ORIGINAL RESEARCH

Qualitative and Quantitative Assessments of Alveolar Bone Dimension and Its Correlation with Tooth Angulation in the Anterior Maxilla for Immediate Implant Placement

Jumanah Babiker[1], Nur Hafizah Kamar Affendi[2], Mohd Yusmiaidil Putera Mohd Yusof[3], Stephen J Chu[4]

Abstract

Aim and objective: The aim of this paper is to ascertain the quantitative measurements of alveolar bone thickness at all maxillary anterior teeth and qualitatively demonstrate the relationship between tooth angulation (TA) and alveolar bone thickness.

Materials and methods: Cone-beam computed tomography (CBCT) images of 189 maxillary anterior teeth were collected. Sagittal view was selected to perform the measurement on alveolar bone wall at crestal, midlevel, and palatal. TA was measured along to the tooth long axis (TLA) related to the alveolar bone housing. Spearman's correlation coefficients were conducted to test the correlation between the variables.

Results: The facial alveolar bone (FAB) is predominantly thin (<1 mm) at the crestal and midroot region. A significant difference was recorded in the median thickness of FAB at the midroot and apical area ($p = 0.001$, $p = 0.021$). The FAB thickness was not gradual with midroot being thinner than crestal. For the palatal alveolar bone (PAB), the thickness was increased continuously toward the apex. At all apical levels of inspected teeth, a significant negative correlation existed between TA and FAB. A positive correlation of TA was only significant at the facial crest of lateral incisor ($r = 0.308$). However, the canines did not correlate with the FAB, but correlated with the PAB at the apical level ($r = 0.478$).

Conclusion: The FAB wall crest of maxillary anterior teeth was generally thin and not gradual with the lateral incisor being the thinnest. A significant correlation of TA existed based on different types of maxillary anterior teeth and alveolar bone level. The maxillary anterior teeth with increased buccolingual angulation were correlated with thicker bone at the apical level.

Clinical significance: The quantitative assessment of FAB and TA in degree may serve as an anatomical index for ideal implant position.

Keywords: Alveolar bone, Cone-beam computed tomography, Facial bone, Immediate implant placement, Palatal bone thickness.

The Journal of Contemporary Dental Practice (2021): 10.5005/jp-journals-10024-3211

Introduction

The execution of restoring immediate implant placement (IIP) in the maxillary anterior teeth involved careful evaluation of the residual alveolar bone, peri-implant soft tissue, and analysis of smile.[1] Some of these important parameters may influence clinician's decision for inserting a prosthetically driven implant position and to satisfy the esthetic demands of the patient. Despite being a contemporary approach for many years, these procedures remain challenging due to impaired anatomy and risk factors such as incorrect surgical technique or displaced implant position.[2] Therefore, it is always recommended to follow the treatment guidelines proposed by various authors to reduce the rate of surgical complications and achieve long-term success in implant rehabilitation.[2–4]

The recommended treatment for IIP in the maxillary anterior teeth is to preserve a facial bone thickness of 2 mm for a predictable esthetic outcome.[5] Yet, it has been well agreed, established, and known that the facial bone thickness in this area is thinner than 2 mm.[6] In long-term, if inadequate bone supports the implant placement, the peri-implant bone may not survive, failed to avascular necrosis, and cause esthetic impact especially in a growing craniofacial development.[7] Furthermore, the lack of randomized control trial in various procedures such as socket shield, partial extractions, and flapless placement has caused uncertainty to verify the long-term success of these protocols.[6,8–11] Since the fate of bone resorption is unpredictable, it is crucial to identify the variations of facial bone thickness between tooth type, genders, age group,

[1]Faculty of Dentistry, Universiti Teknologi MARA (UiTM), Kampus Sungai Buloh, Jalan Hospital, Sungai Buloh, Selangor, Malaysia

[2]Unit of Prosthodontics, Centre of Restorative Dentistry Studies, Faculty of Dentistry, Universiti Teknologi MARA (UiTM), Kampus Sungai Buloh, Jalan Hospital, Sungai Buloh, Selangor, Malaysia

[3]Centre of Oral and Maxillofacial Diagnostics and Medicine Studies, Faculty of Dentistry, Universiti Teknologi MARA (UiTM), Kampus Sungai Buloh, Jalan Hospital, Sungai Buloh, Selangor, Malaysia; Institute of Pathology, Laboratory and Forensic Medicine (I-PPerForM), Universiti Teknologi MARA (UiTM), Sungai Buloh Campus, Sungai Buloh, Selangor, Malaysia

[4]Ashman Department of Periodontology and Implant Dentistry, Department of Prosthodontics, New York University College of Dentistry, New York, United States of America

Corresponding Author: Nur Hafizah Kamar Affendi, Unit of Prosthodontics, Centre of Restorative Dentistry Studies, Faculty of Dentistry, Universiti Teknologi MARA (UiTM), Kampus Sungai Buloh, Jalan Hospital, Sungai Buloh, Selangor, Malaysia, Phone: +60361266545, e-mail:hafizah_kamar@uitm.edu.my

How to cite this article: Babiker J, Affendi NHK, Yusof MYPM, *et al*. Qualitative and Quantitative Assessments of Alveolar Bone Dimension and Its Correlation with Tooth Angulation in the Anterior Maxilla for Immediate Implant Placement. J Contemp Dent Pract 2021;22(11):1237–1242.

Source of support: Nil

Conflict of interest: None

and populations that affect the decision whether to perform IIP or proceed with delayed approach.

In addition to facial bone thickness, the palatal bone thickness seems to be the key anatomic feature for guiding the implant into optimal positions.[12] In clinical situations, the implant was placed on the palatal bone to attain primary stability.[13] Although it can act as bone anchorage, placing it too palatal might compromise the emergence of the implant crown due to over-contouring. Moreover, if the implant apex is in the wrong position, the risk of grayish appearance can occur if the implant platform is facially tilted.[14] For this reason, the tooth angulation (TA) assessment in the residual root anatomy is important to determine the treatment plan, predict the necessity of bone regeneration, select the suitable implant with desired dimension, and plan for the future prostheses.

Numerous studies have identified the quantitative measurements of alveolar bone thickness (facial and palatal) and root angulation.[14–16] However, correlations between these parameters are investigated to a lesser extent. Furthermore, although some methods to discriminate TA were described, there is a lack of knowledge about which method can be used as quantitative measurements. To the best of our knowledge, only few researchers have established the relationship between those parameters. In Caucasian population, Nahas-Scocate et al. found no correlation between tooth inclination and palatal bone on the maxillary incisors, while Sendyk et al. found negative correlations at the apical area.[17,18] Another study has documented that the greater angle with more than 90, the thinner the buccal wall is and implies the risk of buccal bone wall perforation.[19] In a recent study on Asian populations, it was found that an increased buccolingual angulation correlated with thinner palatal bone at the apical area.[14] These findings indicate that ethnicities and populations were unique and varied. As tooth angle and alveolar bone thickness could create a fragile situation for IIP procedure, adequate information from cone-beam computed tomography (CBCT) provides great significance toward optimum treatment plan approach.

Considering creating favorable clinical situations, the goal of this study was to ascertain the quantitative measurements of FAB and palatal alveolar bone (PAB) thickness at levels for all maxillary anterior teeth. The specific objectives were to qualitatively demonstrate the relationship between maxillary anterior TA and alveolar bone thickness at the crestal, midroot, and apical levels. The null hypothesis was that there was no difference in alveolar bone thickness at any level in all-maxillary teeth and that there was no relationship between TA and its underlying alveolar bone wall thickness at any level.

Materials and Methods

CBCT Images Selection

The study was an observational retrospective study and is compliant with the guidelines of strengthening the reporting of observational studies in epidemiology (STROBE).[20] The protocol of this study was approved by the Institute of Research and Management, Universiti Teknologi MARA [600-TNCPI (5/1/6)]. The data were collected at the Diagnostic Imaging Unit of Universiti Teknologi MARA, between December 2020 and May 2021. The collected scans belonged to 151 females and 80 male patients between the age of 18 and 74 years (mean, 44.53 years). CBCT images of 189 teeth were collected, along with the age, gender, and type of tooth. Using the G Power calculator, the sample size was estimated to be 180 teeth, using Cohen's effect size of 0.5, and 10% was added to compensate for the estimated dropouts. To ensure a lower margin of error, a minimum of 62 teeth were determined in each group. The inclusion criteria for the clinical data were listed as follows: (a) Asian race (Malay, Chinese, Indian aged 18–75 years); (b) present of all anterior maxillary and mandibular teeth; (c) no evidence of dental trauma or root fracture; (d) no radiographic images of fillings, restorations, apical lesions, bone loss, and resorption; (e) absence of image distortion or metal artifacts; (f) no history of orthodontic or periodontal treatment.

The CBCT images were acquired using the Carestream 9500 (Carestream Health, Rochester, New York) and analyzed with CS 3D Imaging Software v3.5.7 (Cumberland Blvd., Atlanta, USA, 1600 × 900 Pixel resolution screen). The size of the field of view (FOV) was 10 × 10 cm, with an average resolution (voxel) of 0.18 mm.

Data Measurements

Images were reconstructed in the curved slicing to allow manual tracing in the axial slice. The arch form selector was centered throughout the middle of the arch in the axial plane. To ensure the appropriate cut for each tooth, the midpoint was determined between the distal and mesial crest of each tooth at the cementoenamel junction (CEJ) in the coronal view. To perform measurements, sagittal view was selected from the reconstructed data, resulting in images with the entire root anatomy and alveolar bone. Whenever required, tools from the toolbox options were used to adjust the contrast or brightness for accurate measurements.

The following measurements were made for each maxillary anterior tooth.[21]

- The FAB (FAB1, FAB2, FAB3) thickness and the PAB (PAB1, PAB2, PAB3) were measured perpendicular to the long axis of the tooth at three different locations: 4 mm apical to the CEJ, the middle of the root and at the apex (Fig. 1).
- The TA was evaluated between the tooth long axis (TLA) measured from incisal edge to the tooth root and the alveolar bone wall long axis (ABLA) (Fig. 2).

Statistical Analysis

To estimate intra-examiner reliability for calibration, 10 CBCT scans were randomly selected and were assessed twice with a 2-week

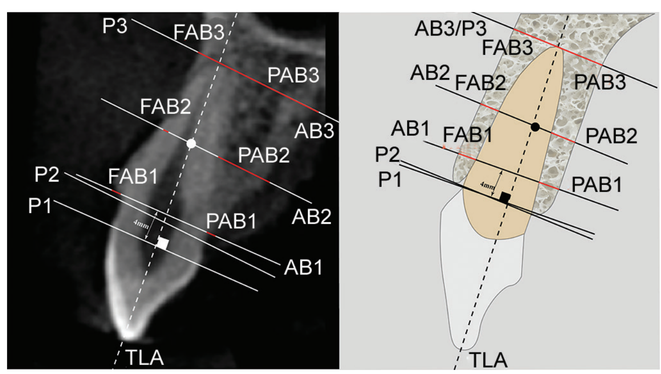

Fig. 1: The tooth long axis was used as a reference (TLA). PI is the line drawn perpendicular (90) to the long axis of the tooth at the cementoenamel junction (CEJ). FAB1 and PAB1 were measured 4 mm apical to P1. P2 is the line drawn perpendicular (90) to the long axis of the tooth, crossing the facial and palatal alveolar bone crest. P3 is the line drawn parallel to P2 at the apical level. FAB3 and PAB3 were measured at the root apex. To obtain the alveolar bone at midroot (FAB2, PAB2), a midpoint was selected between P2 and P3

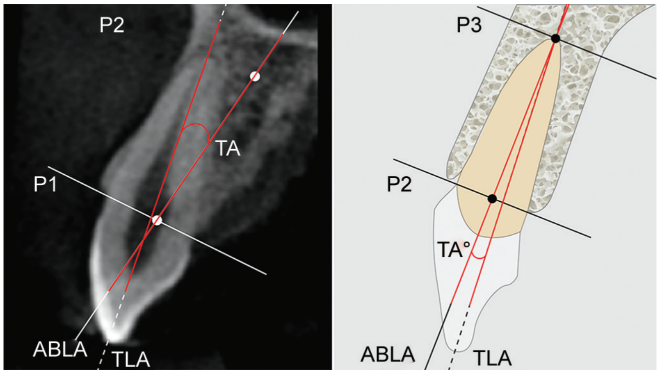

Fig. 2: The tooth long axis was used as a reference (TLA). To determine tooth angulation (TA), two parallel lines were drawn joining the facial and lingual crest (P2) and the root apex (P3). The two midpoints from these lines were determined. These two midpoints were then connected to determine the alveolar bone long axis (ABLA) and extending 2 mm from the root apex. The TA was recorded in degrees by measuring these two axes

interval. For the interexaminer reliability, another examiner was chosen to measure the CBCT images. The intraclass correlation coefficient (ICC) was used to determine the degree of agreement.

All collected data were analyzed using SPSS version 24 (SPSS Inc., Chicago, Illinois). Normality testing using Shapiro–Wilk test was done prior to data analysis. Numerical variables were presented as their frequency, median, and interquartile range with Kruskal–Wallis test. Spearman's correlation coefficient was conducted to examine the correlation coefficient between quantitative variables. Statistical analysis was set at $\alpha = 0.05$.

Results

The method of assessment was highly reproducible, as demonstrated as ICC exceeding 0.9 within a single examiner. Between two examiners, the ICC was 0.9 for alveolar bone thickness and 0.8 for TA. For the Shapiro–Wilk test, most of the measurements were not normally distributed with a skewness of >1 and a kurtosis of >2. Therefore, the nonparametric (Kruskal–Wallis test) was used to compare the median of alveolar bone thickness and TA. Nonparametric correlation test (Spearman's rank) was used to detect the association between TA and alveolar bone wall thickness. As there was a heterogeneous sample between gender and age, the data were only concerned on variables such as alveolar bone thickness and TA.

The facial and palatal of bone thickness in three different locations are shown in Table 1. The measurements were categorized into categories of thin (<1 mm) and thick alveolar bone (≥1 mm). Based on the result, most of the maxillary anterior teeth have thin facial bones at the crest and midroot. It can be observed that 71% (n = 46) of central incisors, 74.2% (n = 46) of lateral incisors, and 71.4% (n = 45) of canines have a thin facial bone crest. As compared to crestal, a higher percentage of thin facial bone was recorded at the midroot level. Toward the apex, most of the teeth show a thick facial bone. For the palatal bone, the bone thickness increased continuously from the crestal level to the apical level of all the recorded teeth.

The variable for median alveolar bone thickness for each maxillary tooth is shown in Table 2. According to the type of tooth, there is no statistically significant difference between the median thicknesses of FAB crest (FAB1) in all maxillary anterior teeth (p = 0.763). Nevertheless, there is a significant difference in the median thickness at midroot (FAB2) and apical area (FAB3) (p = 0.001, p = 0.021). At the midroot level, the median thickness [0.4 (IQR: 0.52)] was the lowest for lateral incisors. It was also recorded that the median alveolar thicknesses of midroot (FAB2) were all lower than crest (FAB1) at all maxillary teeth. This shows that the thickness of the FAB wall was not continuous. At the apical level (FAB3), the median thickness of FAB for maxillary canine [1.5 (IQR: 1.4)] is higher than central and lateral maxillary incisors. As for the palatal bone wall, since the p value (p = 0.001) is less than $\alpha = 0.05$, it can be concluded that the median thickness for the palatal crest is the highest at central incisor [1.6 (IQR: 1.00)]. The lateral incisors have recorded the lowest median thickness at midroot (PAB2) with 2.2 (IQR 1.3). As for canine, it has the highest median thickness of palatal bone of 8.7 (IQR 3.2) at the apical area.

Table 1: Descriptive statistics of the facial alveolar bone (FAB) and palatal alveolar bone (PAB) thickness at [crestal (FAB1, PAB1), midroot (FAB2, PAB2), apical (FAB3, PAB3)] of maxillary anterior teeth

Tooth type	*Central incisor*		*Lateral incisor*		*Canine*	
Parameters	*N = 64*	*%*	*N = 62*	*%*	*N = 63*	*%*
FAB1						
Thin	46	71	46	74.2	45	71.4
Thick	18	28.1	16	25.8	18	28.6
FAB2						
Thin	50	78.1	53	85.5	56	88.9
Thick	14	21.9	9	14.5	7	11.1
FAB3						
Thin	6	9.4	15	24.2	16	25.4
Thick	58	90.6	47	75.8	47	74.6
PAB1						
Thin	14	21.9	27	43.5	22	34.9
Thick	50	78.1	35	56.5	41	65.1
PAB2						
Thin	0	0	1	1.6	1	1.6
Thick	64	100	61	98.4	62	98.4
PAB3						
Thin	0	0	0	0	0	0
Thick	64	100	62	100	63	100

Table 2: The variable, median, and interquartile range of facial alveolar bone (FAB) and palatal alveolar bone (PAB) thickness at [crestal (FAB1, PAB1), midroot (FAB2, PAB2), apical (FAB3, PAB3)] of maxillary anterior teeth

Tooth type	*Central incisor*		*Lateral incisor*		*Canine*		
variable	*Median*	*IQR*	*Median*	*IQR*	*Median*	*IQR*	*p value*
FAB1	0.75	0.50	0.80	0.40	0.80	0.40	0.763
FAB2	0.60	0.60	0.40	0.52	0.40	0.60	0.001
FAB3	1.80	1.10	1.50	1.10	1.50	1.40	0.021
PAB1	1.60	1.00	1.00	0.80	1.10	0.60	0.001
PAB2	3.00	1.51	2.20	1.30	3.30	1.40	0.001
PAB3	7.30	2.40	6.60	2.30	8.70	3.20	0.001

For TA, on average, it can be observed that most of maxillary anterior teeth were in the 11–20 group (Table 3). Only a few percentages were recorded with more than 20 angulation. The Spearman's correlation coefficients matrix of TA and the facial and palatal alveolar thickness are presented in Table 4. In the maxillary anterior teeth, there is a significant negative correlation between TAs of the FAB at the apical level. Meanwhile for the lateral incisor, a positive correlation is only significant at the crestal area ($r = 0.308$). This indicates that as the TA increases, all maxillary teeth have thin facial apex and thick facial crest at only lateral incisors. For the palatal bone, a positive correlation existed between all maxillary incisors at all levels. Thus, this indicates that the greater TAs, the greater bone thickness was recorded. However, different data were recorded on maxillary canines, where an increase in TA only positively correlated with palatal bone thickness at the apical area ($r = 0.478$), but not significant at the crestal area ($r = -0.054$).

Discussion

In the present study, the anatomic landmarks of alveolar bone wall thickness and TA were analyzed to predict its initial dimension prior to IIP or extraction with delayed approach. Results of this study have shown a significant variation in bone thickness on all maxillary anterior teeth at each level. Furthermore, the result also suggested that the reference point at crestal, midroot, and apical areas has influenced treatment approach and clinical outcome, which justify the importance of analyzing these parameters according to the tooth type. These findings also rejected the null hypotheses of no difference in alveolar bone thickness and no correlation between TA and alveolar bone thickness at any level. To the author's knowledge, this work is the first to report on the combination of FAB and PAB thickness at crestal, midroot, and apical levels and its association with TA on all maxillary anterior teeth of incisors and canine.

The importance of facial bone thickness on the crestal level is known to support the gingival margin, shapes of the alveolus, and the crown's emergence profile.[22,23] As the long-term aesthetic success was highly dependent on this structure, having precise measurements on each tooth type is also useful to determine the risk of teeth with greater volume loss. Based on our finding, it clearly validates the trends published from previous studies, with the facial bone crest predominantly thin (<1 mm).[12,21,22,24–26] The results are also in accordance with the recent systematic review, with no statistical difference in FAB thickness in the coronal areas of all different types of anterior maxillary teeth.[6] However, the result should be interpreted with cautious as high heterogeneity and bias was recorded when differences in anatomical reference point were used whether from CEJ or from facial bone crest itself. Therefore, in the present study, 4 mm from the CEJ was used as reference to avoid errors and was reliable for interpreting the result.[6,24] In contrast, our study has recorded that the thickness of FAB was not in gradual from coronal to apical, with lateral incisor being the thinnest. The present data also concurred with the previous study of a similar pattern with midroot being thinner than crestal.[27] Yet, previous study by certain research group has observed that the value of the midlevel measurement was higher toward apical, indicating a continuous increase of facial bone thickness.[16,21,28] As uncertainty and significant variation remain regarding the pattern of FAB, it is noteworthy to mention that this anatomic study may reinforce the contraindication of the flapless approach in certain types of tooth, considering the possibility of raising flap to augment midfacial bone.[29] This finding is further enhanced with a negative correlation between TA and facial bone thickness, which indicated that a larger angle (more retroclined) would go with thinner facial bone at the midroot and apical. Although positive correlation existed at lateral incisor on the crestal level, the maxillary anterior teeth with greater angulation might be vulnerable for higher incidence of fenestration if flapless immediate implant is performed.[19,27]

For the palatal bone wall, the overall median thickness was increased gradually from the crestal to the apex. In the present study, most teeth had thick palatal bone crests between 1 and 1.6 mm, and in agreement with the values recorded by the previous research group.[30,31] These findings, however, were incomparable with the previous study that showed an overall thickness of palatal crest was between 0.5 and 1 mm.[12,32,33] Despite slight variations, this finding is based on the premise that the palatal bone wall thickness was larger than facial bone, has thicker palatal apex, and was beneficial for mechanical engagement between implant surfaces. Based on these findings and other study, it is strongly suggested to place initial drill beneath midlevel bone to gain primary stability.[14] On the other hand, our result has appeared to be inconsistent with previous study that showed a negative correlation of tooth inclination of

Table 3: Descriptive statistics of tooth angulation of maxillary anterior teeth

Tooth type TA parameters	*Central incisor*		*Lateral incisor*		*Canine*	
	N = 64	*%*	*N* = 62	*%*	*N* = 63	*%*
(1–10)	23	35.9	15	24.2	8	12.7
(11–20)	35	54.7	37	59.7	43	68.3
(>20)	6	9.4	10	16.1	12	19

Table 4: Statistical comparison of correlation between tooth angulation and alveolar bone wall thickness (FAB1, FAB2, FAB3, PAB1, PAB2, PAB3) on each maxillary anterior tooth

Tooth type variable TA	*Central incisor*		*Lateral incisor*		*Canine*	
	r	*p value*	*r*	*p value*	*r*	*p value*
FAB1	0.203	0.107	0.308*	0.015	0.028	0.825
FAB2	−0.329**	0.008	−0.078	0.549	0.000	0.999
FAB3	−0.597**	0.000	−0.554**	0.000	−0.522**	0.000
PAB1	0.541**	0.000	0.322*	0.011	−0.054	0.676
PAB2	0.682**	0.000	0.416**	0.001	0.226	0.075
PAB3	0.633**	0.000	0.591**	0.000	0.478**	0.000

*Correlation is significant at the 0.05 level (two-tailed); **Correlation is significant at the 0.01 level (two-tailed) maxillary incisor with palatal bone thickness at the apical area.[14,18] The finding could be related to different types of malocclusion or the sample size may involve proclined teeth. In the present study, as a positive relationship existed between TA and bone thickness, clinicians should not exploit the residual bone with the intention to only achieve the primary stability. Clinicians should be aware that in severely angulated teeth, placing immediate implant in the same angle of the original tooth axes might cause difficulty to achieve a prosthetically driven restoration.[12] Although alternative options of using cemented prosthetic crowns could solve the situation, the excess cement from risky cementation procedures might cause biological complications in the future.[34] Thus, the assessment in CBCT images should be interpreted thoughtfully when suggesting an IIP, as the variable of TA is important and may not represent an ideal scenario.

In recent years, increasing interest is now focused on the morphology of TA and the position guidelines but less was documented on specific TA in degrees related to alveolar bone wall thickness. In the present study, the result has similar finding to those obtained by Wang et al. and Dos Santos et al., with frequent angulation oscillated between 10 and 20.[21,35] In this group of teeth, it was documented to be easy, able to follow the same orientation of tooth, and ideal for screw-retained restoration.[12,21,36] However, special precautions should be given in 1–10 group and more than >20 group as it will result in compromised situations.[37,38] Besides making decision based on radial tooth position, the quantitative method of TA used in the present study might be useful in clinical setting to emphasize the contraindication of IIP.[12,13,32] In addition, the reproducibility of this method and the values obtained from this assessment have been quantified before in the previous study.[21,39] Hence, in extremely challenging clinical situations, this combination of diagnostic assessment may serve as an anatomical index, influence the implant size selection, determine the ideal implant angulation, and decide whether further augmentation is needed for predictable esthetic outcome.

A common limitation of the present study and previous study was a possible over- and underestimation of the actual measurement of alveolar bone thickness made directly with calipers vs CBCT.[40,41] Nevertheless, studies have been performed on the linear measurements using CBCT, and the accuracy of mean difference was reported to be less than 0.05 mm.[42,43] However, with small FOV and 0.18 mm resolution, the CBCT still allows good evaluation on the images. In addition, no assumption was made on the influence of gender, age, and ethnic for the alveolar bone thickness and TA. Although these factors could have the significant effect of the investigated variables, the poor sample distribution has hindered this category to be analyzed. Thus, a future study may categorize an equal gender, ethnicity, type of tooth, and type of TA in degree with different inclination along with medical and dental status for an accurate quantifiable measurement.

Conclusion

Based on the result, it can be established that the FAB wall crest of maxillary anterior teeth was generally thin. The thickness of the FAB wall was not gradual, with the lateral incisor being the thinnest. Negative correlation existed between TA (more buccally inclined) and FAB wall thickness mainly at the apical area at all maxillary anterior teeth, while the positive correlation only occurred on the lateral incisor at the crestal bone. For the PAB, a significant positive correlation existed between the TA of PAB wall all levels on the maxillary incisors. Meanwhile, for canines, the positive correlation only exists at the apical area.

Clinical Significance

This study has combined the alveolar bone thickness (facial, palatal) and its correlation with the TA. The facial bone thickness was not gradual, which indicates an alternative of flapless approach for IIP for certain types of teeth. The angle measurement method used in the present study may be useful in clinical condition and emphasize the indication or contraindication of IIP.

Acknowledgment

Authors would like to thank Dr Mohamed Eldigire Hamid Ahmed for helping with statistical analysis.

References

1. Cabello G, Rioboo M, Fábrega JG. Immediate placement and restoration of implants in the aesthetic zone with a trimodal approach: Soft tissue alterations and its relation to gingival biotype. Clin Oral Implants Res 2013;24(10):1094–1100. DOI: 10.1111/j.1600-0501.2012.02516.x.
2. Buser D, Martin W, Belser UC. Optimizing esthetics for implant restorations in the anterior maxilla: anatomic and surgical considerations. Int J Oral Maxillofac Implants 2004;19(Suppl):43–61. PMID: 15635945.
3. Buser D, Chen ST, Weber HP, et al. Early implant placement following single-tooth extraction in the esthetic zone: biologic rationale and surgical procedures. Int J Periodontics Restor Dent 2008;28(5): 441–451. PMID: 18990995.
4. Kim JH, Lee JG, Han DH, et al. Morphometric analysis of the anterior region of the maxillary bone for immediate implant placement using micro-CT. Clin Anat 2011;24(4):462–468. DOI: 10.1002/ca.21101.
5. Grunder U, Gracis S, Capelli M. Influence of the 3-D bone-to-implant relationship on esthetics. Int J Periodontics Restorative Dent 2005;25(2):113–119. PMID: 15839587.
6. Tsigarida A, Toscano J, de Brito Bezerra B, et al. Buccal bone thickness of maxillary anterior teeth: A systematic review and meta-analysis. J Clin Periodontol 2020;47(11):1326–1343. DOI: 10.1111/jcpe.13347.
7. Daftary F, Mahallati R, Bahat O, et al. Lifelong craniofacial growth and the implications for osseointegrated implants. Int J Oral Maxillofac Implants 2013;28(1):163. DOI: 10.11607/jomi.2827.
8. Gluckman H, Salama M, Du Toit J. A retrospective evaluation of 128 socket-shield cases in the esthetic zone and posterior sites: partial extraction therapy with up to 4 years follow-up. Clin Implant Dent Relat Res 2018;20(2):122–129. DOI: 10.1111/cid.12554.
9. Hürzeler MB, Zuhr O, Schupbach P, et al. The socket-shield technique: a proof-of-principle report. J Clin Periodontol 2010;37(9):855–862. DOI: 10.1111/j.1600-051X.2010.01595.x.
10. Kan JY, Rungcharassaeng K. Proximal socket shield for interimplant papilla preservation in the esthetic zone. Int J Periodontics Restor Dent 2013;33(1):e24. DOI: 10.11607/prd.1346.
11. Tarnow DP, Chu SJ, Salama MA, et al. Flapless postextraction socket implant placement in the esthetic zone: part 1. The effect of bone grafting and/or provisional restoration on facial-palatal ridge dimensional change-a retrospective cohort study. Int J Periodontics Restor Dent 2014;34(3):323. DOI: 10.11607/prd.1821.
12. Gluckman H, Pontes CC, Du Toit J. Radial plane tooth position and bone wall dimensions in the anterior maxilla: a CBCT classification for immediate implant placement. J Prosthet Dent 2018;120(1):50–56. DOI: 10.1016/j.prosdent.2017.09.005.
13. Kan JYK, Roe P, Rungcharassaeng K, et al. Classification of sagittal root position in relation to the anterior maxillary osseous housing for

immediate implant placement: a cone beam computed tomography study. Int J Oral Maxillofac Implants 2011;26(4):873. PMID: 21841998.
14. Do TA, Shen YW, Fuh LJ, et al. Clinical assessment of the palatal alveolar bone thickness and its correlation with the buccolingual angulation of maxillary incisors for immediate implant placement. Clin Implant Dent Relat Res 2019;21(5):1080–1086. DOI: 10.1111/cid.12835.
15. Han JY, Jung GU. Labial and lingual/palatal bone thickness of maxillary and mandibular anteriors in human cadavers in Koreans. J Periodontal Implant Sci 2011;41(2):60–66. DOI: 10.5051/jpis.2011.41.2.60.
16. Porto OCL, Silva BSF, Silva JA, et al. CBCT assessment of bone thickness in maxillary and mandibular teeth: an anatomic study. J Appl Oral Sci 2020;28:e20190148. DOI: 10.1590/1678-7757-2019-0148.
17. Nahás-Scocate ACR, de Siqueira Brandão A, Patel MP, et al. Bone tissue amount related to upper incisors inclination. Angle Orthod 2014;84(2):279–285. DOI: 10.2319/031213-211.1.
18. Sendyk M, de Paiva JB, Abrão J, et al. Correlation between buccolingual tooth inclination and alveolar bone thickness in subjects with Class III dentofacial deformities. Am J Orthod Dentofacial Orthop 2017;152(1):66–79. DOI: 10.1016/j.ajodo.2016.12.014.
19. Khoury J, Ghosn N, Mokbel N, et al. Buccal bone thickness overlying maxillary anterior teeth: a clinical and radiographic prospective human study. Implant Dent 2016;25(4):525–531. DOI: 10.1097/ID.0000000000000427.
20. Vandenbroucke JP, Von Elm E, Altman DG, et al. Strengthening the Reporting of Observational Studies in Epidemiology (STROBE): explanation and elaboration. PLoS Med 2007;4(10):e297. DOI: 10.1371/journal.pmed.0040297.
21. Dos Santos JG, Oliveira Reis Durao AP, de Campos Felino AC, et al. Analysis of the buccal bone plate, root inclination and alveolar bone dimensions in the jawbone. A descriptive study using cone-beam computed tomography. J Oral Maxillofac Res 2019;10(2):e4. DOI: 10.5037/jomr.2019.10204.
22. Braut V, Bornstein MM, Belser U, et al. Thickness of the anterior maxillary facial bone wall-a retrospective radiographic study using cone beam computed tomography. Int J Periodontics Restorative Dent 2011;31(2):125–131. PMID: 21491011.
23. Buser D, von Arx T. Surgical procedures in partially edentulous patients with ITI implants. Clin Oral Implants Res 2000;11(Suppl 1.):83–100. DOI: 10.1034/j.1600-0501.2000.011s1083.x.
24. Januario AL, Duarte WR, Barriviera M, et al. Dimension of the facial bone wall in the anterior maxilla: a cone-beam computed tomography study. Clin Oral Implants Res 2011;22(10):1168–1171. DOI: 10.1111/j.1600-0501.2010.02086.x.
25. Nowzari H, Molayem S, Chiu CH, et al. Cone beam computed tomographic measurement of maxillary central incisors to determine prevalence of facial alveolar bone width >/=2 mm. Clin Implant Dent Relat Res 2012;14(4):595–602. DOI: 10.1111/j.1708-8208.2010.00287.x.
26. Ghassemian M, Nowzari H, Lajolo C, et al. The thickness of facial alveolar bone overlying healthy maxillary anterior teeth. J Periodontol 2012;83(2):187–197. DOI: 10.1902/jop.2011.110172.
27. Lin CY, Pan WL, Wang HL. Facial fenestration and dehiscence defects associated with immediate implant placement without flap elevation in anterior maxillary ridge: a preliminary cone beam computed tomography study. Int J Oral Maxillofac Implants 2018;33(5):1112–1118. DOI: 10.11607/jomi.6575.
28. Zhou Z, Chen W, Shen M, et al. Cone beam computed tomographic analyses of alveolar bone anatomy at the maxillary anterior region in Chinese adults. J Biomed Res 2014;28(6):498. DOI: 10.7555/JBR.27.20130002.
29. Noelken R, Geier J, Kunkel M, et al. Influence of soft tissue grafting, orofacial implant position, and angulation on facial hard and soft tissue thickness at immediately inserted and provisionalized implants in the anterior maxilla. Clin Implant Dent Relat Res 2018;20(5):674–682. DOI: 10.1111/cid.12643.
30. Lee S-L, Kim H-J, Son M-K, et al. Anthropometric analysis of maxillary anterior buccal bone of Korean adults using cone-beam CT. J Adv Prosthodont 2010;2(3):92–96. DOI: 10.4047/jap.2010.2.3.92.
31. AlTarawneh S, AlHadidi A, Hamdan AA, et al. Assessment of bone dimensions in the anterior maxilla: a cone beam computed tomography study. J Prosthodont 2018;27(4):321–328. DOI: 10.1111/jopr.12675.
32. Lau SL, Chow J, Li W, et al. Classification of maxillary central incisors-implications for immediate implant in the esthetic zone. J Oral Maxillofac Surg 2011;69(1):142–153. DOI: 10.1016/j.joms.2010.07.074.
33. Huynh-Ba G, Pjetursson BE, Sanz M, et al. Analysis of the socket bone wall dimensions in the upper maxilla in relation to immediate implant placement. Clin Oral Implants Res 2010;21(1):37–42. DOI: 10.1111/j.1600-0501.2009.01870.x.
34. Wittneben JG, Joda T, Weber HP, et al. Screw retained vs cement retained implant-supported fixed dental prosthesis. Periodontology 2000 2017;73(1):141–151. DOI: 10.1111/prd.12168.
35. Wang HM, Shen JW, Yu MF, et al. Analysis of facial bone wall dimensions and sagittal root position in the maxillary esthetic zone: a retrospective study using cone beam computed tomography. Int J Oral Maxillofac Implants 2014;29(5):1123–1129. DOI: 10.11607/jomi.3348.
36. Poletto-Neto V, Tretto PHW, Zen BM, et al. Influence of implant inclination and prosthetic abutment type on the biomechanics of implant-supported fixed partial dentures. J Oral Implantol 2019;45(5):343–350. DOI: 10.1563/aaid-joi-D-18-00305.
37. Juodzbalys G, Sakavicius D, Wang HL. Classification of extraction sockets based upon soft and hard tissue components. J Periodontol 2008;79(3):413–424. DOI: 10.1902/jop.2008.070397.
38. Lopez-Jarana P, Diaz-Castro CM, Falcao A, et al. Thickness of the buccal bone wall and root angulation in the maxilla and mandible: an approach to cone beam computed tomography. BMC Oral Health 2018;18(1):194. DOI: 10.1186/s12903-018-0652-x.
39. Sanz M, Cecchinato D, Ferrus J, et al. A prospective, randomized-controlled clinical trial to evaluate bone preservation using implants with different geometry placed into extraction sockets in the maxilla. Clin Oral Implants Res 2010;21(1):13–21. DOI: 10.1111/j.1600-0501.2009.01824.x.
40. Lascala CA, Panella J, Marques MM. Analysis of the accuracy of linear measurements obtained by cone beam computed tomography (CBCT-NewTom). Dentomaxillo Facial Radiol 2004;33(5):291–294. DOI: 10.1259/dmfr/25500850.
41. Moreira CR, Sales MA, Lopes PM, et al. Assessment of linear and angular measurements on three-dimensional cone-beam computed tomographic images. Oral Surg Oral Med Oral Pathol Oral Radiol Endodont 2009;108(3):430–436. DOI: 10.1016/j.tripleo.2009.01.032.
42. Yusof NAM, Noor E, Yusof MYPM. The accuracy of linear measurements in cone beam computed tomography for assessing intrabony and furcation defects: a systematic review and meta-analysis. J Oral Res 2020;8(6):527–539. DOI: 10.17126/joralres.2019.077.
43. Yusof NAM, Noor E, Reduwan NH, et al. Diagnostic accuracy of periapical radiograph, cone beam computed tomography, and intrasurgical linear measurement techniques for assessing furcation defects: a longitudinal randomised controlled trial. Clin Oral Investig 2021;25(3):923–932. DOI: 10.1007/s00784-020-03380-8.