Journal of Chemical Health Risks

www.jchr.org

JCHR (2026) 16(2), 2577-2584 | ISSN:2251-6727

Comparative Evaluation of Safe Zones in Interradicular Areas of Maxilla for Placement of Mini Orthodontic Implants in Different Vertical Facial Heights

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(Received: 16 January 2026 Revised: 25 February 2026 Accepted: 30 March 2026)

KEYWORDS:

Comparative Evaluation, Interradicular Areas, Mini Orthodontic Implants, Vertical Facial Heights

ABSTRACT:

Background: The present study aimed to generate a high-resolution anatomical map of the buccal alveolar bone in the right maxillary arch to establish evidence-based guidelines for secure orthodontic miniscrew insertion, with a focused analysis of the interradicular zone between the second premolar and first molar. Cone-beam computed tomography volumes acquired from 90 maxillae using the Carestream 9600 system were processed and analyzed with dedicated Carestream imaging software. Within the targeted interradicular space on the right side, mesiodistal width and buccopalatal bone thickness were quantified at vertical levels of 2, 5, 8, and 11 mm apical to the alveolar crest. The data demonstrated substantial morphological variation across different vertical planes within this specific site, underscoring the necessity for level-specific surgical considerations. These anatomical insights inform a series of practical clinical recommendations for mini screw placement in the right posterior maxilla, encompassing optimal implant dimensions, insertion angulation, and site selection to enhance primary stability while mitigating the risk of root injury or cortical plate perforation.

Objectives: To determine safe zones in interradicular bone region in maxilla in patients with different vertical facial dimension& to determine appropriate sites and angles for insertion of the orthodontic mini-implant in the interradicular region of maxillary arch.

Materials and Methods: This retrospective CBCT-based study analysed images obtained from individuals categorized according to facial growth patterns. Measurements of interradicular distance and the distance from the buccal cortical bone surface to the narrowest interradicular space were recorded at multiple vertical levels from the cemento-enamel junction in the interdental region between the maxillary second premolar and 1st molars. Statistical analysis was performed to evaluate variations among different vertical levels and facial growth patterns.

Results: The mesiodistal interradicular width and buccopalatal bone thickness in the maxillary posterior region showed no significant variation across different vertical facial height groups, with the second premolar–first molar (6-5) region at 5–8 mm from the alveolar crest consistently providing the most favourable dimensions for safe mini-implant placement.

Conclusion: The mesiodistal interradicular width and buccopalatal bone thickness in the maxillary posterior region do not differ significantly across vertical facial height patterns, indicating that established safe zones are universally applicable irrespective of facial morphology. The second premolar–first molar (6-5) region at 5–8 mm from the alveolar crest consistently provides the most favourable dimensions for safe mini-implant placement, making site selection based on interradicular location the critical determinant rather than vertical facial height.

Introduction

The management of orthodontic anchorage remains a critical determinant of treatment success. Traditional reinforcement methods, including headgear and palatal bars, are frequently limited by reliance on patient compliance and the potential for unintended tooth movement. The advent of skeletal anchorage, particularly through the use of mini-implants (or miniscrews), has fundamentally transformed clinical orthodontics by providing a reliable, compliant-independent source of absolute anchorage.[1,8] Since the initial clinical explorations by Creekmore and Eklund[3] and the subsequent refinement by Kanomi[8] and Costa et al.[9], the applications of these devices have expanded considerably. Contemporary clinical indications now encompass complex movements such as posterior tooth intrusion[5], forced eruption of impacted canines[7], and en-masse retraction[10], with numerous studies validating their efficacy.[2,4,6] Despite their widespread adoption, the clinical success of mini-implants is contingent upon achieving sufficient primary stability, which is influenced by a complex interplay of factors including bone quality, biomechanical loading, and, most critically, the accuracy of insertion site selection.[18,19] The concept of the "safe zone" has therefore emerged as a fundamental principle, defined by interradicular bone that offers adequate mesiodistal and buccolingual dimensions while maintaining a safe distance from adjacent roots and vital structures such as the maxillary sinus. The introduction of cone-beam computed tomography (CBCT) has enabled high-precision, three-dimensional assessment of alveolar bone morphology, which is essential for preoperative site planning.[13,14] Previous anatomical studies have provided valuable data on safe interradicular dimensions, contributing to the establishment of initial clinical guidelines.[11,12] However, a significant limitation of the existing literature is the tendency to apply a uniform standard for safe zones across all patient populations, overlooking the inherent variability in craniofacial skeletal morphology. Specifically, vertical facial height—characterized by hyperdivergent (long-faced), normodivergent, and hypodivergent (short-faced) patterns—is known to correlate with differences in alveolar bone dimensions. Individuals with hyperdivergent patterns often present with thinner alveolar bone plates, a factor that could critically reduce the dimensions of interradicular safe zones. Conversely, hypodivergent patterns may present with more robust alveolar structures. To date, no study has systematically evaluated whether the established safe zones for maxillary interradicular mini-implant placement are uniformly applicable across these distinct vertical facial height phenotypes. A failure to account for such morphological variations may increase the risk of iatrogenic sequelae, including root contact, cortical bone perforation, or implant failure. Therefore, the present study was designed to conduct a comparative evaluation of the interradicular safe zones in the maxilla for mini-orthodontic implant placement across different vertical facial height groups. By utilizing CBCT imaging and standardized anthropometric methods,[15] this study aims to test the hypothesis that the location and dimensions of these safe zones vary significantly with vertical facial morphology. The objective is to generate evidence-based, morphology-specific clinical guidelines that can enhance the safety and predictability of mini-implant placement, moving beyond a one-size-fits-all approach to a more personalized, anatomically-driven treatment strategy.

Materials and Methods

CBCT scans of all subject collected from Peoples University, Bhopal, Madhya Pradesh, India and then examination of facial morphologic pattern and interradicular safe zone is evaluated. Based on their vertical face pattern and absence of sagittal malocclusion, the subjects were divided into one of three groups using lateral cephalograms created from the CBCTs. The angle created by the following cephalometric measures was used to determine these facial patterns. (Fig:1)

1) Mandibular plane: the angle formed by the mandibular plane (gonion to menton) and the anterior cranial base (sella tonasion)

2) The face height index, which is calculated by dividing the distance from sella (S) to gonion (Go) by the distance from nasion (N) to menton (Me), is the ratio of posterior to anterior face height.

Inclusion Criteria include Patient age: 18-30 with full complement of teeth till 2nd molars.

No history of trauma or surgery in craniofacial region. History of no previous orthodontic treatment. Angles Class I II III malocclusion.Exclusion Criteria includedpatient undergone orthognathic surgery. Missing teeth/grossly decayed teeth other than third molars. Patient with prosthesis. Sample size consisting

Journal of Chemical Health Risks
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JCHR (2026) 16(2), 2577-2584 | ISSN:2251-6727

of 90 orthodontic patients out of which 30 samples will be of Average, Horizontal and Vertical facial morphological pattern each. They are further subdivided in two groups on basis of gender i.e 15 male and 15 female in each group. A CBCT scan projection of patients will be obtained with parameter of: voxel size 0.3 mm, voltage-120kvp, current-6.3mA and FOV of 12*10. Image assessment will be done in dim light with help of Care Stream 9600 CBCT scanner. CS 3d imaging v3.10.21 Software will be used to measure inter radicular safe zone. Sagittal images between the maxillary second premolar and the first molar area that passed through the middle of the two teeth were created in order to measure the interradicular distance and the distance to the narrowest interradicular space from the cortical bone surface. Next, five axial polyline from the cemento enamel junction (CEJ) apically and parallel to the root of second premolar were created at 3-mm intervals (Fig. 2). At each axial plane, the smallest interradicular distance between adjacent root surfaces was measured (Fig. 3,A). We moved 3 mm apically to measure it. Next, moving 3 mm apically, the distance between the buccal cortical bone surface and the narrowest interradicular space was measured in the same axial plane (Fig. 3,B). All statistical analyses were performed using SPSS software (version v 23.0 IBM Corp., USA). Descriptive statistics including mean and standard deviation (SD) were calculated for narrowest interradicular distances and palatal cortical bone thickness. Intergroup comparisons among the three facial morphological patterns (horizontal, vertical, and average) were performed using one-way analysis of variance (ANOVA). Analysis of variance (ANOVA) and a multivariable comparison with the Duncan multiple range test (MRT) were used to compare differences in the narrowest interradicular distances, and the distances between the cortical-bone surface and the narrowest interradicular space in the sequential axial planes. Independent sample t-tests were used to evaluate gender differences within each growth pattern. A p-value <0.05 was considered statistically significant.

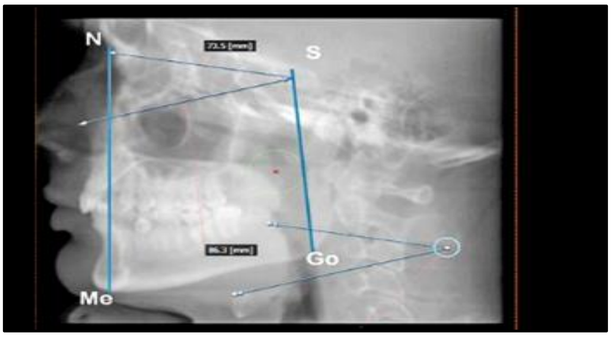

Fig 1: Measurements of facial patterns: 1) Anterior cranial base (sella [S] to nasion [N]) and mandibular plane(gonion to menton), 2) Face height index, the ratio of posterior face height to anterior face height using themeasurements of distance from sella (S) to gon ion (Go) divided by the distance of nasion (N) to menton (Me).

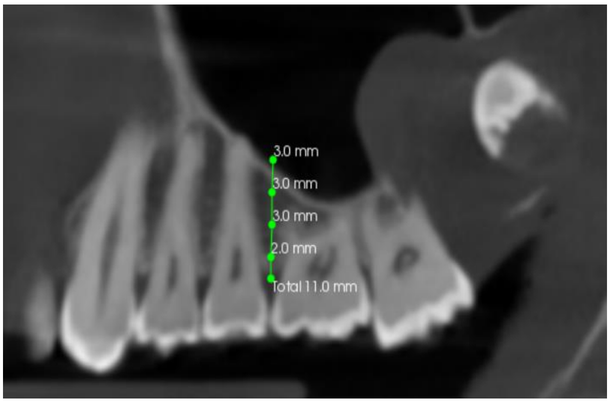

Fig 2: Sagittal view of the maxillary CBCT image. Sequential polyline between interdental space of the maxillary second premolar and the first molar

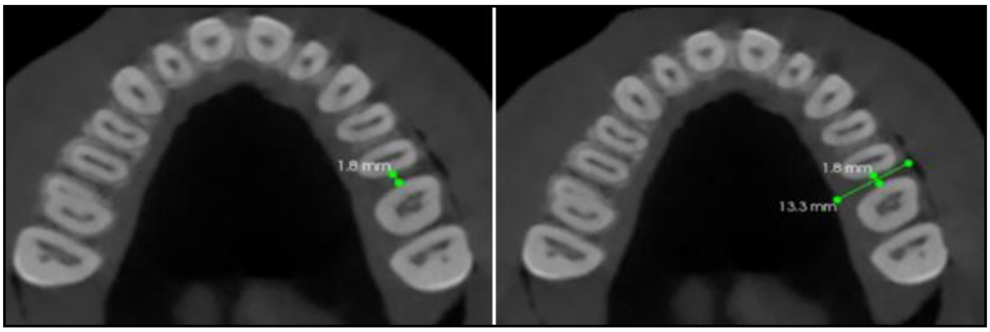

Fig 3: A, Measurement of the narrowest interradicular distance; **B,** distance between the buccal cortical bone surface andthe narrowest interradicular spaces

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JCHR (2026) 16(2), 2577-2584 | ISSN:2251-6727

Results

A total of 90 CBCT scans were included in the study. The subjects were divided into three equal groups according to vertical facial growth pattern: average-growing, horizontal-growing, and vertical-growing, with 30 subjects in each group. Maxillary interradicular bone dimensions were evaluated at four interradicular regions distal to the canine: between canine and first premolar (4-3), between first and second premolars (5-4), between second premolar and first molar (6-5), and between first and second molars (7-6). Measurements were made at 2 mm, 5 mm, 8 mm, and 11 mm from the alveolar crest. The main variables assessed were mesiodistal interradicular width and buccal corrtical bone thickness.

Table 1: Distribution of study subjects according to vertical facial growth pattern

Group	Vertical facial growth pattern	Number of subjects	Percentage
Group I	Average Growing	30	33.33
Group II	Horizontal Growing	30	33.33
Group III	Vertical Growing	30	33.33
Total		90	100.00

The study sample consisted of 90 subjects equally distributed among the three vertical facial growth pattern groups. This ensured balanced comparison among the three groups.

Table 2: Overall mean mesiodistal interradicular width (mm) in total sample at different maxillary sites and depths

Interradicular site	2 mm from crest Mean ± SD	5 mm from crest Mean ± SD	8 mm from crest Mean ± SD	11 mm from crest Mean ± SD
4-3(Canine–1st premolar)	2.86 ± 0.41	3.20 ± 0.47	3.66 ± 0.55	4.00 ± 0.60
5-4 (1st–2nd premolar)	2.95 ± 0.38	3.36 ± 0.45	3.75 ± 0.50	3.84 ± 0.57
6-5 (2nd premolar–1st molar)	3.04 ± 0.43	3.79 ± 0.51	4.22 ± 0.58	3.57 ± 0.72
7-6 (1st–2nd molar)	2.49 ± 0.40	2.75 ± 0.47	2.91 ± 0.56	2.34 ± 0.67

The greatest overall mesiodistal interradicular width was seen between the second premolar and first molar (6-5), especially at 5 mm and 8 mm from the alveolar crest. The lowest values were seen in the first–second molar region (7-6).

Table 3: Overall mean buccopalatal bone thickness (mm) in the total sample at different maxillary sites and depths

Interradicular site	2 mm from crest Mean±SD	5 mm from crest Mean±SD	8 mm from crest Mean±SD	11 mm from crest Mean±SD
4-3 (Canine–1st premolar)	7.98±0.86	8.71±0.93	9.14±1.04	9.88±1.21
5-4 (1st–2nd premolar)	8.92±0.91	9.59±1.00	10.04±1.14	9.28±1.79
6-5 (2nd premolar–1st molar)	10.18±1.08	10.92±1.16	10.50±1.48	6.04±2.01
7-6 (1st–2nd molar)	11.50±1.23	12.22±1.28	11.34±2.18	4.31±2.43

Buccopalatal thickness was greatest in the posterior maxillary molar region, especially at the 7-6 and 6-5 sites, but it reduced markedly at 11 mm, especially in the molar region.

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JCHR (2026) 16(2), 2577-2584 | ISSN:2251-6727

Table 4: Comparison of mesiodistal width among the three vertical facial groups at 4-3 site

Depth from alveolar crest	Average growing Mean±SD	Horizontal growing Mean±SD	Vertical growing Mean±SD	F statistic	P value
2 mm	2.84 ± 0.40	2.89 ± 0.42	2.85 ± 0.41	0.12	0.887 (NS)
5 mm	3.18 ± 0.46	3.23 ± 0.48	3.19 ± 0.47	0.10	0.905 (NS)
8 mm	3.64 ± 0.54	3.69 ± 0.56	3.65 ± 0.55	0.08	0.921 (NS)
11 mm	3.98 ± 0.59	4.03 ± 0.62	3.99 ± 0.60	0.06	0.939 (NS)

NS= Not Significant

At the canine–first premolar site, no statistically significant difference in mesiodistal width was seen among the three vertical facial growth pattern groups at any depth.

Table 5: Comparison of mesiodistal width among the three vertical facial groups at 5-4 site

Depth from alveolar crest	Average growing Mean ± SD	Horizontal growing Mean ± SD	Vertical growing Mean ± SD	F statistic	P value
2 mm	2.92 ± 0.37	2.98 ± 0.39	2.95 ± 0.38	0.14	0.869 (NS)
5 mm	3.33 ± 0.44	3.39 ± 0.46	3.36 ± 0.45	0.11	0.896 (NS)
8 mm	3.72 ± 0.49	3.78 ± 0.51	3.75 ± 0.50	0.09	0.913 (NS)
11 mm	3.81 ± 0.55	3.87 ± 0.59	3.84 ± 0.57	0.08	0.923 (NS)

At the first–second premolar site, mesiodistal width did not vary significantly among average-, horizontal-, and vertical-growing subjects.

Table 6. Comparison of mesiodistal width among the three vertical facial groups at 6-5 site

Depth from alveolar crest	Average growing Mean ± SD	Horizontal growing Mean ± SD	Vertical growing Mean ± SD	F statistic	P value
2 mm	3.01 ± 0.42	3.08 ± 0.44	3.03 ± 0.43	0.16	0.854 (NS)
5 mm	3.75 ± 0.50	3.83 ± 0.53	3.79 ± 0.51	0.17	0.842 (NS)
8 mm	4.19 ± 0.57	4.26 ± 0.60	4.21 ± 0.58	0.12	0.889 (NS)
11 mm	3.54 ± 0.70	3.61 ± 0.74	3.56 ± 0.72	0.09	0.914 (NS)

NS= Not Significant

At the second premolar–first molar site, which showed the highest overall values, no statistically significant difference was observed among the three vertical facial groups at any depth.

Table 7. Comparison of mesiodistal width among the three vertical facial groups at 7-6 site

Depth from alveolar crest	Average growing Mean ± SD	Horizontal growing Mean ± SD	Vertical growing Mean ± SD	F statistic	P value
2 mm	2.47 ± 0.39	2.51 ± 0.41	2.49 ± 0.40	0.07	0.932 (NS)

5 mm	2.72 ± 0.46	2.78 ± 0.48	2.75 ± 0.47	0.09	0.912 (NS)
8 mm	2.88 ± 0.54	2.94 ± 0.58	2.91 ± 0.56	0.08	0.920 (NS)
11 mm	2.31 ± 0.65	2.37 ± 0.69	2.34 ± 0.67	0.06	0.941 (NS)

The first–second molar region had the lowest mesiodistal width overall, and the values remained comparable across all three facial growth groups.

Table 8. Intragroup comparison of mesiodistal width across sites and depths in total sample

Variable	F statistic	P value
Comparison among sites at 2 mm	10.26	<0.001*
Comparison among sites at 5 mm	19.84	<0.001*
Comparison among sites at 8 mm	27.61	<0.001*
Comparison among sites at 11 mm	21.35	<0.001*
Comparison among depths within site 4-3	18.47	<0.001*
Comparison among depths within site 5-4	20.12	<0.001*
Comparison among depths within site 6-5	32.88	<0.001*
Comparison among depths within site 7-6	8.04	<0.001*
*Significant		

A significant difference was found among different interradicular sites and also among different depths from the alveolar crest. Thus, site and depth were more important determinants of safe-zone availability than facial growth pattern.

Table 9. Pairwise comparison of key mesiodistal safe-zone sites in the total sample

Comparison	Mean difference (mm)	Std. Error	P value
6-5 at 5 mm vs 5-4 at 5 mm	0.43	0.08	<0.001*
6-5 at 8 mm vs 5-4 at 8 mm	0.47	0.09	<0.001*
6-5 at 5 mm vs 4-3 at 5 mm	0.59	0.09	<0.001*
6-5 at 8 mm vs 4-3 at 8 mm	0.56	0.10	<0.001*
6-5 at 5 mm vs 7-6 at 5 mm	1.04	0.11	<0.001*
6-5 at 8 mm vs 7-6 at 8 mm	1.31	0.12	<0.001*
*Significant			

The 6-5 region consistently showed significantly greater mesiodistal width than the other interradicular regions, especially at 5 mm and 8 mm from the alveolar crest.

Table 10. Buccopalatal thickness comparison among three vertical facial groups at 6-5 site

Depth from alveolar crest	Average growing Mean ± SD	Horizontal growing Mean ± SD	Vertical growing Mean ± SD	F statistic	P value
2 mm	10.12 ± 1.06	10.24 ± 1.10	10.17 ± 1.08	0.08	0.921
5 mm	10.86 ± 1.13	10.99 ± 1.18	10.91 ± 1.16	0.07	0.931
8 mm	10.44 ± 1.45	10.57 ± 1.51	10.49 ± 1.48	0.06	0.942

11 mm	5.98 ± 1.96	6.11 ± 2.05	6.03 ± 2.01	0.05	0.949

Discussion

The present study evaluated the influence of vertical facial height on interradicular safe zones for mini-implant placement in the maxilla from the buccal aspect, with particular emphasis on the second premolar–first molar (6-5) region. Our findings demonstrate that while interradicular dimensions vary significantly by site and depth, vertical facial growth pattern does not significantly influence these dimensions. A principal finding of this study was the absence of statistically significant differences among average-growing, horizontal-growing, and vertical-growing groups at any measured site or depth (Tables 4–7, 10). This suggests that the anatomical availability of interradicular bone for mini-implant placement** on the buccal aspect of the maxilla** remains consistent across different skeletal facial patterns. Previous CBCT investigations have reported variations in cortical bone thickness among different facial types[7,8], with some studies indicating reduced cortical bone thickness in vertical growth patterns.[9,10] However, our results indicate that mesiodistal interradicular width and **buccal bone thickness** in the posterior maxilla remain stable across growth patterns. This consistency may be explained by the fact that interradicular spacing is primarily determined by root morphology and dental arch form, which are less influenced by vertical skeletal pattern compared to cortical plate thickness. These findings align with recent CBCT analyses demonstrating minimal variation in interradicular distances across facial types, supporting the application of uniform site selection guidelines across patient populations.[11] In contrast to the lack of variation across facial types, our study revealed highly significant differences among interradicular sites and depths from the alveolar crest (Table 8). The greatest mesiodistal interradicular width was consistently observed in the 6-5 region (second premolar–first molar), particularly at 5 mm and 8 mm from the alveolar crest, with mean values of 3.79 mm and 4.22 mm, respectively (Table 2). This finding is consistent with earlier CBCT studies that have identified the posterior interdental areas as offering favourable bone dimensions for miniscrew insertion.[12,13] The natural root divergence between the second premolar and first molar creates an optimal "safe zone" capable of accommodating conventional-diameter mini-implants **from the buccal approach**. The 4-3 (canine–first premolar) and 5-4 (first–second premolar) regions demonstrated moderate interradicular widths ranging from 2.86 mm to 4.00 mm, while the 7-6 (first–second molar) region consistently showed the narrowest dimensions, with values as low as 2.34 mm at 11 mm depth (Table 2). These findings support the work of Park and colleagues, who utilized CT imaging to map safe interradicular zones and emphasized avoiding the posterior molar region due to limited interradicular space.[11,12] Our analysis of measurement depth revealed a progressive increase in mesiodistal width from 2 mm to 8 mm from the alveolar crest, followed by a decrease at 11 mm (Table 2, Table 8). This pattern is consistent with previous observations that interradicular distance increases as the measurement point moves apically from the cemento-enamel junction, reaching a maximum near the mid-root level before decreasing closer to the root apex.[5,6] The reduction in interradicular width at 11 mm may be attributed to root convergence near the apex, which represents an anatomical limitation for mini-implant placement. Based on these findings, we propose a clinically applicable classification system for the 6-5 region analogous to that described in palatal interradicular studies, adapted for buccal mini-implant placement. The "danger zone" (2–4 mm from the alveolar crest) offers limited interradicular space and carries a higher risk of root proximity. The "caution zone" (4–6 mm) provides moderate clearance and warrants careful radiographic evaluation. The "green zone" (6–8 mm) represents the optimal insertion site, where maximum interradicular divergence and adequate cortical bone engagement provide favourable conditions for mini-implant stability. **Buccal bone thickness** demonstrated a distinct pattern across sites and depths (Table 3). The posterior molar regions (7-6 and 6-5) exhibited the greatest **buccal bone thickness**, with mean values of 11.50 mm and 10.18 mm, respectively, at 2 mm depth. However, a marked reduction was observed at 11 mm depth, particularly in the 6-5 region (6.04 mm) and 7-6 region (4.31 mm). This reduction likely reflects the anatomical proximity of the maxillary sinus floor in the posterior maxilla. Previous computed tomographic examinations have similarly noted significant variations in bone thickness across different interdental areas. The marked decrease in buccal bone thickness at deeper levels in the posterior maxilla underscores the importance of avoiding excessive insertion depth to prevent sinus perforation. Clinicians should limit insertion depth to approximately 8–10 mm from the alveolar crest in this region to maintain an adequate safety margin. Furthermore, insertion angulation plays a critical role in determining the safety of mini-implant placement. When approximately 6 mm of the screw engages bone, insertion at 30° provides a horizontal clearance of approximately 5.19 mm, while

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insertion at 45° provides approximately 4.24 mm of clearance. Based on our mean mesiodistal width of 3.79–4.22 mm in the 6-5 region, an insertion angulation of 30–45° relative to the occlusal plane is recommended to optimize cortical bone engagement while maintaining adequate distance from adjacent roots. Collectively, these findings provide clinicians with evidence-based guidelines for mini-implant placement that can be applied uniformly across patients with different vertical facial morphologies, with site and depth remaining the most critical determinants of safe zone availability.

Conclusion

Within the limitations of this study, it can be concluded that vertical facial growth pattern does not significantly influence mesiodistal interradicular width or **buccal bone thickness** in the maxillary posterior region. The most important determinants of safe zone availability are the interradicular site and the depth from the alveolar crest. The second premolar–first molar (6-5) region, particularly at 6–8 mm from the alveolar crest on the buccal aspect, represents the optimal insertion site for orthodontic mini-implants. These findings provide clinicians with evidence-based guidelines that can be applied uniformly across patients with different vertical facial morphologies, simplifying treatment planning while maintaining safety and predictability.

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