A 3D Study of the Influence of Sagittal Facial Growth Pattern on Dimensional Properties of Bone in Anterior Maxilla

การศึกษาสามมิติของอิทธิพลของโครงสร้างใบหน้าในแนวหน้าหลังต่อมิติของกระดูกขากรรไกรบน ส่วนหน้า

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ABSTRACT

The aim of this study was to compare the dimensional properties of bone in the anterior region of maxilla in patients with different sagittal facial growth patterns. 61 CBCT images were divided into three groups according to sagittal facial growth pattern, based on Wits appraisal. Cortical bone thickness (CBT), alveolar bone thickness and interdental root distance were measured between the teeth in the anterior maxilla 6 mm and 8 mm apical to CEJ. CBT, alveolar bone thickness, and interdental root distance showed no significant differences in all measured sites between skeletal Class I, II, and III groups. In the anterior maxilla, the thickest and thinnest cortical bone were 1.09 mm and 0.78 mm. The mean interdental root distance ranged from 2.36 mm to 3.85 mm. In conclusion, miniscrew placement in anterior region of maxilla can be chosen without sagittal skeletal consideration. The optimal sites for miniscrew placement in the anterior maxilla regarding cortical and alveolar bone thickness and interdental root distance were between central and lateral incisors and between lateral incisor and canine.

บทคัดย่อ

งานวิจัยนี้มีวัตถุประสงค์เพื่อเปรียบเทียบมิติของกระดูกขากรรไกรบนส่วนหน้าในคนไข้ที่มีโครงสร้างใบหน้าในแนวหน้าหลังที่แตกต่างกัน ภาพรังสีส่วนตัดอาศัยคอมพิวเตอร์จำนวน 61 ภาพถูกนำมาแบ่งกลุ่มตามโครงสร้างใบหน้าในแนวหน้าหลังตามค่าวิทส์ และทำการวัดความหนาของกระดูกทึบ ความหนาของกระดูกเบ้าฟันและระยะห่างระหว่างรากฟันบริเวณกระดูกขากรรไกรบนส่วนหน้าที่ระดับห่างจากรอยต่อเคลือบฟันกับเคลือบรากฟัน 6, 8 มิลลิเมตร พบว่า ไม่มีความแตกต่างกันอย่างมีนัยสำคัญของความหนาของกระดูกทึบ ความหนาของกระดูกเบ้าฟันและระยะห่างระหว่างรากฟันในทุกตำแหน่งระหว่างคนไข้ที่มีโครงสร้างใบหน้าแบบที่1, 2 และ 3 บริเวณกระดูกขากรรไกรบนส่วนหน้ามีความหนาของกระดูกทึบมากที่สุดคือ 1.09 มิลลิเมตร และ น้อยที่สุดคือ 0.78 มิลลิเมตร ระยะห่างระหว่างรากฟันมีขนาดตั้งแต่ 2.36 - 3.85 มิลลิเมตร โดยสรุป การปักมินิสกรูบริเวณขากรรไกรบนส่วนหน้าสามารถเลือกตำแหน่งปักได้โดยไม่ต้องคำนึงถึงโครงสร้างใบหน้าในแนวหน้าหลัง และตำแหน่งที่เหมาะสมในการปักมินิสกรูบริเวณนี้เมื่อพิจารณาความหนาของกระดูกทึบ ความหนาของกระดูกเบ้าฟันและระยะห่างระหว่างรากฟันคือบริเวณระหว่างฟันตัดซี่กลางและฟันตัดซี่ข้าง และระหว่างฟันตัดซี่ข้างและฟันเขี้ยว

Keywords: cortical bone thickness, CBCT, sagittal facial growth pattern

คำสำคัญ: ความหนาของกระดูกทึบ ภาพรังสีส่วนตัดอาศัยคอมพิวเตอร์ โครงสร้างใบหน้าในแนวหน้าหลัง

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Introduction

Determining the appropriate anchorage is important in orthodontic treatment planning. Miniscrews have become commonly used as absolute anchorage for treating complex malocclusion due to their advantages, including ease of use, low cost, compliance-free anchorage, and not affecting the teeth. Most orthodontists use miniscrews in a variety of treatments, such as correcting tooth protrusion, intruding posterior teeth to correct an anterior openbite, or whole arch distalization or mesialization to correct an anteroposterior discrepancy (Carano et al., 2005).

The main factor that clinicians should consider when placing miniscrews is stability. Cortical bone thickness (CBT) was found to have a strong effect on the primary stability of miniscrews (Wilmes et al., 2006). From previous study, the success rate of miniscrews was significantly correlated with CBT and the thickness should exceed 1 mm to obtain acceptable primary stability (Motoyoshi et al., 2007). Moreover, avoiding root damage during miniscrew placement is crucial. To maintain a healthy periodontium and avoid damaging neighboring roots, the space between miniscrew and dental root should be at least 1 mm. Therefore, the interdental root distance should greater than 3.1mm for 1.2-1.3 mm diameter miniscrews, and at least 3.5 mm for 1.5-mm diameter miniscrews (Poggio et al., 2006).

Previous studies reported CBT mostly in posterior areas of maxilla and mandible (Germec-Cakan et al., 2014; Khumsarn et al., 2016; Ozdemir et al., 2013). However, little research has examined in anterior area of maxilla even though miniscrews in this site can facilitate many treatments such as correcting a gummy smile (Uzuka et al., 2018), deepbite (Kim et al., 2006; Upadhyay et al., 2008) or occlusal plane canting (Carano et al., 2005). Consequently, investigating the bone morphology in the anterior maxilla may provide reference data for orthodontists before placing miniscrews in this area.

Orthodontists routinely treat patients with vertical and sagittal skeletal discrepancies. Many studies examined the influence of vertical facial growth pattern on CBT and found that high-angle patients had thinner cortical bone compared with low- or normal-angle patients (Horner et al., 2012; Ozdemir et al., 2013; Sadek et al., 2016). Patients with different anteroposterior jaw relationships also have different muscle activity and masticatory activity (Cha et al., 2007; Trawitzki et al., 2011). Because bone adapts to an applied force (Sommerfeldt, Rubin, 2001), different muscle activity may affect CBT. Furthermore, dentoalveolar compensation can be observed in patients with different sagittal jaw relationships (Ishikawa et al., 1999). Therefore, these factors may influence CBT. However, currently, there is no report on the influence of different sagittal facial growth patterns on CBT in the anterior maxilla.

Objectives of the study

This study examined the CBT of the anterior maxilla in patients with different sagittal facial skeletal patterns and compared the CBT, alveolar bone thickness, and interdental root distance in different areas of the anterior maxilla to identify favorable sites for miniscrew placement.

Methodology

Sample selection

This study protocol was approved by the Human Research Ethics Committee of Faculty of Dentistry, Chulalongkorn University. The sample comprised 61 cone beam computed tomography (CBCT) images that were obtained from the Department of Radiology, Faculty of Dentistry, Chulalongkorn University between January 2011 and February 2018. The subject aged 18 to 37 years. Sample selection was based on following criteria : (1) Patient age $\geq$ 18 years, (2) Normal vertical skeletal pattern (Palatal plane to mandibular plane angle 25.24±3.78 (Petdachai, 2017)), (3) No previous orthodontic treatment, (4) Maxillary anterior crowding/spacing less than 3 mm and no maxillary anterior teeth loss, (5) No moderate and severe periodontitis, (6) No large metal restorations that could produce scatter and interfere with 3D radiographic evaluation.

Measurement

All CBCT images were analyzed with Infinitt® PACs software (Infinitt Healthcare Co., Ltd., Seoul, Korea). The CBCT images did not cover the Nasion and Sella points due to ALARA (As Low As Reasonably Achievable) protocol used in our department. Consequently, each subject was vertically classified by palatal plane to mandibular plane angle (PP-MP) and the respective 61 CBCT images were divided into 3 groups according to sagittal skeletal pattern. Wits appraisal was used to identify sagittal skeletal pattern: Skeletal Class I (-4.1 mm$\leq$ Wits $\leq$0.7 mm), Skeletal Class II (Wits > 0.7mm), Skeletal Class III (Wits < -4.1mm). There were 22 subjects in skeletal Class I and Class III groups and 18 subjects in skeletal Class II group.

Each CBCT image was reconstructed and oriented. In the axial view, the image was rotated until the sagittal plane passes through anterior nasal spine (ANS) and posterior nasal spine (PNS) (figure 1). In the sagittal view, the image was adjusted until the axial plane was parallel to palatal plane (ANS-PNS) (figure2). In the coronal view, the image was adjusted to make the axial plane parallel to the coronal occlusal line which passes through mesiobuccal cusps of two contralateral maxillary molars (figure 3).

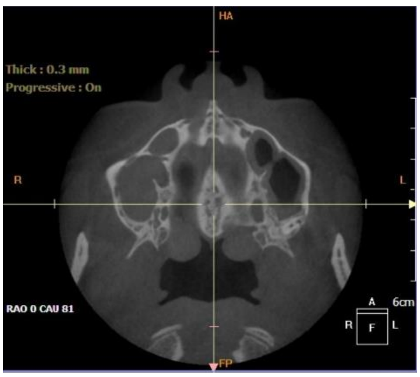

Figure 1 Orientation of CBCT image in axial view

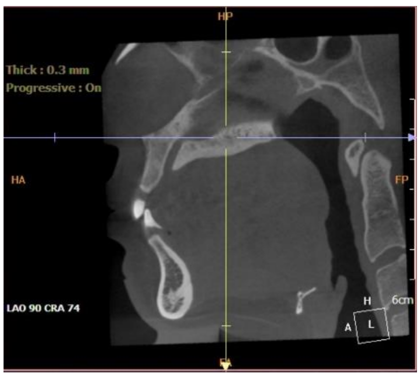

Figure 2 Orientation of CBCT image in sagittal view

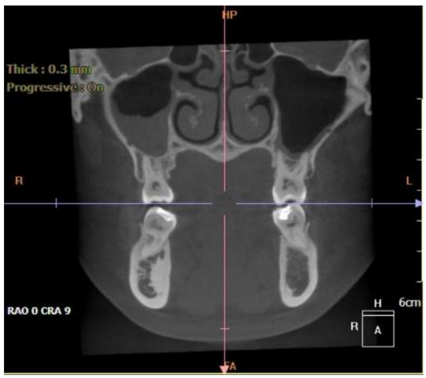

Figure 3 Orientation of CBCT image in coronal view

For each subject, three interdental root regions were evaluated: between the maxillary central incisors (U1-U1), between the maxillary central incisor and the lateral incisor (U1-U2) and between the lateral incisor and canine (U2-U3). For the U1-U2 and U2-U3 regions, the measurement was made only one side which has the best alignment. CBT on labial side, Alveolar bone thickness (labio-palatal thickness of alveolar bone) and interdental root distance was measured 6 mm and 8 mm apical to the cementoenamel junction (CEJ) plane; defined as a plane through the midpoint of the CEJ of the 2 adjacent teeth and parallel to the palatal plane. The CEJ plane was used as the reference point for making measurements because it can be readily identified clinically and radiographically. Furthermore, it is not affected by periodontal problems. Measurement was stopped at 8 mm because of the clinical limitation on the buccal aspect of inserting temporary anchorage devices (TADs) in the attached gingiva for improved success (Tenenbaum, Tenenbaum, 1986).

The interdental area of interest was located on the axial slice. In the axial view, the image was oriented so that the interdental space was bisected by the sagittal plane. In coronal view was also used to ensure that the vertical line bisected the interdental area. After locating interdental area, the sagittal slide thickness was increased to covering two teeth area in axial view to set CEJ plane. Then, the axial plane was moved corono-apically to establish the measurement level in relation to CEJ plane (6 and 8 mm apical to CEJ plane). CBT on the labial side and alveolar bone thickness were measured parallel to the axial plane. The interdental root distance which defined as the narrowest distance between neighboring roots was measured in axial view (figure 4).

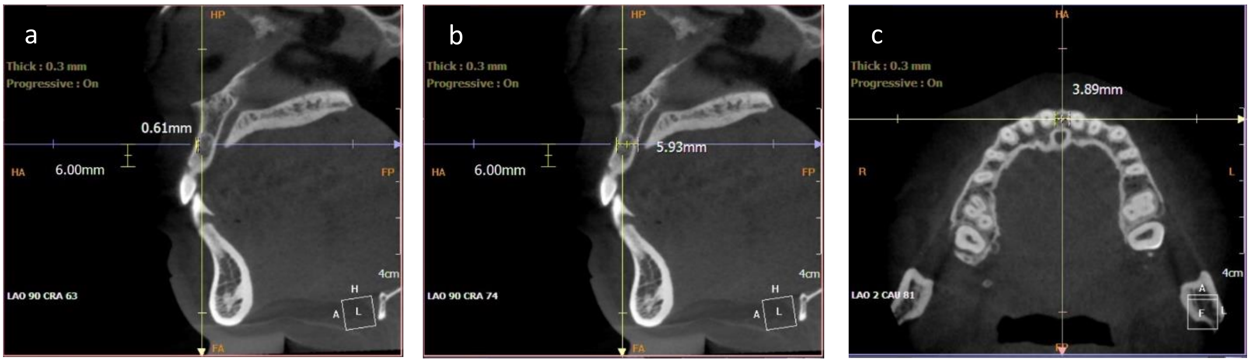

Figure 4 Measurement of cortical bone thickness(a), alveolar bone thickness(b), interdental root distance(c)

Statistical analysis

Measurement and analysis of the data were carried out by a single researcher. Twelve samples were randomly selected and re-measured 2 weeks later by the same investigator to assess intra-observer reliability using intraclass correlation coefficient (ICC). The ICC values for all measurements ranged between 0.744 - 0.981 indicating good intra-examiner reliability. Quantitative analysis was used to obtain means and standard deviations of all measurements. The normal distributions of the variables were verified by the Kolmogorov-Smirnov test. The data showed a non-normal distribution. Kruskal-Wallis test was used to analyze the differences between the three sagittal facial growth pattern group measurements. Differences within the anterior region of maxilla were determined using Friedman's test and Wilcoxon Signed Rank Test. The level of significance was determined at $P<0.05$. All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS 22.0; SPSS Inc., Chicago, IL, USA).

Results

The summary data is shown in Table 1. There were no statistically significant differences between the skeletal Class I, II and III groups regarding sex and vertical facial growth pattern. However, the sagittal facial growth pattern and mean age were significantly different between the three groups.

Table 1 Summary data

	Total (n=61)	Skeletal Class I	Skeletal Class II	Skeletal Class III	p-value
Sex					
Male	20 (32.8%)	6 (27.3%)	8 (47.1%)	6 (27.3%)	0.336
female	41 (67.2%)	16 (72.7%)	9 (52.9%)	16 (72.7%)	
Age (year)	25.54 ± 5.76	25.77 ± 5.06	29.82 ± 6.1	22 ± 3.57	<0.001*
Wits (mm)	-2.38 ± 4.02	-1.5 ± 1.48	2.02 ± 0.98	-6.67 ± 2.75	<0.001*
PP-MP (°)	25.6 ± 1.81	25.33 ± 1.91	25.56 ± 1.67	25.91 ± 1.86	0.579

Values presented as means± SD. or n (%). *p-value<0.05

When comparing between skeletal Class I, II and III groups, CBT (Table 2), alveolar bone thickness (Table 3), and interdental root distance (Table 4) showed no significant differences in all measured sites. Therefore, the data of skeletal Class I, II and III groups were combined to analyze each variable in anterior maxilla area.

Table 2 Comparison of cortical bone thickness for three sagittal facial growth patterns

		Skeletal Class I	Skeletal Class II	Skeletal Class III	p-value
6 mm	U1-U1	0.76±0.11	0.84±0.22	0.76±0.12	0.55
	U1-U2	1.01±0.17	1.07±0.27	0.97±0.19	0.63
	U2-U3	1.07±0.16	1.07±0.26	1.02±0.18	0.65
8 mm	U1-U1	0.83±0.16	0.89±0.21	0.80±0.12	0.39
	U1-U2	1.10±0.22	1.05±0.23	1.04±0.20	0.53
	U2-U3	1.08±0.14	1.09±0.25	1.10±0.21	0.89

Table 3 Comparison of alveolar bone thickness for three sagittal facial growth patterns

		Skeletal Class I	Skeletal Class II	Skeletal class III	p-value
6 mm	U1-U1	7.46 ± 1.35	7.29 ± 2.10	7.35 ± 1.70	0.90
	U1-U2	9.13 ± 2.11	8.57 ± 2.21	8.44 ± 2.17	0.79
	U2-U3	8.45 ± 1.68	8.21 ± 1.69	7.71 ± 1.78	0.44
8 mm	U1-U1	7.44 ± 1.30	7.24 ± 2.05	7.34 ± 1.81	0.91
	U1-U2	9.72 ± 2.16	9.06 ± 2.13	8.98 ± 2.04	0.75
	U2-U3	8.09 ± 1.61	7.94 ± 1.98	7.71 ± 1.86	0.80

Table 4 Comparison of interdental root distance for three sagittal facial growth patterns

		Skeletal Class I	Skeletal Class II	Skeletal Class III	p-value
6 mm	U1-U1	3.04 ± 0.91	3.07 ± 1.02	2.82 ± 0.67	0.52
	U1-U2	2.55 ± 0.64	2.32 ± 0.68	2.21 ± 0.69	0.38
	U2-U3	2.87 ± 0.73	2.33 ± 0.82	2.90 ± 1.01	0.07
8 mm	U1-U1	3.92 ± 1.10	3.98 ± 1.40	3.67 ± 0.85	0.79
	U1-U2	3.09 ± 0.83	2.90 ± 0.79	2.77 ± 0.63	0.43
	U2-U3	3.23 ± 0.58	2.84 ± 0.93	3.29 ± 1.10	0.32

Based on the combined data (Table 5), we found that in anterior maxilla, the CBT at U1-U2, U2-U3 was significantly higher than at U1-U1 6 and 8 mm from the CEJ. For all measured area, the CBT tended to become thicker from 6 to 8 mm apical to CEJ. Statistically significant differences in CBT between these levels were detected at only U1-U1 and U1-U2 areas. The thickest and thinnest cortical bone in anterior maxilla were 1.09 mm at 8 mm level U2-U3 and 0.78 mm at 6 mm level U1-U1, respectively.

With respect to alveolar bone thickness, alveolar bone thickness was greatest at the U1-U2 region and least at the U1-U1 region. Comparing the 6 mm and 8 mm vertical level, the 8 mm level alveolar bone thickness was significantly thicker than at the 6 mm level only at U1-U2 region.

The mean interdental root distance in the anterior region of maxilla ranged from 2.36 ± 0.67 mm to 3.85 ± 1.10 mm. The largest and smallest interdental root distance were at the U1-U1 area and the U1-U2 area, respectively. Statistically significant differences in interdental root distance between 6 and 8 mm apically to CEJ were found in all measured sites.

Table 5 Mean±SD of cortical bone thickness, alveolar bone thickness and interdental root distance in anterior maxilla

Variable	Site	Level		
		6mm	8mm	p-value
Cortical bone thickness	U1-U1	0.78±0.15^{a}	0.84±0.16^{c}	0.002*
	U1-U2	1.01±0.21^{b}	1.06±0.21^{d}	0.04*
	U2-U3	1.05±0.20^{b}	1.09±0.20^{d}	0.06
	p-value	<0.001*	<0.001*	
Alveolar bone thickness	U1-U1	7.37±1.68^{e}	7.35±1.69^{h}	0.75
	U1-U2	8.73±2.15^{f}	9.27±2.10^{i}	<0.001*
	U2-U3	8.11±1.72^{g}	7.91±1.79^{h}	0.09
	p-value	<0.001*	<0.001*	
Interdental root distance	U1-U1	2.97±0.86^{j}	3.85±1.10^{l}	<0.001*
	U1-U2	2.36±0.67^{k}	2.93±0.75^{m}	<0.001*
	U2-U3	2.73±0.89^{jk}	3.14±0.9^{m}	<0.001*
	p-value	0.003*	<0.001*	

*p<0.05

For each column, values with the same superscript letter are not significant different

^{a,b} Cortical bone thickness 6mm ^{c,d} Cortical bone thickness 8mm ^{e,f,g} Alveolar bone thickness 6mm ^{h,i} Alveolar bone thickness 8mm

^{j,k} Interdental root distance 6mm ^{l,m} Interdental root distance 8mm

Discussion

Miniscrews are rapidly gaining popularity as an anchorage due to its advantages: cost effectiveness, ease of use, no patient compliance and no undesirable side effect on teeth. To achieve the result of treatment as planned, miniscrews should be maintained in the mouth all the period of treatment time. The important factor that directly influenced to the success rate of miniscrew was CBT. A placement site with a CBT greater than 1 mm had a higher success rate compared to a position where the cortical bone was thinner (Motoyoshi et al., 2009).

Numerous studies have investigated CBT in patients with different facial types (Horner et al., 2012; Ozdemir et al., 2013; Veli et al., 2014). Previous studies have shown that vertical facial type significantly affected CBT (Horner et al., 2012; Ozdemir et al., 2013). Moreover, another study determined that patients with a high mandibular plane angle often had thin cortical bone and miniscrew failure (Miyawaki et al., 2003). However, in addition to vertical facial discrepancies, orthodontic patients also present with sagittal facial discrepancies. Patients with different anteroposterior jaw relationships have different muscle activity and masticatory activity (Cha et al., 2007; Trawitzki et al., 2011). Because bone morphology adapts to an applied force (Sato et al., 2005; Sommerfeldt, Rubin, 2001), we hypothesized that the different muscle activity in patients with different sagittal facial types might result in differences in CBT in the anterior maxilla.

The present study showed no significant difference in CBT in the anterior maxilla between sagittal facial types. This finding is inconsistent with those of Al-Jaf et al. (2018) who examined the influence of sagittal facial type on posterior area of maxilla and mandible and found that CBT was significantly different between skeletal Class I,II and III groups. A possible explanation is that, although there are many studies reporting the differences in muscle activity between sagittal facial types, these differences in the anterior maxilla may not be sufficient to result in differential bone remodeling subsequent to the initial development of the morphology of the maxilla compared with those in the posterior maxilla. In addition, the occlusal contact of the anterior teeth is less than that of the posterior teeth (Hattori et al., 2009), thus, the occlusal load during anterior tooth function is insufficient to affect CBT. In contrast, Germec-Cakan et al. (2014) reported no influence of sagittal facial types on CBT in posterior teeth of maxilla and mandible. Their disparate finding may be because they included patients with normo-divergent facial pattern, and also hypo- and hyper- divergent facial patterns that previous studies found an impact of vertical facial types on CBT (Horner et al., 2012; Ozdemir et al., 2013; Sadek et al., 2016). Another possible explanation for our finding is that the compensatory mechanism of incisors related to sagittal facial growth pattern may not affected on cortical bone thickness. Therefore, to confirm this effect, future study should investigate cortical bone thickness in patient with different incisor inclinations.

In this study, the age of the patients in each sagittal skeletal group was significantly different, however, they were all adult patients, and thus developmentally mature. Therefore, the difference in age between groups did not have an impact on our result.

In anterior maxilla, CBT tended to increase from U1-U1 to U2-U3 regions and was significantly thicker in the U1-U2, U2-U3 regions than U1-U1 region. This finding was also reported by Baumgaertel and Hans (2009) who measured CBT at 2 mm to 6 mm from the alveolar crest in the maxilla and mandible. They found that CBT increased from anterior to posterior areas. Choi et al. (2014) also found similar results. CBT was an important factor that directly influenced to the success rate of miniscrews (Wilmes et al., 2006). Min et al. (2012) found the success rate of miniscrews increased as CBT increased. Motoyoshi et al. (2009) concluded that a clinical CBT threshold of 1 mm improved the miniscrew success rate. In the present study, the mean CBT at the anterior part of the maxilla ranged from 0.78±0.15 mm to 1.09±0.2 mm, and the CBT in the U1-U1 area was less than 1 mm. Therefore, miniscrew placement in U1-U1 region should be performed with caution. However, this finding might not significantly affect the clinical success of miniscrews, because CBT can be compensated by variations of miniscrew angulation or miniscrew design (Park et al., 2006). Additionally, miniscrews are most commonly used in the anterior maxilla for anterior teeth intrusion that uses light force, which might not cause miniscrew loosening (Van Steenbergen et al., 2005).

The alveolar bone thickness was greatest in the U1-U2 region and least in the U1-U1 region. This finding was also reported by Choi et al. (2014). This U1-U1 area related to the incisive foramen so when placing miniscrews in this area, it should be placed in an oblique direction in order to access the wider space and avoid the incisive foramen or placed higher than 8 mm from CEJ. However, in this position, miniscrews might irritate the mucosal tissue or become loose. Lai and Chen (2014) claimed that placing a miniscrew in keratinized mucosa resulted in a higher success rate than in oral mucosa. Consequently, they recommended that miniscrew head should be surgically covered with mucosa when placed in oral mucosa. To improve their clinical success rate, it has been suggested that the length of miniscrew should be more than 8 mm (Miyawaki et al., 2003; Park et al., 2006). Therefore, the area where miniscrews can be placed was at U1-U2 6 and 8 mm from CEJ and U2-U3 6 mm from CEJ.

Miniscrew placement between the root of the teeth is a crucial procedure. Miniscrews should be placed into the alveolar bone without causing any damage to the adjacent roots. The interdental root distance from this study ranged from 2.36±0.67 mm to 3.85±1.10 mm. This finding seems to coincide with the study of Choi et al. (2014) who reported interdental root distance ranging from 2.28±0.60 mm to 3.88±0.84 mm. When considering interdental root distance, Schnelle et al. (2004) recommended at least 3mm for safe placement of miniscrew. We found that only the U1-U1 and U2-U3 regions 8 mm from CEJ demonstrated an interdental root distance greater than 3 mm. Thus, these locations should be safe for miniscrew placement. Moreover, it has been shown that miniscrew stability was maintained when the miniscrew did not invade the periodontal ligament (Janson et al., 2013). The diameter of commonly used miniscrew is 1.2 mm - 1.6 mm and the periodontal space is 0.25 mm (Amstad-Jossi et al., 2012). In this study, interdental root distance was measured from dental root surface, therefore, when the two sides of periodontal space (0.5 mm) was removed from this distance, the net space for miniscrew placement ranged from 1.86 mm to 3.35 mm. These results indicate that maxillary anterior miniscrews can be safely placed in these locations because there is sufficient space to accommodate a 1.2–1.6 mm diameter miniscrews.

Based on the criteria of CBT more than 1 mm, interdental root distance greater than 2.1 mm, and alveolar bone thickness sufficient to accommodate the length of miniscrews (8 mm); the results of the present study indicated that the optimal sites for placing miniscrews in the anterior maxilla were between the central and lateral incisors and between the lateral incisor and canine at a 6 mm level from CEJ; between central and lateral incisors at 8 mm level from CEJ.

A limitation of this study was its small sample size and that the Wits appraisal used in this study to classify sagittal facial types of patients can be affected by occlusal plane cant (Iwasaki et al., 2002), thus, the sample may not have the actual difference in anteroposterior skeletal profile. Further research should include a larger sample size and use larger fields of view CBCT, so the sagittal skeletal pattern classification can be combined with ANB angle measurements.

Conclusion

Cortical bone thickness in anterior maxilla showed no significant difference between sagittal facial types. Miniscrew placement sites in anterior area of maxilla can be determined without considering the sagittal facial types of patients. The optimal sites for miniscrew placement in anterior maxilla regarding cortical and alveolar bone thickness and interdental root distance were between the central and lateral incisors and between the lateral incisor and canine.

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