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ORIGINAL ARTICLE

Palatal bone thickness and associated factors in adult miniscrew placements: A cone-beam computed tomography study

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Abstract Palatal bone thickness measurements obtained by cone-beam computed tomography (CBCT) in 30 men and 28 women were evaluated for associated factors. Palatal bone thickness was measured at 20 locations unilateral to the midpalatal suture and posterior to the incisive foramen. Tongue position, presence of posterior crossbite, and palatal morphology were recorded. Lateral cephalograms acquired from CBCT data were used to calculate Frankfort-mandibular plane angles (FMA). At almost all sites, bone thickness was greater in males than in females, but the difference was statistically significant at only seven sites. Bone thickness showed no associations with tongue position, palatal morphology, or presence of posterior crossbite. In women, FMA significantly correlated with bone thickness at 12 locations. In conclusion, palatal bone thickness is unassociated with tongue position, posterior crossbite, or palatal morphology. In hyperdivergent women, however, available bone may be smaller than normal in the middle and posterior palatal areas; in such cases, a shorter than normal miniscrew may be needed to avoid penetrating the nasal cavity.

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Introduction

The orthodontic miniscrew is now the most frequently used temporary anchorage device because of its many advantages, including its simple surgical placement and removal and its low cost. However, if primary stability is not achieved upon insertion, the miniscrew may loosen during orthodontic treatment [1].

The anterior midpalatal and paramedian palate regions are potential sites of miniscrew placement [2,3] because these areas are devoid of major blood vessels and nerves. Therefore, these regions are relatively safe for orthodontic treatments requiring miniscrew placement [3]. However, caution is needed to avoid nearby anatomical structures such as the nasal cavity above the palate and the incisive canal in the anterior palate. Selecting an excessively long miniscrew raises the risk of perforating the nasal cavity and related complications [4,5]. If the selected miniscrew is too short, however, the insertion depth into the bony structure may be insufficient to ensure good primary stability. Therefore, clinicians require sufficient topographical knowledge of the midpalate and paramedian palate regions to perform this procedure efficiently.

Recently developed cone-beam computed tomography (CBCT) technology now provides highly accurate and detailed information for a broad spectrum of clinical and research applications [6,7]. Since the stability of orthodontic miniscrews depends mainly on mechanical retention [8], researchers have studied methods of accurately assessing bone thickness [9–11], volume, and quality [12] to provide guidelines for selecting appropriate miniscrew insertion sites.

Craniofacial and dentoalveolar development is dependent on interacting genetic and environmental factors over time [13]. For example, one environmental factor that can affect morphological development of craniofacial features is respiration mode [14]. Many studies suggest that respiratory function affects maxillofacial growth and that mouth breathing is associated with a vertical facial profile [15]. Morphologic traits associated with respiratory obstruction and mouth breathing include an excessive anterior facial height, a steep mandibular plane angle, a low tongue posture, a narrow palatal vault, and a posterior crossbite [13].

Although the midpalatal and paramedian palate regions tend to have relatively good bone quality [6], miniscrew failures may still occur in these areas [5]. Because bone thickness is a key factor in achieving primary stability [3], identifying the factors associated with palatal bone thickness can help clinicians identify cases of inadequate bone thickness so that orthodontic anchorage plans can be modified accordingly.

This study identified factors associated with palatal bone thickness measured using CBCT. By using these data to identify appropriate implantation sites with optimal bone thickness, clinicians can ensure primary stability in miniscrew implants.

Materials and methods

This study analyzed CBCT scans from 58 patients (30 men: mean age, 25.79 years; range, 23.9–27.7 years and 28 women: mean age, 27.66 years; range, 25.0–30.3 years) treated at the Department of Orthodontics, Kaohsiung Medical University Hospital (KMUH), Kaohsiung, Taiwan. Exclusion criteria were an impacted tooth in the region of interest (ROI) in the anterior midpalatal and paramedian palate, two or more missing posterior teeth, and history of maxillofacial trauma. The study protocol was approved by the University Hospital Ethnical Committee (KMUH-IRB-20140111).

The settings for the i-CAT cone-beam three-dimensional (3D) imaging system (Imaging Sciences International, Hatfield, PA, USA) used for the CBCT scans were 120 kVp; 47 mA; exposure time, 40 seconds; resolution, 0.25 mm voxel size; and field of view, 20 cm × 25 cm. All scans were performed with the head of the patient in a natural position and with the patient biting in centric occlusion. Data were stored in Digital Imaging and Communications in Medicine (DICOM) 3D format, and a medical image analyzing system (iCAT vision software, version 1.6.2.0; Imaging Sciences International, Hatfield, PA, USA) was used for image reconstruction. Measurements were made on sagittal reconstructions.

All reconstructed images were oriented in the standardized position before performing the measurements. After locating the incisive foramen and posterior nasal spine (PNS) in horizontal view, a reference line was constructed across the midpalatal suture (Fig. 1A). In sagittal view, a midsagittal reference line was then projected through the distal margin of the incisive foramen and PNS (Fig. 1B); all subsequent measurements were made perpendicular to this reference line.

Measurements taken 0 mm, 2 mm, 4 mm, and 6 mm lateral to the midpalatal suture were designated D0, D2, D4, and D6, respectively. Measurements taken 6 mm,

Figure 1. (A) Horizontal view: incisive foramen can be clearly identified. (B) Sagittal view and midsagittal reference line passing through incisive foramen and posterior nasal spine (PNS).

10 mm, 14 mm, 18 mm, and 22 mm posterior to the incisive foramen were designated P6, P10, P14, P18, and P22, respectively. The 20 total measurement locations were thus designated P6D0-6, P10D0-6, P14D0-6, P18D0-6, and P22D0-6. Since the right and left sides of the palate did not significantly differ, only the left side of the palate was measured in the 20 locations (Fig. 2). In cases of an impaction or an erupting tooth follicle preventing measurements on the left side, the measurements were made at the corresponding location on the right side.

Palatal vault dimension was determined by recording palatal width and palatal depth at the cemento-enamel junction level at the upper first molar. The tongue position was also recorded. A dorsal surface of the tongue in contact with the palate or filling the palatal vault was considered normal. A low tongue position was defined as a tongue that did not fill the palatal vault or a tongue that left space below the palate. Posterior crossbite at the first molar and second molar regions, regardless of unilateral or bilateral crossbite, was also recorded. These parameters were expressed as dichotomous variables.

Lateral cephalometric images were acquired from CBCT data. In each participant, the Frankfort-mandibular plane angle (FMA) was calculated to determine the correlation between FMA and vertical palatal bone thickness.

Statistical analysis was performed using JMP 8.0 statistical discovery software (SAS Institute Inc., Cary, NC, USA). Two-sample *t* tests were used to identify the significance of sex differences in bone thickness, associations between bone thickness and tongue position, and associations between bone thickness and posterior crossbite. The Pearson correlation coefficient was calculated to determine the correlation of palatal bone thickness with palatal vault dimensions and FMA.

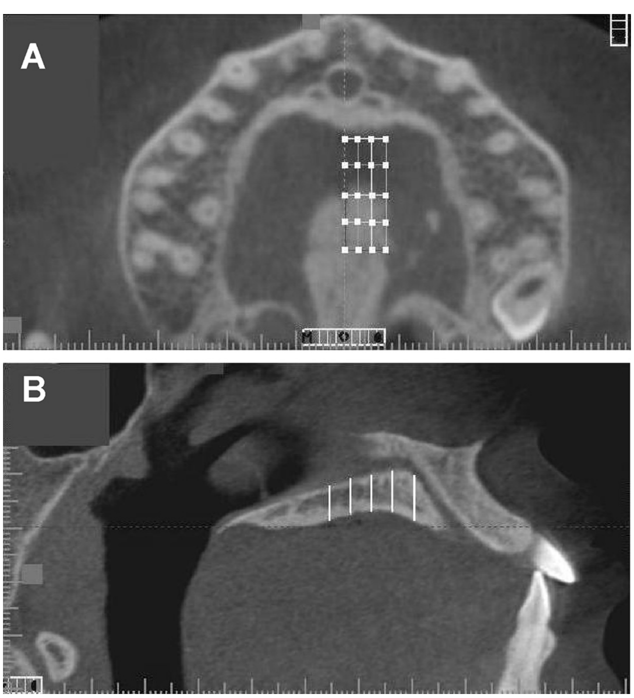

Figure 2. Region of interest (ROI) in the midpalatal and paramedian palatal region. (A) The white dots represent the 20 coordinates where measurements were performed. (B) Illustration of bone thickness measurements.

The reliability of the measurements was confirmed by additional measurements in 15 CBCT scans randomly selected 1 month after the initial measurements. The bone thickness measurements were repeated, and cephalometric tracing and FMA measurements were repeated in 15 randomly selected CBCT scans. Intraclass correlation coefficients (ICCs) showed acceptable intraobserver agreement of repeated measurements. The ICCs for bone thickness measurements and for FMA were 0.95 and 0.97, respectively.

Results

Palatal bone thickness

In almost all sites, palatal bone thickness was greater in males than in females. However, the difference was statistically significant only at P6D0, P6D4, P6D6, P10D0, P10D2, P10D4, and P10D6 ($p < 0.05$; Table 1). Bone thickness along the midpalatal suture anteroposteriorly was sufficient in both males (7.07 mm to 9.04 mm) and females (6.28 mm to 9.03 mm); however, at 2 mm, 4 mm, and 6 mm lateral to the midpalatal suture, bone thickness showed the opposite trend of decreasing thickness from the anterior to posterior area. Bone thickness measurements were smallest at the most posterior and most lateral ROI (P22D6;

Table 1 Comparison of mean palatal bone thickness (mm) at each ROI between male and female groups.

ROI	Male (n = 30)	Female (n = 28)	Mean difference	p
	Mean (SD)	Mean (SD)		
P6D0	7.07 (1.48)	6.28 (1.50)	0.80	0.0465*
P10D0	7.67 (1.81)	6.62 (1.84)	1.05	0.0329*
P14D0	7.73 (1.75)	7.22 (2.20)	0.51	0.3318
P18D0	8.13 (2.02)	7.91 (2.39)	0.22	0.7066
P22D0	9.04 (2.02)	9.03 (2.37)	0.01	0.9841
P6D2	6.77 (1.63)	6.29 (2.16)	0.48	0.3410
P10D2	6.22 (1.83)	5.18 (1.49)	1.04	0.0213*
P14D2	5.60 (1.69)	4.86 (1.70)	0.75	0.0988
P18D2	5.48 (1.67)	5.15 (1.93)	0.33	0.4876
P22D2	5.51 (1.79)	5.58 (2.07)	−0.08	0.8768
P6D4	8.91 (3.04)	7.16 (2.36)	1.75	0.0180*
P10D4	5.95 (2.49)	4.61 (1.66)	1.34	0.0203*
P14D4	4.55 (1.82)	3.92 (1.61)	0.64	0.1648
P18D4	4.04 (1.57)	3.87 (1.87)	0.16	0.7218
P22D4	3.95 (1.71)	3.82 (2.02)	0.13	0.7866
P6D6	8.64 (2.62)	6.75 (2.35)	1.89	0.0055*
P10D6	5.60 (2.38)	4.06 (1.66)	1.54	0.0063*
P14D6	3.60 (1.74)	3.69 (3.88)	−0.09	0.9074
P18D6	3.06 (1.50)	2.74 (1.29)	0.31	0.4007
P22D6	2.88 (1.59)	2.47 (1.27)	0.41	0.2906

P#D#: P# denotes anteroposterior distances at 6 mm, 10 mm, 14 mm, 18 mm, and 22 mm posterior to the distal margin of the incisive foramen; D# denotes mediolateral distances at 0 mm, 2 mm, 4 mm, and 6 mm lateral to the midpalatal suture.
*Statistically significant at $p < 0.05$.
ROI = region of interest; SD = standard deviation.

2.88 mm in men and 2.47 mm in women). Tongue position and presence of posterior crossbite showed no significant associations with palatal bone thickness in the two-sample *t* test (data not shown).

Correlation

Except at P22D2, the Pearson correlation coefficient test revealed no significant association between bone thickness and palatal width ($r = 0.37$ and $p = 0.0455$) (Table 2). Palatal depth showed only a moderate association with palatal bone thickness at the posterior region of the midpalatal suture in males: P14D0 ($r = -0.38$ and $p = 0.0426$), P18D0 ($r = -0.56$ and $p = 0.0017$), and P22D0 ($r = -0.48$ and $p = 0.0083$) (Table 3). In the female group, bone thickness was inversely correlated with FMA at the posterior palatal region (P10D0, P14D0, P14D2, P14D4, P18D0, P18D2, P18D4, P18D6, P22D0, P22D2, P22D4, and P22D6) (Table 4). Conversely, no measurement locations in the male group showed correlations between bone thickness and FMA angle.

Discussion

Advances in CBCT technology now enable the acquisition of considerable valuable data in a single scan. In orthodontics, radiographs used for diagnosis and treatment planning (e.g., lateral cephalograph, posteroanterior cephalograph, and panoramic radiograph) can be acquired from CBCT image data. Kumar et al [16] compared CBCT-synthesized lateral cephalograms with conventional lateral cephalograms to identify differences in cephalometric measurements between these imaging modalities. Their results showed that the precision and accuracy of a CBCT-synthesized lateral cephalogram is comparable to that of a conventional lateral cephalogram.

The palatal bone is among the best orthodontic miniscrew placement sites because of its easy access for miniscrew insertion and its high-quality bone structure [2,3]. An important clinical decision when performing this procedure is selecting an appropriate miniscrew length to avoid penetrating the nasal cavity while simultaneously ensuring sufficient bone penetration to establish adequate stability. Kang et al [10] studied computed tomography (CT) records to determine the bone thickness in the palates of adult patients who had received orthodontic mini-implants. Average measurements were significantly larger in males than in females. The current study similarly showed larger palatal bone thickness measurements in the male group. However, the sex difference reached statistical significance in only seven sites.

In children and adolescents, miniscrew placement at the midpalatal suture is generally avoided because incomplete

Table 2 Correlation between palatal width and palatal bone thickness by sex.

ROI	Male ($n = 30$)		Female ($n = 28$)	
	Correlation coefficient (*r*)	*p*	Correlation coefficient (*r*)	*p*
P6D0	0.06	0.7717	0.05	0.7886
P10D0	0.12	0.5327	0.09	0.6453
P14D0	0.13	0.5005	0.07	0.7190
P18D0	0.16	0.3978	0.20	0.3289
P22D0	0.19	0.3309	0.14	0.4974
P6D2	0.15	0.4512	−0.36	0.0664
P10D2	0.11	0.5678	−0.26	0.1886
P14D2	0.24	0.2053	0.07	0.7434
P18D2	0.29	0.1291	0.03	0.8826
P22D2	0.37	0.0455*	0.05	0.8088
P6D4	−0.14	0.4583	−0.16	0.4129
P10D4	0.01	0.9521	−0.11	0.5936
P14D4	0.13	0.5008	0.13	0.5272
P18D4	0.25	0.1996	0.14	0.4704
P22D4	0.31	0.1042	0.16	0.4329
P6D6	−0.14	0.4657	−0.02	0.9060
P10D6	−0.13	0.5040	−0.08	0.7079
P14D6	0.06	0.7532	0.05	0.8130
P18D6	0.07	0.7198	0.00	0.9847
P22D6	0.11	0.5539	0.04	0.8277

P#D#: P# denotes anteroposterior distances at 6 mm, 10 mm, 14 mm, 18 mm, and 22 mm posterior to the distal margin of the incisive foramen; D# denotes mediolateral distances at 0 mm, 2 mm, 4 mm, and 6 mm lateral to the midpalatal suture.
*Statistically significant at $p < 0.05$.
ROI = region of interest.

Table 3 Correlation between palatal height and palatal bone thickness by sex.

ROI	Male ($n = 30$)		Female ($n = 28$)	
	Correlation coefficient (*r*)	*p*	Correlation coefficient (*r*)	*p*
P6D0	−0.06	0.7517	0.06	0.7873
P10D0	−0.21	0.2698	−0.11	0.5790
P14D0	−0.38	0.0426*	−0.16	0.4233
P18D0	−0.56	0.0017*	−0.18	0.3887
P22D0	−0.48	0.0083*	−0.15	0.4535
P6D2	0.18	0.3380	−0.06	0.7649
P10D2	0.03	0.8881	−0.24	0.2313
P14D2	−0.17	0.3888	−0.28	0.1736
P18D2	−0.23	0.2353	−0.27	0.1907
P22D2	−0.26	0.1769	−0.35	0.0782
P6D4	0.25	0.1935	0.11	0.6091
P10D4	0.11	0.5743	0.01	0.9776
P14D4	0.02	0.8986	−0.13	0.5344
P18D4	−0.09	0.6425	−0.21	0.2936
P22D4	−0.18	0.3485	−0.32	0.1165
P6D6	0.28	0.1312	0.15	0.4546
P10D6	0.17	0.3704	0.10	0.6219
P14D6	0.00	0.9924	0.09	0.6696
P18D6	−0.05	0.7836	−0.19	0.3446
P22D6	−0.13	0.5007	−0.27	0.1908

P#D#: P# denotes anteroposterior distances at 6 mm, 10 mm, 14 mm, 18 mm, and 22 mm posterior to the distal margin of the incisive foramen; D# denotes mediolateral distances at 0 mm, 2 mm, 4 mm, and 6 mm lateral to the midpalatal suture.
*Statistically significant at $p < 0.05$.
ROI = region of interest.

Table 4 Correlation between Frankfort-mandibular plane angles (FMA) and palatal bone thickness by sex.

ROI	Male ($n = 29$)[a]		Female ($n = 26$)[b]	
	Correlation coefficient (r)	p	Correlation coefficient (r)	p
P6D0	−0.0208	0.9196	−0.1515	0.4507
P10D0	−0.0609	0.7675	−0.4038	0.0367*
P14D0	0.0034	0.9867	−0.5803	0.0015*
P18D0	−0.1072	0.6023	−0.5054	0.0072*
P22D0	0.0458	0.8240	−0.4734	0.0126*
P6D2	−0.0711	0.7300	0.3126	0.1124
P10D2	−0.1241	0.5459	−0.1514	0.4511
P14D2	−0.0922	0.6542	−0.5167	0.0058*
P18D2	0.0092	0.9646	−0.5300	0.0045*
P22D2	0.0470	0.8197	−0.4577	0.0164*
P6D4	0.1493	0.4666	0.1701	0.3963
P10D4	−0.0772	0.7079	−0.1209	0.5480
P14D4	−0.2167	0.2877	−0.5396	0.0037*
P18D4	−0.2346	0.2487	−0.5978	0.0010*
P22D4	−0.1175	0.5675	−0.5377	0.0038*
P6D6	0.0769	0.7090	0.1525	0.4475
P10D6	−0.1413	0.4912	−0.1154	0.5665
P14D6	−0.3499	0.0797	0.1201	0.5507
P18D6	−0.2256	0.2678	−0.4829	0.0107*
P22D6	−0.2122	0.2981	−0.4774	0.0118*

P#D#: P# denotes anteroposterior distances at 6 mm, 10 mm, 14 mm, 18 mm, and 22 mm posterior to the distal margin of the incisive foramen; D# denotes mediolateral distances at 0 mm, 2 mm, 4 mm, and 6 mm lateral to the midpalatal suture.
*Statistically significant at $p < 0.05$.
ROI = region of interest.
[a] One patient was excluded from analysis because occlusion was not in maximal intercuspation (MIP).
[b] Two patients were excluded from analysis because occlusion was not in MIP.

calcification of the suture may affect miniscrew stability and may limit its function as a site for maxillary bone growth [17]. In children, adolescents, and even young adults, the paramedian palate may be a more suitable mini-implant placement site [12,18].

For a miniscrew placement in the palatal area, the clinician must be careful to avoid penetrating the nasal cavity [18]. Extension of the miniscrew into the nasal cavity may induce localized inflammation that may adversely affect the nasal mucosa. For example, perforation of the nasal cavity by an endosseous implant is reportedly associated with rhinosinusitis and quasineoplastic lesions [4,5]. Penetration of the nasal cavity by the miniscrew may also cause patient discomfort.

In the patients in this study, the average bone thickness of the anterior palate at the midpalatal suture (P6D0) and at 2 mm lateral to the suture (P6D2) ranged from 6.28 mm to 7.07 mm. Bone thickness gradually increased with the lateral distance of the coordinates (D4—D6), especially in the male group, in which average bone thickness was 8.91 mm and 8.64 mm at P6D4 and P6D6, respectively (versus 7.16 mm and 6.75 mm, respectively, in the female group). The observed correlation between bone thickness and lateral distance from the midpalatal suture is expected because the incisive canal is oblique to the midpalatal suture in the anterior palate.

Although studies show that bone thickness is larger in the anterior palate than in the middle and posterior regions of the palate [3], the anterior palate may not be the optimal miniscrew insertion site in terms of simplicity and orthodontic treatment mechanics. In this study, the average bone thickness in the molar region (P18—P22) along the midpalatal suture was 8.13—9.04 mm in males and 7.91—9.03 mm in females. Soft tissue increases thickness by an additional 1 mm [19]. Therefore, this region can safely accommodate a miniscrew length of 8 mm. In the molar region 2 mm lateral to the midpalatal suture, however, bone availability is substantially lower but still within the acceptable range: 5.48—5.51 mm in males and 5.15—5.58 mm in females. Therefore, this region requires a miniscrew length of 5—6 mm. Bone thickness approximates 4 mm at a distance of 4 mm lateral to the midpalatal suture and approximates 3 mm at a distance of 6 mm lateral to the midpalatal suture. Hence, to minimize the risk of perforating the nasal cavity, the site of a miniscrew placement in the molar region should not deviate by more than 2 mm from the midpalatal suture.

Several studies that have reported CT measurements of vertical thickness of the palatal bone have shown considerable individual variation in available bone thickness [9,10]. Previous attempts to identify predictors of vertical thickness in the palatal bone [11] have found that age and palatal morphology have no clinically meaningful relationship to bone thickness. The current study further showed that tongue position and presence of a posterior crossbite are unassociated with palatal bone thickness, possibly because of the complex etiology of malocclusion.

In females, the FMA angle showed a significant inverse association with palatal bone thickness, mostly at the middle to posterior region of the palate. The correlation coefficient showed a moderate association ranging from −0.4577 to −0.5978, which implies that bone thickness is negatively associated with facial divergence over the posterior palatal region. Therefore, to avoid patient discomfort caused by penetration of the nasal cavity in hyperdivergent females who require orthodontic miniscrew placement at a posterior palatal region, the selected miniscrew should be 1—2 mm shorter than those used in orthodivergent and hypodivergent females. In this study, the FMA angle was associated with palatal bone thickness only in the female group, apparently due to sexual dimorphism. Facial divergence is generally larger in children. As growth continues, however, the height of the mandibular ramus increases, and the FMA angle gradually decreases. In the mandibular ramus, studies show that males have greater growth and larger height increases compared to females [20]; males also have a relatively more pronounced decrease in mandibular plane angle with age [20]. Finally, males have a longer growth period; growth potential can continue until age 20 years in males whereas growth gradually declines after approximately age 16 years in females. Therefore, the association between palatal bone thickness and FMA angle in males may be masked by sex differences in growth patterns.

Compared to patients with orthodivergent facial patterns, patients with hyperdivergent facial patterns are more likely to experience complications during orthodontic treatment. Measures must be taken to avoid unwanted side effects such as increased anterior facial height resulting from ineffective vertical control, which may negatively affect post-treatment aesthetics. Several previous studies have confirmed the effectiveness of skeletal anchorage devices such as miniscrews for controlling the vertical dimension and molar intrusion [21]. By enabling counterclockwise rotation of the mandible, effective molar intrusion can reduce facial height and improve post-treatment aesthetics. Therefore, compared to patients with other facial patterns, hyperdivergent patients are more likely to require miniscrews for increased anchorage during orthodontic treatment.

In conclusion, tongue position, presence of posterior crossbite, and palatal morphology are not significantly associated with palatal bone thickness. In hyperdivergent females, however, bone availability is lower than normal in the middle and posterior regions of the palate; therefore, shorter than normal miniscrews may be needed to avoid penetrating the nasal cavity during miniscrew placements in these regions.

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