

The most popular current method of bone quality assessment is that developed by Lekholm and Zarb,[13] who introduced a scale of 1 to 4 based on the preoperative radiographic assessment and the sensation of resistance experienced by the operator when preparing the implant site. This method may have less than desirable reproducibility and objectivity. Consequently, there has been a desire for a method of evaluating bone quantity and bone quality that is both accurate and offers a high degree of reproducibility for use in presurgical examinations.

Since implants in the maxillary molar region in particular appear to have a lower osseointegration rate before loading and a lower survival rate over time as compared with other sites[14–19] and require considerable caution in terms of performing the implant surgery, diagnosis and evaluation of the bone prior to surgery are especially important in this region. Possible reasons for this include this area being located directly below the maxillary sinus and the limited (extremely limited in some cases) quantity of bone available. In addition, since bone density in this region is also lower in comparison with other sites,[20–22] its ability to support the implant is also considered to be low.

When considering the bone-implant complex in terms of biomechanics, the concept of the biomechanical safety factor can be considered in the context of the equation $\delta a = \delta b/S$ (where δa = allowable stress, δb = critical stress, and S = safety factor) with respect to the bone-implant interface. Considering that a repetitive load is applied to the implant, it is not preferable to make the biomechanical safety factor excessively small. In addition, δb is affected by the implant surface material and surface properties that have an effect on the bonding force between the bone and implant, and is also influenced by conditions unique to the patient, such as bone quantity (a factor that determines the length and diameter of the implant) and bone density surrounding the implant. Thus, to maintain the value of allowable stress δa at an implant site where bone density is low, it is thought to be necessary to either select an implant with a large δb value for interface bonding strength or an implant with a large surface area (large length and/or diameter).

In addition, when the bone density at the implant placement site is low, the initial stability of the implant immediately after placement may also be low, thereby resulting in the risk of osseointegration not becoming established during the healing period. It has been clearly demonstrated both experimentally and clinically that, in cases where the cutting torque required for self-tapping of the implant or for drilling a hole at the implant placement site is high, both bone density and initial implant stability are usually high.[23,24] Since predicting these cutting torque values at the stage of presurgical diagnosis involves predicting initial implant stability and bone density, this would appear to be significant in terms of developing a treatment protocol having a high degree of predictability. Thus, in this study, the relationship between CT values of the bone surrounding implants and the cutting values required for tapping during implant placement was examined for the purpose of verifying that initial stability (bone quality) during implant placement could be predicted and quantified from presurgical CT data.

Bone mineral density (BMD) can be measured by the quantitative CT (QCT) method.[25,26] Significant positive correlations have been found between the pull-out resistance and bone density measured by QCT[27] and between trabecular bone volume and BMD.[28] Research has also shown that it is possible to predict mechanical properties of bone by QCT,[29,30] and a correlation existed between BMD measured with QCT and the insertion torque of dental implants in cadaver mandibles.[31]

Routine CT scanning is usually employed instead of QCT for diagnosis and treatment planning in patients who need implants. QCT is neither simple nor popular compared with routine CT, because a reference phantom and data calibration are necessary for QCT imaging. Also, it has been reported that there is a strong correlation between the value in

Hounsfield units obtained by routine CT scanning and the subjective bone quality score,[32] so the correlation between data obtained by routine CT scanning and cutting torque values was investigated.

In this study, implant placement accuracy was considered to be improved by using a stereolithographic surgical guide (SurgiGuide), because it allowed physical transfer of the implant plan to the patient's mouth.[33,34] The reason for using the average cutting torque values of phase 1 and phase 2 of measurements made by the OsseoCare system for cutting torque values was that, in the case of applying a torque of 40 Ncm to the implant at the final stage of implant placement in phase 3, there is the risk of thread ridges already formed in the bone being damaged, and in consideration of this, tightening during the final 2 to 3 revolutions was performed with a hand wrench.

In the present study, a significant correlation was observed between CT values and cutting torque values during implant placement in maxillary and mandibular bone at a level of significance of .01 or less, and the correlation coefficient was 0.77. These findings suggest a strong correlation between CT values and cutting torque values during implant placement and indicate that it may be possible to predict and quantify initial implant stability and bone quality from presurgical diagnosis using routine CT scan data and implant simulation software.

In the clinical setting, in the case of implant placement at a site for which CT values have been determined to be low using placement simulation, initial implant stability can be expected to be low and supporting ability inferior. A treatment protocol calling for the use of an implant having surface characteristics and a shape such that the critical stress of the interface is large,[35–37] or the placement of more implants than usual, may be required at such sites. This treatment protocol concept may be especially important to an immediate loading case, where both initial implant stability and supporting ability are indispensable.

The cutting torque value data that were used to assess bone quality in this report were obtained with 1 implant system, so the results cannot be compared with those for other systems, which may differ in screw type or surface texture. Accordingly, a universal parameter that is applicable to various implant systems, such as resonance frequency, is now under consideration for further studies.

CONCLUSION

Preoperative CT scanning was suggested to be effective for predicting the initial stability of the implant and the bone quality, thus making more reliable treatment planning possible.

REFERENCES

1. Tolman DE, Laney WR. Tissue-integrated dental prostheses: The first 78 months of experience at the Mayo Clinic. Mayo Clin Proc 1993;68:323–331.
2. Lazzara R, Siddiqui AA, Binon P, et al. Retrospective multicenter analysis of 3i endosseous dental implants placed over a five-year period. Clin Oral Implants Res 1996;7:73–83.
3. Bergendal T, Engquist B. Implant-supported overdentures: A longitudinal prospective study. Int J Oral Maxillofac Implants 1998;13:253–262.
4. Grunder U. Immediate functional loading of immediate implants in edentulous arches: Two-year results. Int J Periodontics Restorative Dent 2001;21:545–551.
5. Lekholm U, Adell R, Brånemark P-I. Complications. In: Brånemark P-I, Zarb GA, Albrektson T. Tissue-Integrated Prostheses: Osseointegration in Clinical Dentistry. Chicago: Quintessence, 1985:233–240.
6. Morris HF, Ochi S, Orenstein IH, Petrazzuolo V. AICRG, Part V: Factors influencing implant stability at placement and their influence on survival of Ankylos implants. J Oral Implantol 2004;30:162–170.
7. Balshi TJ, Wolfinger GJ, Balshi SF II. Analysis of 356 pterygomaxillary implants in edentuluous arches for fixed prosthesis anchorage: A 3-year clinical prospective study. Int J Oral Maxillofac Implants 1999;14:398–406.
8. Mecall RA, Rosenfeld AL. The influence of residual ridge resorption patterns on implant fixture placement and tooth position. 2. Presurgical determination of prosthesis type and design. Int J Periodontics Restorative Dent 1992;12:32–51.
9. Verde MA, Morgano SM. A dual-purpose stent for the implant-supported prosthesis. J Prosthet Dent 1993;69:276–280.
10. Sethi A. Precise site location for implants using CT scans: A technical note. Int J Oral Maxillofac Implants 1993;8:433–438.
11. Johansson P. Assessment of bone quality from cutting resistance during implant surgery. Int J Maxillofac Implants 1994;9:279–288.
12. Rothman SLG. Interactive implant surgical planning with SIM/plant. In: Dental Applications of Computerized Tomography. Chicago: Quintessence, 1998:139–152.
13. Lekholm U, Zarb GA. Patient selection and preparation. In: Brånemark P-I, Zarb GA, Albrektsson T (eds). Tissue-Integrated Prostheses: Osseointegration in Clinical Dentistry. Chicago: Quintessence, 1985:199-209.
14. Testori T, Wiseman L, Woolfe S, Porter SS. A prospective multicenter clinical study of the Osseotite implant: Four-year interim report. Int J Oral Maxillofac Implants 2001;16:193–200.
15. Becker W, Becker BE, Alsuwyed A, Al-Mubarak S. Long-term evaluation of 282 implants in maxillary and mandibular molar positions: A prospective study. J Periodontol 1999;70:896–901.
16. Tinsley D, Watson CJ, Ogden AR. A survey of U.K. centres on implant failures. J Oral Rehabil 1999;26:14–18.

17. Nevins M, Langer B. The successful application of osseointegrated implants to the posterior jaw: A long-term retrospective study. Int J Oral Maxillofac Implants 1993;8:428–432.
18. Albrektsson T, Dahl E, Enbom L, et al. Osseointegrated oral implants: A Swedish multicenter study of 8139 consecutively inserted Nobelpharma implants. J Periodontol 1988;59: 287–296.
19. Drago CJ. Rates of osseointegration of dental implants with regard to anatomical location. J Prosthodont 1992;1:29–31.
20. Ulm C, Kneissel M, Schedle A, et al. Characteristic features of trabecular bone in edentulous maxillae. Clin Oral Implants Res 1999;10:459–467.
21. Truhlar RS, Orenstein IH, Morris HF, Ochi S. Distribution of bone quality in patients receiving endosseous dental implants. J Oral Maxillofac Surg 1997;55(12 suppl 5):38–45.
22. Razavi R, Zena RB, Khan Z, Gould AR. Anatomic site evaluation of edentulous maxillae for dental implant placement: A 3-year clinical prospective study. J Prosthodont 1995;4:90–94.
23. Friberg B, Sennerby L, Grondahl K, Bergstrom C, Back T, Lekholm U. On cutting torque measurements during implant placement. Clin Implant Dent Relat Res 1999;1:75–83.
24. Sugaya K. Study on method for examining bone quality for dental implant. Relationship between cutting force and bone mineral content [in Japanese]. Shikwa Gakuho 1990;90: 607–633.
25. Rogers LF. Metabolic, endocrine, and related bone diseases. In: Juhl JH, Crummy AB (eds). Essentials of Radiologic Imaging. Philadelphia: J. B. Lippincott, 1993:215–254.
26. Lindh C, Nilsson M, Klinge B, Petersson A. Quantitative computed tomography of trabecular bone in the mandible. Dentomaxillofac Radiol 1996;25:146–150.
27. Kido H, Schulz EE, Kumar A, Lozada J, Saha S. Implant diameter and bone density: Effect on initial stability and pull-out resistance. J Oral Implantol 1997;23:163–169.
28. Lindh C, Petersson A, Klinge B, Nilsson M. Trabecular bone volume and bone mineral density in the mandible. Dentomaxillofac Radiol 1997;26:101–106.
29. Lind PM, Lind L, Larsson S, Orberg J. Torsional testing and peripheral quantitative computed tomography in rat humerus. Bone 2001;29:265–270.
30. Kopperdahl DL, Morgan EF, Keaveny TM. Quantitative computed tomography estimates of the mechanical properties of human vertebral trabecular bone. J Orthop Res 2002;20: 801–805.
31. Homolka P, Beer A, Birkfellner W, et al. Bone mineral density measurement with dental quantitative CT prior to dental implant placement in cadaver mandibles: Pilot study. Radiology 2002;224:247–252.
32. Norton MR, Gamble C. Bone classification: An objective scale of bone density using the computerized tomography scan. Clin Oral Implants Res 2001;12:79–84.
33. Sarment DP, Sukovic P, Clinthorne N. Accuracy of implant placement with a stereolithographic surgical guide. Int J Oral Maxillofac Implants 2003;18:571–577.
34. Tardieu PB, Vrielinck L, Escolano E. Computer-assisted implant placement. A case report: Treatment of the mandible. Int J Oral Maxillofac Implants 2003;18:599–604.
35. O'Sullivan D, Sennerby L, Meredith N. Measurements comparing the initial stability of five designs of dental implants: A human cadaver study. Clin Implant Dent Relat Res 2000;2: 85–92.
36. Buser D, Nydegger T, Oxland T, et al. Interface shear strength of titanium implants with a sandblasted and acid-etched surface: A biomechanical study in the maxilla of miniature pigs. J Biomed Mater Res 1999;45:75–83.
37. Khang W, Feldman S, Hawley CE, Gunsolley J. A multi-center study comparing dual acid-etched and machined-surfaced implants in various bone qualities. J Periodontol 2001;72: 1384–1390.