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Original Article

Evaluation of total bone and cortical bone thickness of the palate for temporary anchorage device insertion

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KEYWORDS
Adolescent;
Cortical bone;
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Abstract *Background/purpose:* The palate has become a popular site for the placement of temporary anchorage devices (TADs) owing to its bone quantity and quality. This study aimed to investigate total and cortical bone thicknesses in the whole palate as well as palatal width using a standard grid system and cone-bean computed tomography (CBCT) images.
Materials and methods: The CBCT images of 43 samples were selected. The total bone and cortical bone thicknesses of the palate were surveyed on 64 points per patient. The palatal width was measured. The difference between the age and sex groups was analyzed.
Results: The total palatal bone thickness in the adult group ranged from 9.85 ± 2.04 to 1.87 ± 0.79 mm. In the adolescent group, we found one-third of the incisor roots in the area 3 mm distal to the incisive foramen and 8 mm lateral to the mid-palatal suture. The cortical bone thickness in adults was significantly thicker in the posterior paramedian area than that in adolescents.
Conclusion: The thickest vertical bone is located in the zone 3 mm distal to the incisive foramen and 4—8 mm lateral to the midpalate. The zone 6 mm posterior to the incisive foramen and 2—8 mm lateral to the midpalate exhibited optimal thickness and was away from the incisor roots. This region could be a safe zone for adolescent patients to place TADs. When TADs are to be inserted at the posterior palate, the 2-mm paramedian area should be the first region of choice.

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Introduction

The temporary anchorage device (TAD) has been widely used in the field of orthodontics and has largely expanded the limitations of orthodontic treatment.[1] TAD placement in the anterior palate has been reported since 1996 by Wehrbein et al.[2] This has been recommended by the literature as an ideal site for the placement of orthodontic mini-screws due to its adequate bone quantity and keratinized gingiva.[3–8] Nowadays, several orthodontic appliances have been introduced to incorporate with palatal TAD for different purposes, such as MSE® for maxillary expansion and Beneslider® for molar distalization.[3] To produce the desired biomechanics for orthodontic tooth movement, the placement of TAD in the middle or posterior palate cannot be ruled out. Because the stability of TAD is primarily determined by mechanical retention rather than by osteointegration,[9–11] it is essential to obtain knowledge regarding total bone and cortical bone thicknesses of the whole palate.

Winsauer et al. conducted a review to investigate the bone height of the vertical palate.[12] They found that there was a lack of uniformity in the imaging technique and coordination system. Six of sixteen studies measured the vertical bone height of the cadaver using histological methods or cephalograms. Six of the remaining ten reports used CT images for measurements. However, the measurement of vertical bone thickness on lateral cephalometric films has proven to be inaccurate.[13] The slice thickness of medical CT could affect the resolution of images when measuring bone thickness. Meanwhile, the radiation dose of medical CT has been a major concern when used in routine clinical practice.[14] Although the radiation dose of cone-bean computed tomography (CBCT) has been largely reduced compared with medical CT,[15] the adverse effects of radiation are still an issue in growing patients.[1] To avoid repeated exposure to radiation as well as the burden of placement failure, it is important to recognize total bone and cortical bone thicknesses of the palate before TAD placement in adolescent patients.

To date, few studies have conducted thorough investigations about palatal width, cortical bone thickness, and total bone thickness in certain areas of the palate in adults and growing adolescents. Therefore, our study aimed to assess the total and cortical bone thicknesses of the whole palate as well as the palatal width using a standard grid system and CBCT images.

Materials and methods

Subjects

This retrospective study was conducted by assessing CBCT images from patients who had visited the Department of Stomatology of National Cheng-Kung University Hospital from 2015 to 2019. The exclusion criteria were patients with (1) systemic illness or trauma history; (2) cleft palate or other craniofacial deformities involving the palate; (3) previous orthodontic treatments; (4) cysts, impacted teeth, supernumerary teeth in the palate area; and (5) the absence of upper first molar or a large metal restoration that might affect the quality of the image. All CBCT images were taken using the DCT 100 machine (Taiwan CareTech Corporation, Kaohsiung, Taiwan) at 120 kV, 5 mA, with a field of view of 15 cm $\times$ 9 cm and a voxel size of 0.25 mm.

The CBCT images of a total of 43 samples were selected. All images were assigned into one of the two age groups: Group 1, comprising 22 adults (8 males and 14 females, mean age: 23.64 ± 4.18 years) and Group 2 comprising 21 adolescents (13 males and 8 females, mean age: 14.29 ± 1.82 years). This study was approved by the Ethics Committee of National Cheng-Kung University Hospital (IRB No. B-ER-103-290).

Measurement methods

The DCT 100 image software (Taiwan CareTech Corporation, Kaohsiung, Taiwan) was used to measure bone thickness. A coordinate system was defined by using the intersection of the posterior border of the incisive foramen and midsagittal palate as the reference point (0,0). The X-axis was set as a mediolateral (ML) imaginary tangent to the posterior border of the incisive foramen, with a 2-mm interval from the mid-palatal suture to both the right and left sides. The Y-axis anteroposteriorly (AP) passed through the palate, from the center of the incisive foramen to the posterior nasal spine (Fig. 1).

Total bone and cortical bone thicknesses of the palate were obtained as linear measurements parallel to the Z-axis, with a 3-mm interval in the sagittal plane (Fig. 2), resulting in 32 measuring points at each side of the palate and 64 points per patient in total (Fig. 1). Two measuring points from opposite sides of the palate were averaged. The measuring point was marked with an asterisk in Fig. 1, for example, was named AP6/ML2. The palatal width was defined by measuring the linear distance from the cementoenamel junction of the right upper first molar to the left first molar (Fig. 3).

Statistical analysis

Data distribution was tested using the Kolmogorov–Smirnov test. Intergroup difference in total bone thickness was evaluated using the t-test, whereas intragroup difference was evaluated using the one-way ANOVA with Turkey's honestly significantly difference test. Because data of cortical bone thickness were not normally distributed, the Mann–Whitney's U test was used to detect differences

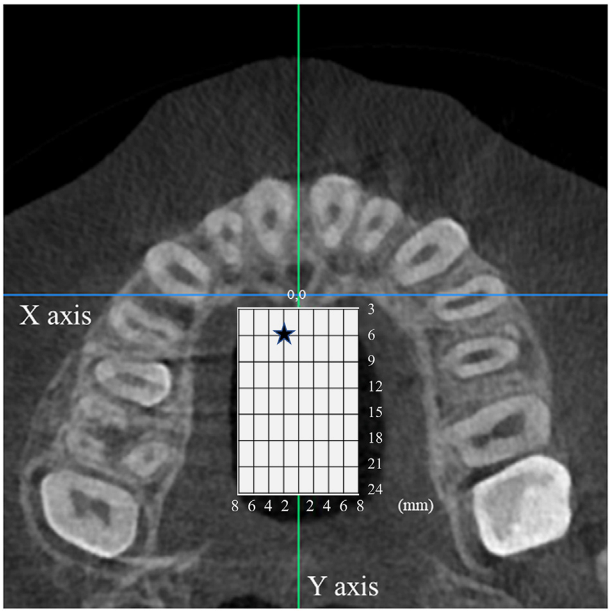


Figure 1 X axis is defined as a line that tangent to the posterior border of incisive foramen. Y axis passes through the midpalate, from the posterior border of incisive foramen to posterior nasal spine. The first coordinate is anteroposterior (AP) distance from posterior border of incisive foramen, with 3-mm interval. The second coordinate is mediolateral (ML) distance from midpalate, with 2-mm interval each. Measuring point (marked asterisk), for example, is named AP6/ML2 of the right side.

between age groups. All data were analyzed using SPSS Version 17.0® (SPSS, Chicago, ILL, USA), with the significance level set at $p = 0.05$.

Two of the forty-three patients were chosen at random and underwent measurements again after 1 month for intra-examiner reliability by the interclass correlation coefficient (ICC) test.

Results

The ICC ($r = 0.949$ for total bone thickness; $r = 0.894$ for cortical bone thickness) indicated excellent reliability for both measurements.

No significant difference was observed between males and females in both age groups. Therefore, male and female data were pooled together for further analyses. Intragroup differences in total bone thickness were detected and could be further allocated into four subgroups (zones A—D), as shown in Fig. 4. The A zone, 3-mm posterior to the posterior rim of the incisive foramen and 4- to 8-mm lateral to the midsagittal line, exhibited the thickest bone, with a thickness of 9.52 ± 1.86 mm in adults. The B zone, 6-mm posterior to the posterior rim of the incisive foramen and 2- to 8-mm lateral to the midsagittal line, exhibited a thickness of 6.60 ± 1.42 mm. The D zone located more posteriorly than 12 mm, except the 2-mm paramedian region, had the smallest bone volume (mean $= 2.80 \pm 1.04$ mm). Total bone tended to become thinner from anterior to posterior and from medial to lateral in the posterior palate. No significant difference was observed between adults and adolescents in terms of total bone thickness. During the measurement of total bone thickness, we found that one-third percentage of incisor roots in the area AP3/ML8 in the adolescent group (33%, 7 of 21 adolescent samples) (Fig. 5).

The mean cortical bone thickness is shown in Table 1. There were no significant differences in the cortical bone thickness between 64 measurement points of the whole palate in both age groups. The cortical bone thickness in adults was significantly greater in 13 of 32 sites than that in adolescents, mainly in the posterior paramedian area, 2- to

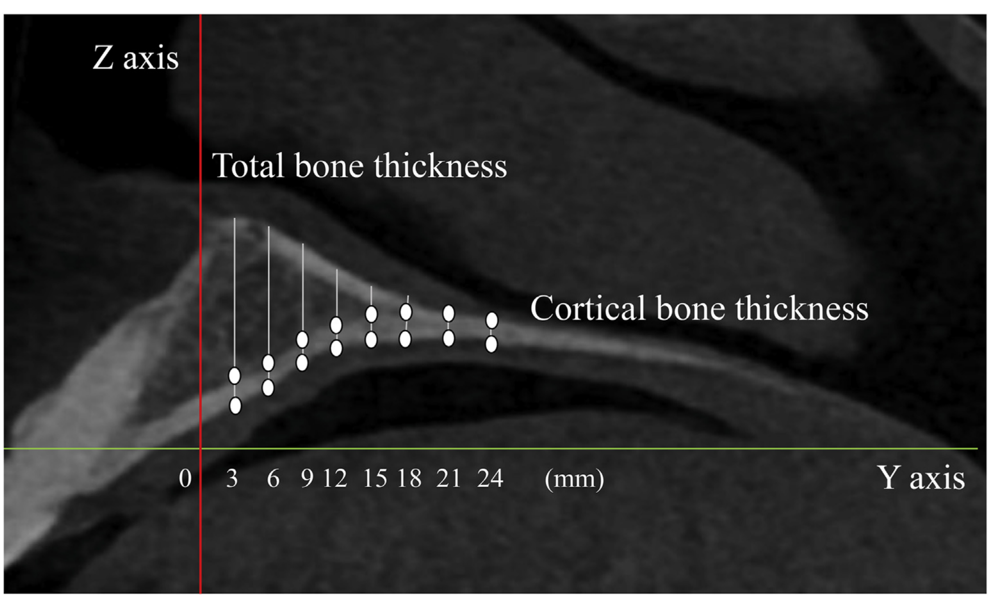


Figure 2 In each sagittal view, the total and cortical bone thickness were measured parallel to the Z axis at 3-mm interval anteroposteriorly.

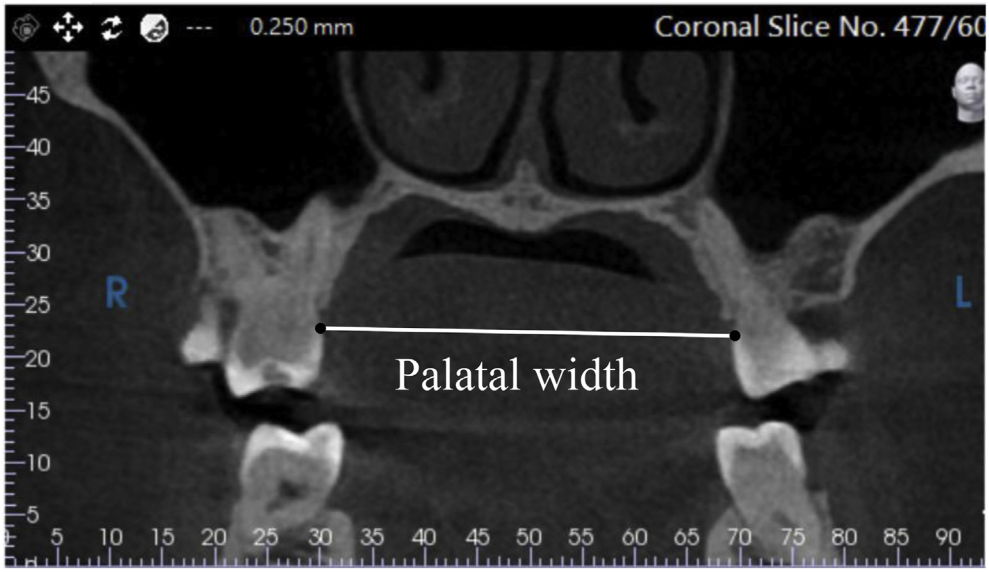
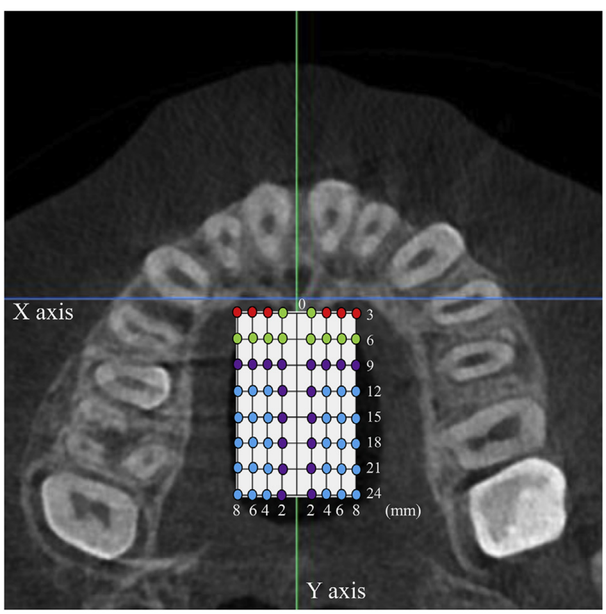


Figure 3 Palatal width was defined by measuring the linear distance from cementoenamel junction of one upper first molar to the other.



Total bone thickness (mm)		
	Adult	Adolescent
A zone	9.52 ± 1.86	10.48 ± 2.41
B zone	6.60 ± 1.42	7.53 ± 2.52
C zone	4.80 ± 1.34	5.33 ± 1.65
D zone	2.80 ± 1.04	3.18 ± 1.35

Figure 4 64 measuring points could be further allocated into four zones. (A-D zone) The A zone, 3-mm posterior to the posterior rim of the incisive foramen and 4- to 8-mm lateral to the midsagittal line. (AP3/ML4-8, Red) The B zone, 6-mm posterior to the posterior rim of the incisive foramen and 2- to 8-mm lateral to the midsagittal line. (AP3/ML2 & AP6/ML2-8, Green) The D zone located more posteriorly than 12 mm to the incisive foramen, except the 2-mm paramedian region. (AP12-24/ML4-8, Blue).

4-mm mediolateral area, and 9- to 21-mm anteroposterior area.

The transverse width of the palate is shown in Table 2. There was no significant difference in the width of the palate between the two age and sex groups.

Discussion

The palate has become a popular site for the placement of orthodontic TADs owing to its stability and lack of vital structures.[3–8] Several studies have reported total bone thickness using different types of grid systems. One measuring grid was a clinical landmark created using tooth contact points as reference lines.[2,5] However, it might be difficult to identify reference lines in crowded or asymmetric dentitions. Other studies have used the intersection of the posterior border of the incisive foramen and midsagittal palate as the reference point (0,0), with horizontal as well as vertical reference lines being subsequently defined.[1,6–12] This coordination system has been used in most studies, including ours, because it eliminates

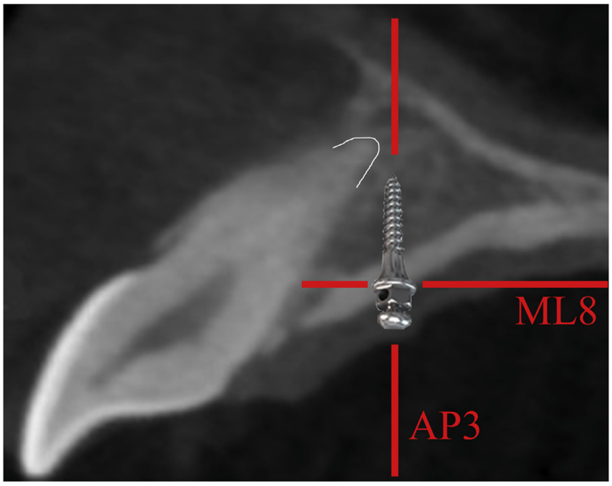


Figure 5 A sagittal section of CBCT image at the zone, 3-mm posterior to the posterior rim of the incisive foramen and 8-mm lateral to the midsagittal line (AP3/ML8) of an adolescent. TAD insertion at AP3/ML8 site may damage the root of incisors.

errors in the identification of the landmarks when used in malaligned dentitions. Besides, the estimated insertion direction of the orthodontic TAD could also affect the measurement of the available bone volume, particularly in the anterior palatal area. The total bone height is thicker when measured perpendicularly to the bone surface than when it is measured perpendicularly to the incisive foramen—Posterior Nasal Spine (PNS) line. Hourfar et al. and Baumgaertel et al. inspected the bone height perpendicularly to the bone surface and found that it was thicker than that observed in our study in the anterior palate.[5,6]

The data in the present study show that the thickest vertical bone is located 3-mm distal to the incisive foramen and 4—8-mm lateral to the mid-palatal suture and that this thickness decreased posteriorly. These findings are in agreement with those of most previous studies.[3–5,7,8,16–18] In our study, 32 measuring points at each side of the palate were further divided into subgroups A—D according to the statistical results. The assignment of subgroup zones is different in different studies. A study has investigated the difference between the measuring points without allocating them into areas.[17] On the other hand, some authors have arbitrarily allocated the points into regions and have compared the intragroup values.[8,18,19] This method might affect the final results of bone thickness due to the average values that were in fact statistically significantly different.

Ludwig[3] reported that the ideal area for mini-screw insertion is 3—9-mm anteroposterior and within 6 mm mediolaterally including the mid-palatal suture. Winsauer[12] reviewed several articles and indicated that the area 3 mm behind the incisive foramen and 3—9 mm mediolaterally had substantial bone volume for TAD placement. However, we found a high percentage of presence of incisor roots at areas AP3/ML8 (33%, 7 of 21 adolescent samples). King's and Bernhart's studies also demonstrated the same findings.[16,20] King et al. found that the teeth formed the boundary of measurement at three locations: P4D6, P4D9, and P8D9 (73.8%, 98.4%, and 51.9%, respectively). These findings suggest that TAD insertion in these zones might cause accidental root injury. Furthermore, root proximity is a major risk factor for TAD failure.[21] Owing to the fear of root damage and mini-screw failure in adolescent patients,

Table 1 Cortical bone thickness (unit: mm).

	AP3		AP6		AP9		AP12	
ML2	Adult	Adolescent	Adult	Adolescent	Adult	Adolescent	Adult	Adolescent
	2.07	1.90	1.89	1.83	2.15*	1.83	2.03*	1.61
ML4	Adult	Adolescent	Adult	Adolescent	Adult	Adolescent	Adult	Adolescent
	1.79	1.61	1.69	1.54	1.76*	1.46	1.97*	1.51
ML6	Adult	Adolescent	Adult	Adolescent	Adult	Adolescent	Adult	Adolescent
	1.70	1.70	1.45	1.53	1.24	1.26	1.54*	1.18
ML8	Adult	Adolescent	Adult	Adolescent	Adult	Adolescent	Adult	Adolescent
	1.72	1.54	1.42	1.53	1.37	1.10	1.45	1.18
	AP15		AP18		AP21		AP24	
ML2	Adult	Adolescent	Adult	Adolescent	Adult	Adolescent	Adult	Adolescent
	2.42*	1.75	2.54*	1.98	2.60*	1.91	2.62*	1.90
ML4	Adult	Adolescent	Adult	Adolescent	Adult	Adolescent	Adult	Adolescent
	2.32*	1.68	2.40*	1.76	2.38*	1.91	2.34	2.05
ML6	Adult	Adolescent	Adult	Adolescent	Adult	Adolescent	Adult	Adolescent
	1.50*	1.24	1.61	1.18	1.56	1.54	1.39	2.08
ML8	Adult	Adolescent	Adult	Adolescent	Adult	Adolescent	Adult	Adolescent
	1.44	1.53	1.34	1.15	1.33	1.48	1.36	1.76

In "*" sites, the thickness was greater in adults. ($p < 0.05$).
AP3 ~ AP24: anteroposterior distance from posterior border of incisive foramen, with 3-mm interval.
ML2 ~ ML8: mediolateral distance from midpalate, with 2-mm interval.

Table 2 Palatal width (unit: mm).

	Male	Female	
Adult	38.99 ± 4.90	36.89 ± 2.39	ns
Adolescent	39.01 ± 3.21	36.87 ± 3.81	ns
	ns	ns	

ns: not significant.

it is advisable to insert TAD in the zone that is situated 6 mm behind the incisive foramen and 2–8 mm lateral to the mid-palatal suture. In our study, the average thickness was 7.53 ± 2.52 mm for adolescents and is considered to be adequate for TAD placement.

In the present study, the total bone thickness of the posterior palate (9 mm posterior to the incisive foramen) decreased from medial to lateral, suggesting that if an area other than the anterior palate is chosen for TAD placement, the 2-mm paramedian area would be the first area of choice (the C zone in our study). These results agree with those obtained in a research conducted in Asian populations,[8,17,19] while in studies conducted in the Caucasian population, the measurement was thinner (2.71 ± 1.40 mm).[5]

In our study, there was no significant difference in total bone thickness between sex and age groups. This result was in line with those of some other studies.[8,19] On the contrary, Kang et al. found sexual dimorphism regarding the posterior palatal bone thickness.[17] This might result from their small sample size and slice thickness of their CT images.

Within the scope of our search, we found only two articles that investigated cortical bone thickness of the palate;[5,10] one survey in the entire palate and the other only in the paramedian palate. Baumgaertel et al. concluded that the mean value of cortical bone thickness was 1–1.49 mm[5]; this value is thinner than that reported in our study. In Baumgaertel's study, the measurements of cortical bone thickness were analyzed and classified by subgroups into only four zones anteroposteriorly. Moreover, their samples were dry skulls of elderly Caucasian people. Farnsworth et al. investigated the cortical bone thickness of the palate in the 3-mm paramedian and 3–9-mm anteroposterior area. They found no age difference in these areas.[10] However, we found that there was a significant difference between age groups at sites 2–4 mm mediolateral and 9–21 mm anteroposterior. These results indicate that the adult group has significantly thicker cortical bone in the median posterior palate area compared with the adolescent group. Because the cortical bone plays an important role in providing mechanical retention of TAD,[9,11] the result also implies that the failure rate might be higher in adolescent patients when TADs are placed in the paramedian posterior area.

In terms of palatal width, El Nahass et al. found significantly wider palates in males than in females in the Egyptian population (36.7 ± 3.4 mm vs. 34.0 ± 2.9 mm).[22] Ferrario also found similar results.[23] However, this sexual dimorphism in palatal dimensions was not found in the present study, which could be attributed to higher individual variations in our adult male samples (standard deviation = 4.90 mm). The palatal dimension was 2 mm wider compared with previous studies, suggesting that the Taiwanese population might have slightly wider palates than the Caucasian and Egyptian populations. It is beneficial to place orthodontic appliances in the palate.

In conclusion, the thickest vertical bone for TAD placement is located in the A zone, 3 mm distal to the incisive foramen and 4–8 mm lateral to the mid-palatal suture. Owing to the fear of root damage in adolescent patients, it is advisable to insert TADs in the B zone that is situated 6 mm behind the incisive foramen and 2–8 mm lateral to the mid-palatal suture. When mini-screws are to be placed at the posterior palate, the 2-mm paramedian area should be the first region of choice (C zone, mean = 4.80 ± 1.34 mm in adults and 5.33 ± 1.65 mm in adolescents). The D zone had the smallest bone thickness (mean = 2.80 ± 1.04 mm). When the TAD is inserted in the D zone, caution should be applied to prevent the perforation of the nasal cavity. In terms of cortical bone thickness, the adult group had a significantly thicker cortical bone in the paramedian posterior palate area. This result also implies that when TADs are placed in the paramedian posterior area, the failure rate might be higher in adolescent patients than in adults.

Declaration of competing interestCOI

The author(s) have no conflicts of interest relevant to this article.

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