Cone Beam Computed Tomographic Measurement of Maxillary Central Incisors to Determine Prevalence of Facial Alveolar Bone Width ≥2 mm

Hessam Nowzari, DDS, PhD;* Shervin Molayem, DDS;† Ching Hsiu Ketty Chiu, DDS;† Sandra K. Rich, RDH, PhD‡

ABSTRACT

Background: The initial thickness of maxillary bone has significant impact on the responding level of facial bone and soft tissue after extraction and immediate implant placement. A prevailing notion is that following implant placement in fresh extraction sites, at least 2 mm of facial bone is needed to prevent soft tissue recession, fenestration, and dehiscence.

Purpose: The purpose of this study was to use cone beam computed tomography (CBCT) to measure horizontal width of facial alveolar bone overlying healthy maxillary central incisors and to determine prevalence of bone thickness ≥2 mm.

Materials and Methods: Tomographic data from 101 randomly selected patients were evaluated by two independent observers. Assessments were made of facial bone width at levels 1.0 to 10.0 mm apical to the bone crest.

Results: Healthy maxillary central incisors ($n = 202$) were measured from 101 patient scans. The percent of teeth with facial bone ≥2 mm at levels 1, 2, 3, 4, and 5 mm from the bone crest was 0, 1.5, 2.0, 3.0, and 2.5%, respectively. Overall mean thickness of the bone was 1.05 mm for right and left central incisors combined. The range of individual measurements for all levels was 0 to 5.1 mm. The occurrence of ≥2 mm thickness bone measurements increased with increasing depth. However, mean widths observed at levels 6 to 10 mm from the crest ranged only 1.0 to 1.3 mm because of apparent fenestration occurrence (0 mm bone) in approximately 12% of teeth. Overall, no significant differences in bone thickness were found between ethnic, gender, age, or scan groups.

Conclusions: Using CBCT, occurrences of ≥2 mm maxillary facial alveolar bone were found on no more than 3% of root surfaces 1.0 to 5.0 mm apical to the bone crest in this sample of maxillary central incisors. The study evidenced prevalence of a thin facial alveolar bone (<2 mm) that may contribute to risk of facial bone fenestration, dehiscence, and soft tissue recession after immediate implant therapy.

KEY WORDS: dehiscence, facial bone, fenestration, immediate implant, maxillary central incisor

INTRODUCTION

The periodontal ligament cells biologically renew the alveolar bone and promote periodontal regeneration. With tooth extraction, the interface between the periodontal ligament cells and the alveolar bone proper is disrupted and contribution to the bone healing process is discontinued. The width of the facial alveolar ridge after extraction and prior to implant placement, as well as changes in width that occur during bone healing and remodeling, can influence risk of implant complications.[1] Investigators have suggested that when placing implants in fresh extraction sites, at least 2 mm of

*Professor, clinical dentistry, and director, advanced periodontics, University of Southern California School of Dentistry, Los Angeles, CA, USA; †resident, advanced periodontics, University of Southern California School of Dentistry, Los Angeles, CA, USA; ‡associate professor, advanced periodontics, University of Southern California School of Dentistry, Los Angeles, CA, USA

Reprint requests: Dr. Hessam Nowzari, University of Southern California Dental Science Center-DEN, 925 W. 34th Street, Room 119, Los Angeles, CA 90089-0641, USA; e-mail: nowzari@usc.edu

DOI 10.1111/j.1708-8208.2010.00287.x

presurgical facial bone may be needed for optimal healing of both hard and soft tissues.[2–4] A consideration of bone dimensions at time of placement necessarily includes all bony walls; however, this study focused specifically on cone beam computed tomographic (CBCT) measurement of horizontal width of the facial bone overlying the maxillary central incisors.

Literature on healing dynamics at both extraction and peri-implant sites can guide the treatment planning for maxillary anterior implant placement and help anticipate complications related to fenestration, dehiscence, and soft tissue recession. Investigators have measured facial bone at the extraction sites in human and dog models. Presence of fenestrations (13%) and dehiscence (17%) in the facial socket wall were clinically observed by Chen and colleagues[5] in a case series study of 85 consecutive patients. Botticelli and colleagues[6] measured buccal bone walls of human extraction sockets prior to immediate implant placements by using caliper instruments at a level approximately 1 mm apical to the bone crest. They found the mean widths of buccal and lingual walls to be 1.4 ± 0.04 mm and 1.6 ± 0.06 mm, respectively.

Araújo and Lindhe[7] investigated dimensional alterations of the alveolar ridge at four time intervals, three levels apical to the bone crest, following extractions in a dog model. They observed that after extraction, resportion of buccal walls appeared more pronounced with buccal walls consistently thinner than lingual walls at every level for every time interval. At peri-implant sites, Araújo and colleagues[8] measured buccal and lingual walls of fresh extraction sites following implant placement in beagle dogs. At 4 and 12 weeks postsurgically, the investigators noted marked reduction in the thickness of buccal bone walls. They concluded that there was a greater occurrence of dehiscence and compromised bone healing when there was a thin buccal bone wall as well as buccal placement of the implant. With regard to healing of the extraction site, other investigators have concluded that, while both buccal and lingual portions of the ridge will lose some vertical bone after tooth removal, horizontal bone loss can be major.[9–12]

CBCT provides a highly accurate method to evaluate bone architecture. Bone measurements taken with calipers and with cephalometry have been questioned for reproducibility and accuracy because of the frequency of bone irregularities and the possibilities for human error. CBCT has been used previously to quantify facial bone in dentistry for orthodontic research[13] and to measure bone volume following regenerative periodontal therapy.[14] Therefore, the present investigators chose CBCT as the preferred measurement technique for determining facial bone width.

As a 2-mm threshold accounted for a significant negative correlation between the width of the buccal alveolar ridge and the amount of bone resorption at peri-implant sites in a dog model, Qahash and colleagues[2] and others[3,4] have concluded that implant surgical protocols may need to provide at least a 2-mm width of buccal wall in order to maintain supporting alveolar bone. With the assumption that thickness of facial bone is closely associated with outcomes of anterior implant placement, the purpose of the present study was to use CBCT to determine mean width and prevalence of a thickness of 2 mm or more in the facial alveolar bone overlying maxillary central incisors.

MATERIALS AND METHODS

The University of Southern California Institutional Review Board approved the patient chart and database review protocol of this study (# UP-09-00002).

One hundred forty-five scans were randomly selected from the CBCT database taken for pre- or post-implant therapy or for orthodontic therapy at the University of Southern California School of Dentistry Imaging Center. Scans of patients who had implants placed in maxillary anterior teeth and/or presented with periodontitis were eliminated from the sample. Scattered images because of orthodontic brackets and distorted cementoenamel junction (CEJ) excluded 44 patient scans from the study. As a result, 101 patients (53 male and 48 female) were included in the scan sample. The mean age represented by the scans was 48.5 years (range: 15–82 years); 26.5% were between 15 and 35 years old, 21.4% between 36 and 49 years old, 26.5% between 50 and 60 years old, and 25.5% between 61 and 82 years old. The patients evaluated were 53 Caucasians, 21 Hispanic Americans, 15 Asian Americans, 11 African Americans, and 1 Native American.

Two CBCT machines were used in these scans, Galileos Comfort and NewTom 3G. Specific details on the machine are listed below.

NewTom 3G

This machine was manufactured by QR s.r.l, Verona, Italy, and distributed in the United States by AFP

Imaging (http://www.qrverona.it/, http://www.afpimaging.com/newtom). X-ray settings were at 110 kV and 1 to 15 mA and the effective dose was 60 μSv. Total scan time was 36 seconds and X-ray emission time was approximately 5 seconds. Three-dimensional resolution was 0.3 mm and signal grey scale was 12-bit. All scans used in this study were with resolution volume 7.9″ cm (12″ FOV). EasyGuide™ from Keystone Dental, Inc. (Burlington, MA, USA) including DICOM converters was used to view the images (http://www.keystonedental.com/easyguide/planningsoftware/features.aspx).

Galileos Comfort

This machine was manufactured by Sirona the Dental Company which has headquarters in Bensheim, Germany and Long Island, New York, USA (http://www.sirona.com/ecomaXL/index.php?site=SIRONA_COM_galileos_comfort). X-ray settings were at 85 kV and 5–7 mA and the effective dosage was 68 μSv. Total scan time was 14 seconds and exposure time was 2 to 6 seconds. The field of views was (15 × 15 × 15) cm^3 and displayed three-dimensional resolution was 0.3/0.15 mm. SIDEXIS XG (SIrona DEntal X-ray Imaging System neXt Generation) software manufactured by the same company was used for viewing and analyzing of the images (http://www.sidexis.de/ecomaXL/index.php?site=SIDEXIS_E_home).

Both computer programs displayed three different views simultaneously on a Dell Latitude™ D810 laptop computer (Dell™, Round Rock, TX, USA) equipped with graphic card 512 MB, 1680 × 1050 pixels. The following three views were used in both programs: (1) axial view, (2) panoramic view with 3D navigation, and (3) vertical cross-section views perpendicular to the maxillary arch. To locate the same cross section of each tooth, locators were placed bisecting the cingulum of each central incisor on horizontal cross-section views and bisecting the mesial-distal dimension of each CEJ of the panoramic view.

Both programs provide a ruler measuring function with precision to one-tenth of a millimeter. Two observers were calibrated using 10 randomly selected scans from the Sirona (SIDEXIS XG) program and 14 from the EasyGuide program. An assessment of the reproducibility of measurements between observers measuring the same quantity to one-tenth of a millimeter was calculated at a correlation of 0.95 for the 24 scans.

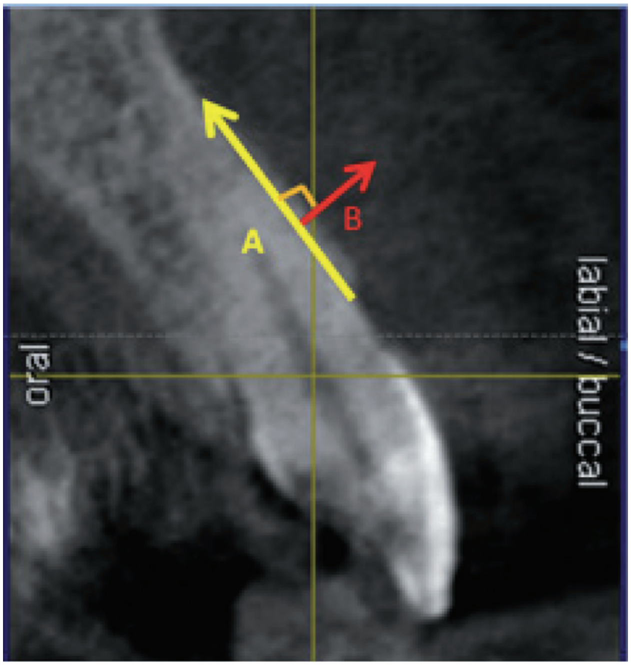

Figure 1 Line *A* indicates the direction of measurements taken along the root surface (1–10 mm from the facial bone crest). Line *B* is perpendicular to line *A* and indicates the direction for measurement of width of the facial bone.

Each of the two observers measured 101 scans independently at the exact same slice and magnification. Measurements were taken at points 1 to 10 mm from the facial bone crest (Figure 1) and measurements from the two observers were averaged to calculate final measurements for each scan.

The following measurements were obtained for each tooth: (1) distance from the CEJ to the bone crest, and (2) width of facial bone overlying the maxillary central incisors, measured as the distance between the surface of the root and the outer surface of the hard tissue wall.

Demographic and general information were collected for each patient scan. Subcategories were formed to study the effect of race/ethnicity, gender, age, and type of scan on bone thickness.

Statistical Analysis

All statistical analyses, beginning with descriptive statistics (frequencies, means, and standard deviations) were conducted using SPSS v. 15.0 (Chicago, IL, USA). One-way analysis of variance (ANOVA), followed by Tukey's post hoc analysis, was conducted to compare the bone width at each measurement level on maxillary left and right incisors by age and ethnic group. Student's

TABLE 1 Mean Distance, Standard Deviation, and Range (mm) from the Cementoenamel Junction to the Facial Bone Crest for Maxillary Central Incisors (*n* = 202) by Gender

	Right Central Incisor (mm)	Left Central Incisor (mm)	Both (mm)
Female (*n* = 53)	2.3 ± 0.82 (0.5–4.2)	2.2 ± 0.79 (0.6–4.2)	2.2 ± 0.81 (0.5–4.2)
Male (*n* = 48)	2.6 ± 0.86 (1.0–4.9)	2.5 ± 0.82 (0.9–4.4)	2.6 ± 0.84 (0.9–4.9)
All	2.5 ± 0.84 (0.5–4.9)	2.4 ± 0.81 (0.6–4.4)	2.4 ± 0.83 (0.5–4.9)

independent *t*-tests were conducted to compare the bone width at each measurement by gender and type of scan (Galileos vs NewTom). Because of reduced availability of measures after the 8-mm level, multivariate ANOVA was not advisable for analysis of bone width data. Individual variation in angulation of the teeth in the jaw may have resulted in displacement of root tips off the tomographic slice evaluated at 9 and 10 mm levels. To account for inflation of alpha and intercorrelation between measures, experiment-wise error was controlled for with a Bonferroni correction such that alpha = 0.0045. Paired *t*-tests were used to examine differences between the two teeth for each bone width.

RESULTS

Total mean thickness of the facial bone at combined points 1 to 10 mm was 1.0 ± 0.52 mm and 1.1 ± 0.56 mm for the right and left incisors, respectively. The range of individual measurements for all levels was 0 to 5.1 mm. Summary data for maxillary right and left central incisor facial bone width are displayed in Tables 2 and 3.

A significant difference in bone width measured by the 2-tailed paired *t*-tests was between maxillary left and right incisors at 7 mm from the bone crest ($p = .03$), but this finding did not achieve the Bonferroni conservative *p* value. The Bonferroni correction was applied to control for the inflation of experiment-wise error because of multiple statistical tests within the same hypothesis and the risk of inflating alpha (the predetermined *p* value of 0.05). There are no other indications of significant differences in the bone width measurements between the right and left maxillary central incisors at any specific level 1 to 10 mm from the facial bone crest.

With regard to gender differences in facial bone width, male patients exhibited a trend toward thicker bone for maxillary right central incisors at 5 through 9 mm and for maxillary left central incisors at 7 mm. However, no significant differences in bone thickness were measured at the level of Bonferroni correction between gender, age, ethnic, or scan groups.

At 1 mm from the crest, no patient had a facial bone of 2 mm or more. At 2 mm from the crest, a facial bone of ≥2 mm was detected only in three sites and at 3, 4, and 5 mm from the crest, at 4, 6, and 5 sites, respectively. The % occurrence of teeth with a facial bone ≥2 mm at 1, 2, 3, 4, and 5 mm from the crest was 0, 1.5, 2.0, 3.0, and 2.5%, respectively, with no significant differences among ethnic, age, gender, or scan groups.

Apparent fenestrations (0-mm bone measurements) were detected at 6, 7, 8, 9, and 10 mm from the crest apices at a 12% occurrence ($n = 24$ of 202 teeth in 21 patients) (Table 4). No fenestrations (0-mm bone) were detected within the first 5 mm from the facial bone crest.

The distance from the CEJ to bone crest averaged 2.4 ± 0.83 mm for both maxillary central incisors (Table 1). In the female patients, the distance from the CEJ to the facial bone crest averaged 2.3 ± 0.82 mm for the maxillary right incisor and 2.2 ± 0.79 mm for the maxillary left incisor. In the male patients, the distance from the CEJ to the facial bone crest averaged 2.6 ± 0.86 mm for the maxillary right incisor and 2.5 ± 0.82 mm for the maxillary left incisor. The occurrence of CEJ-bone crest distances ≥4 mm was 3.5% (3 maxillary left and 4 maxillary right central incisors).

A significant difference in CEJ to bone distance was found within the racial/ethnicity group based on one-way ANOVA and Tukey's HSD post hoc test at $p = .01$. Black Americans exhibited significantly greater distance (2.9 ± 0.59 mm) CEJ to bone crest than Hispanic Americans (1.9 ± 0.70 mm), but this significance was determined for the maxillary left incisor group only. No other significant differences were measured between age, gender, ethnicity, and scan groups with regard to distance of CEJ to the bone crest.

TABLE 2 Width of the Facial Bone Overlying Maxillary Right Central Incisors, Measured 1 to 10 mm from the Facial Bone Crest

Distance from Crest (mm)	Mean	Maximum	Minimum	Mode	Median	SD
1	1.0	1.9	0.3	1.0	1.0	0.3
2	1.2	2.2	0.4	1.2	1.1	0.4
3	1.2	2.2	0.5	1.1	1.1	0.4
4	1.1	2.3	0.3	0.9	1.0	0.4
5	1.1	2.3	0.4	1.4	1.0	0.4
6	1.0	2.8	0	1.0	0.9	0.4
7	1.0	3.4	0	0.9	0.9	0.5
8	1.0	4.4	0	0	0.9	0.7
9	1.0	2.8	0	0	1.0	0.7
10	1.2	5.1	0	0	1.0	1.0

DISCUSSION

The present study measured the thickness of the facial alveolar bone overlying the maxillary right and left central incisors and determined a low occurrence of a bone of ≥2 mm (Table 4). No significant differences in bone width were determined between ethnic and age groups and, in spite of a normal anatomical trend for thicker male than female bone,[15] a thin facial bone predominated for all groups.

A large study with caliper measurement of human subjects by Spray and colleagues[3] determined mean facial bone thickness at 1.8 ± 1.41 mm following osteotomy site preparation for 2685 implants. Facial bone was measured at .05 mm below the crest and was not reported by area of the mouth for comparison with our measurements in the maxillary anterior teeth, which began at 1 mm below the crest.

For direct comparison to our study, we located only two studies whereby investigators specifically attempted measurement of human maxillary anterior facial bone width, one with cadavers and one with human bony sockets after tooth extraction. A study by Katranji and colleagues[16] measured (at the alveolar crest and 3 mm apical to the alveolar crest) 28 human cadaver heads with a Boley gauge and calculated mean facial cortical thickness of the dentate maxillary anterior ($n = 15$) at 1.59 ± 0.07 mm. Our finding with CBCT for 202 central incisors from 101 patients was a mean bone thickness of 1.12 ± 0.30 mm at 3 mm below the crest (Tables 2 and 3).

TABLE 3 Width of the Facial Bone Wall Overlying Maxillary Left Central Incisors, Measured 1 to 10 mm from the Facial Bone Crest

Distance from the Crest (mm)	Mean	Maximum	Minimum	Mode	Median	SD
1	1.0	1.7	0.4	0.8	1.0	0.3
2	1.1	2.0	0.4	0.9	1.1	0.3
3	1.2	2.0	0.5	1.3	1.2	0.4
4	1.1	2.7	0.3	0.5	1.2	0.4
5	1.1	2.6	0.3	1.3	1.2	0.4
6	1.1	3.0	0	1.2	1.1	0.5
7	1.1	3.5	0	0	1.0	0.6
8	1.1	4.5	0	0	1.0	0.7
9	1.2	5.1	0	0	1.1	0.9
10	1.3	5.1	0	0	1.2	1.1

TABLE 4 Frequency of Facial Bone Width Measurements of ≥2, ≥1, <1 mm, and =0 (No Bone) at 1 to 10 mm Apically from Bone Crest for Maxillary Right and Left Central Incisors

	Distance from the Crest of the Bone									
	1 mm	2 mm	3 mm	4 mm	5 mm	6 mm	7 mm	8 mm	9 mm	10 mm
Tooth #8 (*n* = 101)										
(*n*) ≥2 mm	0	3	3	3	1	2	4	6	7	8
(*n*) ≥1 mm	53	67	67	54	46	40	42	41	34	27
(*n*) <1 mm	48	34	34	46	53	59	56	52	34	26
(*n*) =0	—	—	—	—	—	1	3	6	12	9
(*n*) unable to evaluate	0	0	0	1	2	2	3	8	33	48
Tooth #9 (*n* = 101)										
(*n*) ≥2 mm	0	0	1	3	4	4	6	9	8	9
(*n*) ≥1 mm	54	69	71	62	59	56	54	51	45	31
(*n*) <1 mm	47	32	30	38	40	42	43	42	30	21
(*n*) =0	—	—	—	—	—	2	4	5	9	8
(*n*) unable to evaluate	0	0	0	1	2	3	4	8	26	49

Botticelli and colleagues[6] measured the facial bone wall (1 mm apical to the bone crest) with a caliper immediately after 21 extractions. The study included both maxillary anterior teeth and premolars and they reported a mean bone width of 1.4 ± 0.04. Our study determined a mean facial bone width of 1.02 ± 0.63 mm at 1.0 mm below the crest for the 202 combined maxillary incisors (see Tables 2 and 3).

A recent study by Tomasi and colleagues[17] measured facial bone width at the crest of the bone, at the time of implant placement, for 92 subjects and divided the measurements into two categories, ≤1.0 mm (*n* = 65) and >1.0 mm (*n* = 27) of bone width. We cannot compare with these figures either as we measured 1.0 to 10.0 mm below the crest in healthy, natural tooth sites. Variations on measurement approaches by different investigators have limited comparability of results between the few existing studies on facial bone width measurement.

The 21 human clinical[6] and 15 cadaverial[16] measurements previously cited provided evidence to suggest that <2 mm may be a norm for the marginal facial bone of the maxillary anterior teeth. With CBCT, our investigation with 202 maxillary incisors supports the findings of a thin maxillary anterior facial bone in the former studies and further establishes that a thin anterior facial alveolar bone (<2 mm) prevails both marginally and up to 10 mm apically from the alveolar crest.

Furthermore, in the present study at 1 mm from the bone crest, no bone widths ≥2 mm were detected. At 2, 3, 4, and 5 mm, a bone of ≥2 mm thickness was detected in only 3 sites (1.5%), 4 sites (2.0%), 6 sites (3%), and 5 sites (2.5%), respectively, indicating the relatively rare occurrence of ≥2 mm bone in the facial marginal bone of the maxillary anterior area.

Additionally, our study is in agreement with Chen and colleagues[5] with regard to prevalence of fenestrations for which we determined a 12% occurrence (*n* = 24 of 202 teeth in 22 patients) (Table 4). They reported that 59 sites (69.4%) of facial socket walls were intact, 15 sites (17.6%) of labial bone exhibited small dehiscence, and an additional 11 sites (13%) exhibited facial fenestration near the root apices. In our study, following the root apically, the frequency detection of ≥2 mm thick facial bone increased (see Table 4). Nevertheless, the mean values for the different levels of measurement fluctuated only from 1.0 to 1.3 mm (see Tables 2 and 3) likely because of a high occurrence of bone fenestration observed at measurement levels 6 to 10 mm from the bone crest. The fact that no fenestrations were detected in a healthy sample until 6 mm from the bone crest is a relevant clinical finding. A thin bone coronal to this point may become a dehiscence during healing and lead to the further clinical and esthetic complication of soft tissue recession. Becker and colleagues[18] have noted that bone healing and resultant characteristics can affect soft tissue morphology. A thin, scalloped facial bone can contribute to a lack of support for soft tissue height and papillae.[19,20]

Although the distance between the CEJ and bone crest in this healthy sample averaged 2.4 ± 0.8 mm, a wide range of 0.5 to 4.9 mm was measured. A small percentage (3.5%) of scans in the sample presented a CEJ-crest measurement of 4 mm or more. The CEJ-crest measurements are an important consideration in treatment after implant placement as the risk for soft tissue recession may be increased with a greater distance and a thin facial bone may add to the risk.[21–23]

CONCLUSION

The CBCT measurements support the finding of a predominantly thin facial bone overlying maxillary central incisors. Because of naturally occurring biological events, this thin and fragile facial bone wall is prone to resorptive processes that can lead to fenestration and dehiscence following tooth extraction. Thus, the facial aspect of an extraction site in this area is susceptible to defects that may interfere with the osseointegration of an immediately placed implant.

A thin facial bone was noted in 97% of the 202 teeth analyzed in 101 randomly selected patient scans regardless of age, gender, or ethnicity. Based on the results of this study, it is essential to consider that immediate implant placement in the maxillary anterior position may pose the possibility of bone-related complications for a great majority of patients. Informed treatment decisions based on thorough site evaluation before implant placement is a necessity and effective doctor–patient communication will help to encourage realistic expectations and to ensure understanding of potential outcomes.

ACKNOWLEDGMENT

This study was supported by the University of Southern California, School of Dentistry, Advanced Education in Periodontology Program research funds.

REFERENCES

1. Evans CDJ, Chen ST. Esthetic outcomes of immediate implant placements. Clin Oral Implants Res 2008; 19:73–80.
2. Qahash M, Susin C, Polimeni G, Hall J, Wikesjö UM. Bone healing dynamics at buccal peri-implant sites. Clin Oral Implants Res 2008; 19:166–172.
3. Spray JR, Black CG, Morris HF, Ochi S. The influence of bone thickness on facial marginal bone response: stage 1 placement through stage 2 uncovering. Ann Periodontol 2000; 5:119–128.
4. Grunder U, Gracis S, Capelli M. Influence of the 3-D bone-to-implant relationship on esthetics. Int J Periodontics Restorative Dent 2005; 25:113–119.
5. Chen ST, Darby IB, Reynolds EC, Clement JG. Immediate implant placement postextraction without flap elevation. J Periodontol 2009; 80:163–172.
6. Botticelli D, Berglundh T, Lindhe J. Hard-tissue alterations following immediate implant placement in extraction sites. J Clin Periodontol 2004; 31:820–828.
7. Araújo MG, Lindhe J. Dimensional ridge alterations following tooth extraction. An experimental study in the dog. J Clin Periodontol 2005; 32:212–218.
8. Araújo MG, Wennström JL, Lindhe J. Modeling of the buccal and lingual bone walls of fresh extraction sites following implant installation. Clin Oral Implants Res 2006; 17:606–614.
9. Johnson K. A study of the dimensional changes occurring in the maxilla following tooth extraction. Aust Dent J 1969a; 14:241–244.
10. Johnson K. A study of the dimensional changes occurring in the maxilla following closed face immediate denture treatment. Aust Dent J 1969b; 14:370–376.
11. Pietrokovski J, Massler M. Alveolar ridge resorption following tooth extraction. J Prosth Dent 1967; 17:21–27.
12. Schropp L, Wenzel A, Kostopoulos L, Karring T. Bone healing and soft tissue contour changes following single-tooth extraction: a clinical and radiographic 12-month prospective study. Int J Periodontics Restorative Dent 2003; 4:313–323.
13. Rungcharassaeng K, Caruso JM, Kan JYK, Kim J, Taylor G. Factors affecting buccal bone changes of maxillary posterior teeth after rapid maxillary expansion. Am J Orthod Dentofacial Orthop 2007; 132:428.e1–428.e8.
14. Grimard BA, Hoidal MJ, Mills MP, Mellonig JM, Nummikoski PV, Mealy BL. Comparison of clinical, periapical radiograph, and cone-beam volume tomography measurement techniques for assessing bone level changes following regenerative periodontal therapy. J Periodontol 2009; 80:48–55.
15. The anatomical basis of clinical practice. In: Sandring S, ed. Gray's anatomy. 39th ed. Edinburgh, Toronto: Elsevier Churchill Livingstone, 2005:489.
16. Katranji A, Misch K, Wang HL. Cortical bone thickness in dentate and edentulous human cadavers. J Periodontol 2007; 78:874–878.
17. Tomasi C, Sanz M, Cecchinato D, Ferrus J, Lang NP, Lindhe J. Bone dimensional variations at implants placed in fresh extraction sockets: a multilevel multivariate analysis. Clin Oral Implants Res 2010; 21:30–36.
18. Becker W, Ochsenbein C, Tibbetts L, Becker RF. Alveolar bone anatomic profiles measured from dry skulls. Clinical ramifications. J Clin Periodontol 1997; 24:727–731.
19. Palacci P, Nowzari H. Soft tissue enhancement around dental implants. Periodontol 2000 2008; 47:113–132.
20. Nowzari H, Chee W, Yi K, Pak M, Chung WH, Rich SK. Analysis of radiographic and clinical outcomes of 17

NobelPerfect™ implants in 6 patients. Clin Implant Dent Relat Res 2006; 8:1–10.

21. Chodquet V, Hermans M, Adriaenssens P, Daelemans P, Tarnow D, Malevez C. Clinical and radiographic evaluation of the papilla level adjacent to the single-tooth dental implants. A retrospective study in the maxillary anterior region. J Periodontol 2001; 72:1364–1371.
22. Tarnow DP, Cho SC, Wallace SS. The effect of inter-implant distance on the height of inter-implant bone crest. J Periodontol 2000; 71:546–549.
23. Bengazi F, Wennstrom JL, Lekholm U. Recession of the soft tissue margin at oral implants. A 2-year longitudinal prospective study. Clin Oral Implants Res 1996; 7:303–310.