ORIGINAL ARTICLE

Volume 21 Issue 1 2026

DOI: 10.21315/aos2026.2101.OA01

ARTICLE INFO

Submitted: 04/04/2025
Accepted: 22/04/2026
Online: 30/06/2026

Analysis of Mucosal Thickness, Bone Quality, and Root Anatomy for Oblique Temporary Anchorage Device Placement in the Posterior Palatal Region

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To cite this article: Azis NMN, Othman NK, Mohyiddin NN, Nor MM, Fauzi AA (2026). Analysis of mucosal thickness, bone quality, and root anatomy for oblique temporary anchorage device placement in the posterior palatal region. *Arch Orofac Sci*, **21**(1): 31–41. https://doi.org/10.21315/aos2026.2101.OA01

To link to this article: https://doi.org/10.21315/aos2026.2101.OA01

ABSTRACT

This retrospective cross-sectional study evaluated the anatomical features of the palatal posterior supra-alveolar region to identify optimal sites and safe zones for temporary anchorage device (TAD) placement at oblique insertion angles. Cone beam computed tomography (CBCT) scans of 111 dentate patients were analysed to measure palatal mucosal thickness, cortical bone thickness, total bone depth, interradicular distances, and molar root curvature at 45°, 60°, and 75° relative to the occlusal plane. Descriptive statistics were calculated, normality was assessed using the Shapiro-Wilk test, and one-way ANOVA and Pearson correlation analyses were performed to determine statistical differences and relationships between variables ($p < 0.05$). Palatal mucosal thickness exceeded 4 mm at all sites, with significant variation across insertion angles. Cortical bone thickness ranged from 1.2 mm to 2.0 mm, while total bone depth consistently exceeded 4.5 mm. Interradicular distances increased with apical depth, providing at least 3 mm to 4 mm of space beyond 6 mm from the cemento-enamel junction in most regions. Molar root curvature ranged from moderate to severe. Overall, palatal tissue and bone were adequate for oblique TAD insertion, with the insertion angle significantly influencing bone and soft tissue availability. Maximum bone engagement was generally achieved at 45°, and greatest soft tissue thickness at 45° to 60°, depending on the tooth. Given the variability in root curvature and limited interradicular space, TAD placement is best performed apical to the tooth roots. For this population, the optimal insertion site is between the distal root of the second premolar and the palatal root of the first molar at a 45° angulation.

Keywords: *Mucosal thickness; Bone quality; Root anatomy; TADs; Anchorage*

INTRODUCTION

The use of temporary anchorage devices (TADs) for skeletal anchorage in orthodontic movement has gained popularity in recent years. These can include osseointegrated implants, such as midpalatal implants, as well as mechanically retained devices, such as mini-screws (Ramirez-Ossa *et al*., 2020). The placement of TADs depends on the specific orthodontic requirements, with higher success rates observed in the posterior maxilla compared to the anterior region (Papageorgiou *et al*., 2012). In contrast, when considering palatal insertion sites, particularly in the posterior palate, the overall failure rate is reported to be 4.7%, with specific rates of 1.3% in the midpalatal region, 4.8% in the paramedian region, and 5.5% in the parapalatal region (Mohammed *et al*., 2018). The palatal posterior region also offers the most extensive interradicular space, a sufficiently robust cortical plate, and a moderately thick attached gingiva (King *et al*., 2007). Placement in the posterior palatal vault, apical to the roots of posterior teeth, has been described by several authors (Cunha *et al*., 2017; Lombardo *et al*., 2018; Maino *et al*., 2020; Nucera *et al*., 2022) and termed the "Palatal Posterior Supra-Alveolar Insertion Site" (Nucera *et al*., 2022).

The success of TAD placement depends on a detailed understanding of the anatomical structures in the target area, particularly in complex regions such as the palatal posterior zone. Skeletal factors, including cortical bone thickness and bone mineral density, play a critical role in primary stability, while tooth-related factors, such as root anatomy and proximity, influence safe placement and reduce the risk of root contact (Gardner *et al*., 2025). Soft tissue factors such as tissue quality, thickness, mobility, and frenal attachment affect both ease of insertion and long-term stability of the TADs. Evidence from a recent scoping review by Gardner *et al*. (2025), highlights that placement site and peri-implant oral hygiene or soft-tissue health are consistently associated with TAD success.

In addition, procedural factors such as insertion depth also play a significant role. These factors determine the appropriate diameter, length, and shape of the TADs (Cunha *et al*., 2017) and also impact stability (Meursinge *et al*., 2012), insertion angle (Leo *et al*., 2016), depth of placement, and the risk of contact with tooth root (Gintautaite & Gaidyte, 2017). Other factors, including loading protocol, patient age, bone quality, and operator experience, showed variable effects, emphasising the multifactorial nature of TAD outcomes and the need for patient-specific planning (Gardner *et al*., 2025). Together, these anatomical, soft tissue, and procedural determinants provide the evidence-based framework necessary for predictable and effective TAD placement in orthodontic treatment.

While palatal soft tissue anatomy is well-documented for mucogingival grafting, data on palatal mucosal thickness at angles relevant to TAD insertion in the posterior region remain limited. Historically, the concept of skeletal anchorage in orthodontics was first proposed by Gainsforth & Higley (1945), involving Vitallium screw insertions in canine-bearing bone, which laid the groundwork for modern TADs, with perpendicular insertion being the norm in earlier approaches. However, as recognition of anatomical limitations and stability concerns has increased, oblique insertion pathways have been adopted more widely. Nucera *et al*. (2022) demonstrated that mucosal thickness increases with insertion angles inclined to the occlusal plane, but the effect of varying inclinations remains underexplored. This is relevant because TADs seated with a high soft tissue collar can create increased lever arms, potentially affecting their stability (Petrey *et al*., 2010; Nucera *et al*., 2022).

Adequate bone depth and interradicular space are critical for accommodating TADs of the appropriate length and preventing complications such as perforation of the maxillary sinus, nasal cavity, or tooth roots. Cortical bone thickness plays a significant role in ensuring primary stability of TADs, whereas cancellous bone thickness exerts a secondary influence (Ahn *et al.*, 2021). A systematic review by Tepedino *et al.* (2020) examined cortical bone thickness and interradicular sites suitable for TADs placement. The review highlighted significant limitations, including the high heterogeneity among the included studies. Notably, none of the included studies measured the cortical bone thickness at angles similar to those used to insert TADs in the palatal posterior region.

Given the growing use of TADs in orthodontics and the importance of anatomical precision for their successful placement, further research is needed to address existing knowledge gaps regarding the palatal posterior supra-alveolar region. This study aims to analyse mucosal thickness, bone quality, and root anatomy in this region to identify optimal locations and safety zones for the oblique insertion of TADs in the posterior maxilla.

MATERIAL AND METHODS

This retrospective cross-sectional study is part of a periodontal phenotype investigation in a Malaysian population. Ethical approval was granted by the ethics committee of the Universiti Kebangsaan Malaysia (UKM PPI/111/8/JEP-2023-321), and the study adhered to the principles of the Declaration of Helsinki (1964) and its amendments. Cone beam computed tomography (CBCT) scans taken between 2019 and 2023 were retrieved from the Radiology Department at the Faculty of Dentistry, Universiti Kebangsaan Malaysia. Attempts were made to ensure that only scans obtained before the initiation of orthodontic treatment were included. Informed consent was not obtained, as all CBCT images were clinically justified and sourced from existing departmental records. The data were anonymised before analysis.

The sample size was calculated using G*Power software version 3.1.9.4, with parameters set at $\alpha = 0.05$, power = 0.8, and an estimated effect size of 0.3, based on findings by Nucera *et al.* (2022), yielding a proposed sample size of 111. The study included dentate patients aged 18 years and older with upper second premolars, first molars, and second molars and high-quality CBCT images. Exclusion criteria included developmental abnormalities (e.g., cleft palate), maxillary tumours, severe crowding (Index of Orthodontic Treatment Needs - Grade 4 and Grade 5) and severe periodontal disease (Stage III and Stage IV generalised periodontitis). All CBCT scans needed to be obtained with the patients in the natural head position. CBCT images meeting the criteria were analysed using Planmeca or iCat software to process Digital Imaging and Communications in Medicine (DICOM) files, with outcome measures recorded from one side of the palate for each of the evaluated cases.

To ensure accuracy and consistency, 10 CBCT data sets were measured twice by two independent assessors. Inter- and intra-examiner reliability was evaluated using the intraclass correlation coefficient (ICC) to assess agreement between the assessors. The results were compared against reference measurements performed by a registered oral and maxillofacial radiologist with extensive experience in CBCT interpretation, which served as the gold standard. Measurement reproducibility was considered acceptable if the values for each parameter fell within ±0.5 mm. For calibration, each parameter was measured three times independently by both assessors, while for the study measurements, a single calibrated operator performed all assessments, repeating each measurement three times at each site. The mean of the three readings was used for statistical analysis to minimise variability and improve accuracy. The ICC score ranged from 0.60 to 0.9 for both examiners, indicating measurement reliability from moderate to excellent.

Study Parameters

Palatal mucosal thickness, cortical bone thickness, and total bone depth were measured at insertion angles of 45°, 60°, and 75° to the occlusal plane, following the protocol of Nucera *et al.* (2022). These angulations were selected as they reflect clinically relevant trajectories for TAD placement in the posterior palate (Fig. 1). CBCT datasets were reconstructed to obtain coronal slices perpendicular to the alveolar process at the site of interest. Briefly, three landmarks were identified: the free gingival margin, the mid-palatal suture, and the midpoint of the line connecting these two landmarks. From this midpoint, a perpendicular line was traced to the palatal mucosal profile, and the intersection point was designated as zeroP. Additional reference points were defined 2 mm apical (–2P) and 2 mm coronal (+2P) to zeroP. Measurements were then obtained at each of these three points along lines inclined at 45°, 60°, and 75° to the occlusal plane.

Orthogonal slicing of the CBCT images, defined as reformatting the dataset into planes oriented at right angles to the long axis of the tooth roots, was utilised to measure the interradicular distance at 2 mm intervals apical from the cemento-enamel junction based on Golshah *et al.* (2021) (Fig. 2). The measurements were taken at the following locations (i) between the second premolar and the mesiobuccal root of the first molar; (ii) between the distal root of the second premolar and the palatal root of the first molar; (iii) between the distobuccal root of the first molar and the mesiobuccal root of the second molar; and (iv) between the palatal root of the first molar and the palatal root of the second molar.

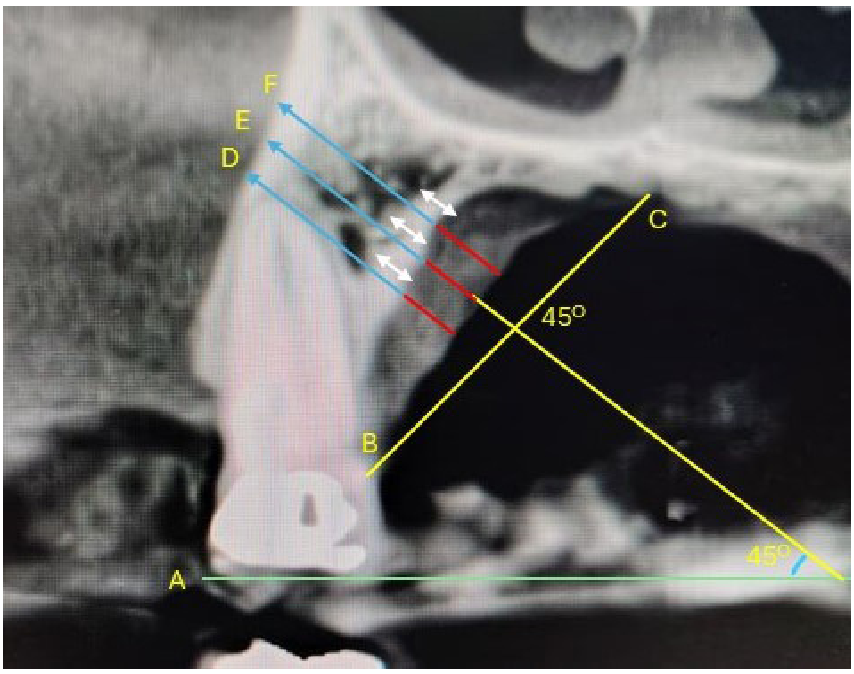

Fig. 1 The measurement of the mucosal thickness, cortical bone thickness and total bone depth at 45° to the occlusal plane: (A) green line showing the occlusal plane; (B) indicating the free gingival margin; (C) showing the mid-palatal suture, the intersection of the two yellow lines shows the midpoint of the BC line; (D) measurement taken at +2P; (E) measurement taken at zeroP; and (F) measurement taken at -2P. The total bone depth was evaluated (blue line), cortical bone thickness (white arrows) and palatal mucosa thickness (red lines).

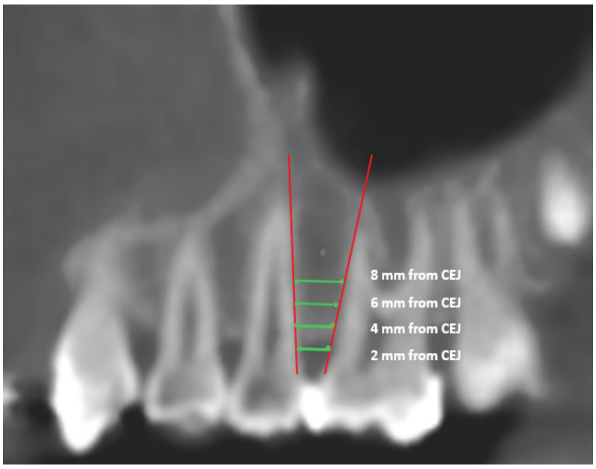

Fig. 2 Measurements of the interradicular distance at 2 mm intervals apical from the cemento-enamel junction.

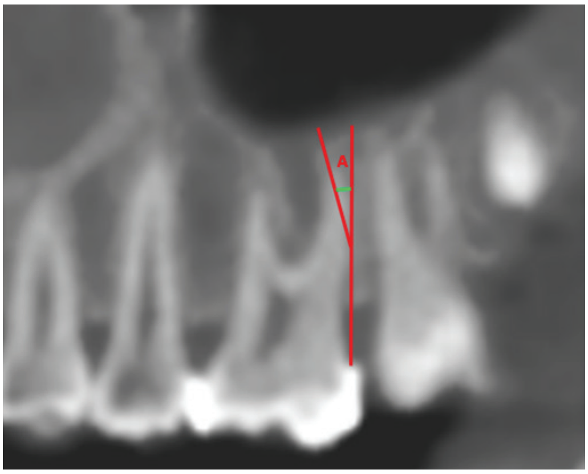

Fig. 3 Measurement of root curvature using Schneider's method. A straight line was drawn parallel to the long axis of the tooth root, and a second line was drawn from the apical foramen to intersect the first at the point where the canal begins to deviate from the long axis. The angle formed at this intersection (A) represents the root curvature.

In all subjects, Schneider's classification was used to evaluate the root curvature of maxillary second premolars, first molars, and second molars (Schneider, 1971). The evaluation was performed in the sagittal plane of each tooth to allow reliable visualisation of canal curvature. A straight line was drawn parallel to the long axis of the tooth root. A second line was drawn from the apical foramen to intersect with the first at the point where the canal began to leave the long axis of the tooth. The angle formed at the intersection of these lines was measured to determine the root curvature (Fig. 3). The measured angle was then categorised according to a modification of the cut-off angles by Schneider, such as: straight (5° or less), moderate (>°5 to 20°), or severe (more than 20°), based on the obtained values (Schneider, 1971).

Statistical Analysis

Data analysis was conducted using SPSS version 29.0 (IBM, Armonk, NY, USA), with statistical significance set at $p < 0.05$. The normality of continuous variables was assessed using the Shapiro-Wilk test. Descriptive statistics, including means and standard deviations, were calculated for all variables. Pearson correlation analysis was used to explore relationships between continuous parameters, while one-way ANOVA assessed statistical differences between groups.

RESULTS

A total of 111 CBCT images were retrieved from the Unit of Radiology, Faculty of Dentistry, Universiti Kebangsaan Malaysia. These included records from 64 female patients and 47 male patients. The majority of participants were Malay (59.55%), followed by Chinese (30.63%), Indian (6.31%), and other ethnicities (3.6%).

Palatal Mucosal Thickness and Bone Thickness

The measurements of the tissue thickness and bone thickness (sum of cortical bone thickness and cancellous bone thickness) at the different angles for the included teeth are shown in Table 1. There were no differences in tissue or bone thickness between the different ethnic groups and genders.

Table 1 The measurement for the tissue thickness and bone thickness at 45°, 60° and 75° for the second premolar, first molar and second molar

Location and angle of measurement		Palatal mucosal thickness	Cortical bone thickness	Cancellous bone thickness	Total bone thickness; Mean ± SD	Total of palatal mucosal thickness and bone thickness
Second premolar	45°	4.42	1.97	4.16	6.13	10.55
	60°	4.47	1.51	4.33	5.84	10.31
	75°	4.57	1.43	3.91	5.34	9.91
First molar	45°	4.60	1.31	2.97	4.28	8.88
	60°	4.81	1.34	2.9	4.24	9.05
	75°	4.76	1.26	2.24	3.50	8.26
Second molar	45°	6.39	1.29	2.66	3.95	10.34
	60°	6.71	1.23	2.47	3.70	10.41
	75°	6.24	1.24	1.85	3.09	9.33

A repeated measures ANOVA with a Greenhouse-Geisser correction determined that palatal tissue thickness at the second molar differed significantly between the degrees of measurement, $F(1.40, 154.05) = 6.20$, $p = 0.007$. Post hoc analysis with a Bonferroni adjustment revealed significant differences between 60° and 75° (mean difference = 0.47 mm, 95% CI [0.22, 0.72], $p < 0.001$) and between 45° and 60° (mean difference = 0.32 mm, 95% CI [0.02, 0.61], $p = 0.029$), but not between 45° and 75°. Similarly, mean bone thickness differed significantly between the degrees of measurement at the second premolar, $F(1.61, 177.45) = 6.94$, $p = 0.003$; first molar, $F(1.94, 212.89) = 11.31$, $p < 0.001$; and second molar, $F(1.79, 195.54) = 14.89$, $p < 0.001$.

Interradicular Distance

The interradicular distances between the roots of the included teeth are presented in Table 2. The average interradicular distance measured between the distal root of the second premolar and the first molar (mesiobuccal root) was 3.04 ± 0.95 mm. Between the second premolar (distal root) and the first molar (palatal root), it was 4.77 ± 1.57 mm. The average distance between the first molar (distobuccal root) and the second molar (mesiobuccal root) was 2.88 ± 1.32 mm. In contrast, between the first molar (palatal root) and the second molar (palatal root), it was 4.15 ± 1.14 mm. Notably, the interradicular distance increased with greater distance from the cemento-enamel junction.

Root Curvature

The distribution of root curvatures based on tooth type is illustrated in Fig. 4. The mean root curvature angles were as follows: 6.62 ± 4.00 degrees for the second premolar, 6.39 ± 3.36 degrees for the palatal root of the first molar, 11.16 ± 5.82 degrees for the mesiobuccal root of the first molar, and 9.21 ± 4.58 degrees for its distobuccal root. For the second molar, the mean curvature angles were 5.95 ± 3.04 degrees for the palatal root, 12.29 ± 5.10 degrees for the mesiobuccal root, and 11.20 ± 4.53 degrees for the distobuccal root. The mesiobuccal and distobuccal roots of the molars exhibited a greater curvature severity than the other roots.

Table 2 The interradicular distance between the roots of the included teeth measured at 2 mm, 4 mm, 6 mm and 8 mm from the cemento-enamel junction

Location of measurement	Second premolar (distal root) and first molar (MB root); Mean ± SD	First premolar and first molar (palatal root); Mean ± SD	First molar (DB root) and second molar (MB root); Mean ± SD	First molar (palatal root) and second molar (palatal root); Mean ± SD
2 mm	2.66 ± 0.95	4.21 ± 4.41	2.57 ± 0.79	3.57 ± 0.88
4 mm	2.93 ± 0.93	4.42 ± 1.09	3.22 ± 4.13	3.89 ± 0.89
6 mm	3.16 ± 1.03	4.90 ± 1.21	2.83 ± 0.88	4.23 ± 0.98
8 mm	3.42 ± 1.17	5.56 ± 1.38	2.92 ± 1.02	4.90 ± 3.53
Average	3.04 ± 0.95	4.77 ± 1.57	2.88 ± 1.32	4.15 ± 1.14

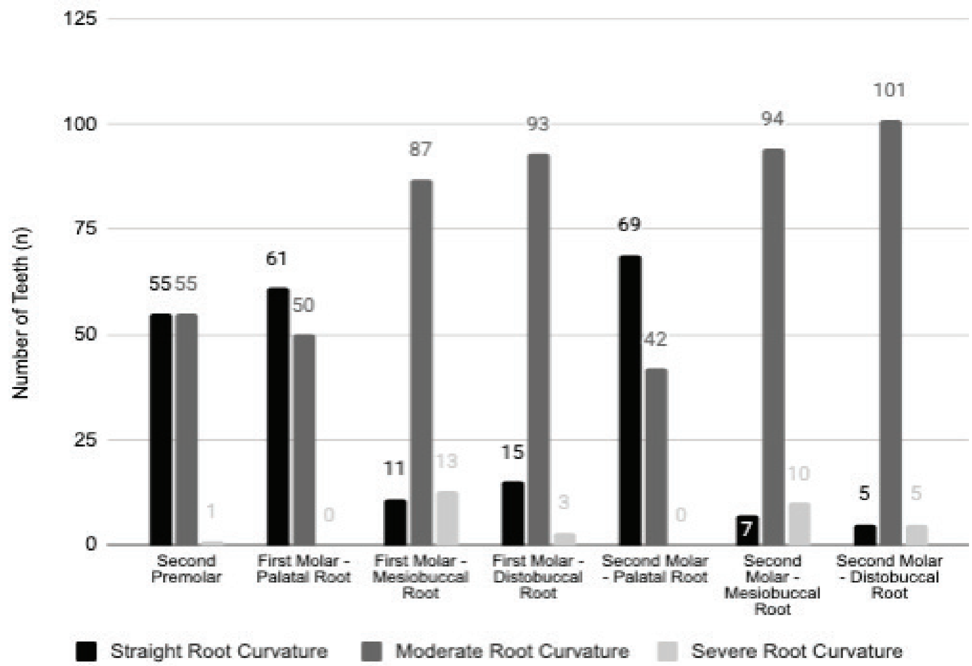

Fig. 4 The distribution of root curvatures based on tooth types.

DISCUSSION

Placement of TADs in the palatal posterior alveolar process can be performed either apical to the tooth roots or between the tooth roots. Placement between the tooth roots, while commonly used, often has limitations, such as an increased risk of damaging the tooth roots and the presence of thin cortical bone, especially if adjacent teeth have been extracted. These factors can compromise the stability of the TAD and the health of nearby teeth. On the other hand, apical placement can avoid these issues but may present its own challenges, such as limited bone thickness and proximity to critical anatomical structures, including the nasal cavity.

Oblique insertion of TADs instead of perpendicular placement has been recommended due to greater bone availability in the apical region, as shown in several studies (Wilmes *et al.*, 2008; da Costa Sabec *et al.*, 2015). Leo *et al.* (2016) also emphasised using 60° to 70° angles during insertion to achieve the best stability. However, few studies have investigated palatal mucosal thickness, cortical bone thickness, and total bone depth at oblique angles relevant to TAD placement in the posterior palatal region (Nucera *et al.*, 2022). This study found that palatal mucosal thickness exceeded 4 mm at all investigated sites, greater than the reported range of 3.13–3.81 mm in the systematic review by Ahn *et al.* (2021). The palatal tissue thickness also differed with the different degrees of measurement. Thicker palatal tissues can increase the distance between the abutment head and the cortical plate, which may reduce TAD retention (Petrey *et al.*, 2010).

Previous studies suggest that a placement angle of 60° to 70° for TADs results in the highest torque values, as it maximises cortical bone engagement and promotes superior initial stability (Wilmes *et al.*, 2008). In this study, cortical bone thickness ranged from 1.2 mm to 2 mm. A thickness of 1 mm to 1.2 mm has been reported as the minimum requirement for TAD stability, while a thickness exceeding 1.5 mm may necessitate predrilling before insertion (Baumgaertel, 2010; Papadopoulos & Papageorgiou, 2013). Therefore, predrilling might be required in certain areas, such as the premolar region, due to the increased cortical bone thickness in these sites. The range of values observed in this study was similar to those reported by Nucera *et al.* (2022) but higher than those reported by Tepedino *et al.* (2020). This discrepancy may be attributed to population differences or variations in measurement methods, as the studies included by Tepedino *et al.* (2020) did not assess cortical bone thickness at an oblique angle.

The success rate of TAD placement has been reported to be higher when the insertion depth is ≥ 4.5 mm and when more than half of the TAD is embedded in bone (Ichinohe *et al.*, 2019). Additionally, Choi *et al.* (2023) recommended a minimum insertion depth of over 6 mm in the posterior region for optimal outcomes. In line with these recommendations, the insertion of TADs at all oblique angles examined in this study (45°, 60°, and 75°) would satisfy these criteria. This suggests that oblique insertion angles may provide adequate bone support for TAD stability in the posterior maxilla.

The minimum interradicular distance required for TAD insertion is 3 mm to 4 mm to allow for a 1 mm clearance from the tooth roots and to accommodate the average TAD diameter of 1.5 mm (Schnelle *et al.*, 2004). Furthermore, root injuries caused by contact with TADs can be significant, even after their removal (Çelik Güler & Malkoç, 2019). A clearance of 1.5 mm was observed at most of the investigated sites located apical to 6 mm from the cemento-enamel junction, except between the distobuccal root of the first molar and the mesiobuccal root of the second molar. Additionally, the root curvature of the first and second molars was found to be moderate to severe in most cases. These findings are consistent with previously reported studies on root curvature and interradicular distances for TAD placement (Al Amri *et al.*, 2020; Valizadeh *et al.*, 2022). Other factors, such as dental crowding, may also reduce the available interradicular space (Tepedino *et al.*, 2017). Therefore, inserting TADs between these posterior teeth may be challenging, and apical placement could be a more suitable approach.

The findings of this study can be used to guide clinically relevant considerations that may affect TAD success. Variations in palatal mucosal thickness can influence lever arms and increase the risk of soft tissue impingement, potentially compromising stability. Patterns of cortical bone thickness and density inform the suitability of oblique insertion, with thicker regions sometimes requiring predrilling to achieve optimal engagement. Clinically, careful planning of the insertion trajectory and attention to root angulation are essential to minimise the risk of root contact, acknowledging that reproducing precise insertion angles in vivo can be challenging. By integrating CBCT-based anatomical findings with these practical considerations, this study provides evidence-based guidance to enhance the predictability, safety, and stability of TAD placement in the posterior palate.

This study has several limitations. The retrospective design relied on pre-existing CBCT scans, which may not have been optimised for the specific anatomical assessments. Variations in occlusal loading or biomechanical factors that affect TAD stability were not considered. Measurements were also limited to standardised angles (45°, 60°, and 75°), which may not represent all clinical scenarios. Future research should include diverse populations, functional analyses of TADs at varying angles, and integration of clinical outcomes with radiographic data to better understand anatomical factors influencing TAD success.

CONCLUSION

The mucosal thickness and bone quality in the palatal aspect of the posterior maxilla, particularly around the second premolar, first molar and second molar, are sufficient for the oblique insertion of TADs. Changes in the insertion angle significantly affect the amount of tissue and bone available for TAD engagement. The maximum bone engagement is typically achieved at a 45° angulation, while the greatest soft tissue thickness occurs at 45° to 60°, depending on the tooth. Posterior maxillary teeth exhibit variability in root curvature and have a limited interradicular distance, especially between the distobuccal root of the first molar and the mesiobuccal root of the second molar. Hence, TAD insertion in this region is recommended apical to the tooth roots. Based on anatomical considerations, the optimal insertion angle for TADs in the palatal aspect of the posterior maxilla is approximately 45°, positioned between the distal root of the second premolar and the palatal root of the first molar. This angulation maximises bone and soft tissue engagement while ensuring adequate space to avoid the tooth roots.

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