RESEARCH PAPER

Comparison of Safe Zones in Interradicular Areas of Mandible for Placement of Mini Orthodontic Implants in Different Vertical Facial Heights - A Retrospective Study

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ABSTRACT

Background: Orthodontic mini-implants, commonly referred to as temporary anchorage devices, provide reliable skeletal anchorage and have become an important component of contemporary orthodontic treatment. Successful placement of these devices requires adequate interradicular space and sufficient cortical bone thickness to avoid root injury and ensure primary stability. Cone-beam computed tomography allows precise three-dimensional evaluation of alveolar bone morphology and has become a valuable tool for identifying safe insertion sites for orthodontic mini-implants.

Objective: To evaluate the interradicular distance and the distance from the buccal to lingual cortical bone in the alveolar process between the mandibular second premolar and 1st molar among individuals with different facial growth patterns using CBCT imaging.

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 to lingual cortical bone were recorded at multiple vertical levels from the cemento-enamel junction in the interradicular region between the mandibular second premolar and 1st molar. Statistical analysis was performed to evaluate variations among different vertical levels and facial growth patterns.

Results: Both interradicular distance and buccolingual distance increased progressively with increasing distance from the CEJ across all growth patterns. The region located approximately 8 mm apical to the CEJ demonstrated the greatest interradicular space and cortical bone engagement, indicating favourable anatomical conditions for orthodontic mini-implant placement.

Conclusion: The interradicular region between the mandibular 2nd premolar and 1st molar at approximately 8 mm apical to the CEJ represents the most favourable site for orthodontic mini-implant placement. In males, significant differences in bone dimensions were observed among growth patterns, whereas in females, although variations existed, they were not statistically significant. The horizontal and average growth patterns exhibited comparatively higher BL and IR values than the vertical growth pattern across males.

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INTRODUCTION

Anchorage control stands as a pivotal element in orthodontic treatment planning.[1] Ensuring the stability of the anchorage unit is crucial for controlling orthodontic anchorage.[2] In recent years, mini-implants have gained widespread acceptance as a dependable approach for achieving absolute orthodontic anchorage.[3,4,5]

Small-diameter mini-implants present numerous advantages over alternative anchorage systems, such as easy insertion and retrieval, enhanced accessibility to diverse anatomical sites, minimal patient morbidity, absence of residual surgical sequelae, and the capacity for immediate functional loading.[6,7]

The clinical success of mini-implants is governed by a multitude of factors, including their length and diameter, structural design, surface properties, surgical protocol and operator expertise, as well as bone quality and quantity, magnitude of applied force, degree of primary stability, proximity to adjacent roots, presence of attached gingiva around the screw head, and overall oral hygiene status. [8,9,10,11]

The fundamental basis of mini-implant stability lies in its mechanical interlock with the surrounding osseous structure. Suboptimal bone quality or inadequate bone volume may adversely affect retention and compromise implant stability.[3] Several studies have investigated interradicular areas suitable for mini-implants placement, commonly referred to as "safe zones.[12] Bone morphology has been associated with the success rates of mini- implants.[6,13] Cortical bone thickness is regarded as a critical determinant of the primary stability of mini-implants. Increased thickness of the alveolar cortical bone has been associated with enhanced primary stability and, consequently, improved success rates.[14,15] Moreover, the relationship between cortical bone thickness and vertical growth patterns has been substantiated, as most investigations disclose reduced cortical bone thickness in individuals with vertical growth pattern compared to those with average or horizontal growth. [16]

Previous studies have established the reproducibility of CBCT readings for alveolar bone
assessment and the reliability of CBCT in assessing interradicular space and cortical bone
thickness.[17] When it comes to measuring interradicular dimensions, three-dimensional
imaging shows excellent accuracy.[18] Additionally, minimal interradicular clearance and
sufficient cortical engagement are emphasized as requirements for mini-implant stability in
systematic research and clinical guidelines. Careful preoperative radiographic evaluation is essential to reduce complications and improve success rates.[1,19]

A paucity of literature exists specifically addressing the assessment of safe zones for mini-implant placement in the mandibular alveolar bone across varying facial growth patterns with an adequately balanced gender distribution, despite the availability of numerous CBCT-based anatomical investigations and established clinical guidelines. A comprehensive evaluation is warranted, considering the potential influence of skeletal growth patterns on mandibular alveolar bone morphology and interradicular anatomy.

Accordingly, the present prospective study aims to evaluate the safe zones in interradicular spaces within the mandibular alveolar process at different vertical levels between second premolar and 1st molar using cone-beam computed tomography (CBCT) in individuals exhibiting vertical, horizontal, and average growth patterns. The findings are expected to provide clinically relevant guidelines for the safe and effective placement of orthodontic mini-implants in the mandible.

MATERIALS AND METHODS

CBCT scans from 90 individuals were collected at Peoples University in Bhopal, Madhya Pradesh, India, and used to evaluate facial morphological patterns along with interradicular safe zones. Based on their vertical facial pattern, the individuals were categorized into three groups based on lateral cephalograms generated from the CBCT scans. The angle created by the following cephalometric measures was used to determine these facial patterns:(Fig 1)

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

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.

The inclusion criteria comprised patients aged 18–30 years with fully erupted permanent dentition (excluding third molars), with Angles Class I, II and III, no history of trauma or surgery in the craniofacial region and no prior orthodontic treatment. The exclusion criteria included patients who had undergone orthognathic surgery, those with missing or grossly decayed teeth (excluding third molars), individuals with prosthesis, and patients with cleft palate.

Sample consisted of 90 orthodontic patients, with 30 individuals each representing average, horizontal, and vertical facial morphological patterns. Each group was further subdivided on the basis of gender into 15 males and 15 females. CBCT scan projections of the patients were obtained using the following parameters: voxel size of 0.3 mm, voltage of 120 kVp, current of 6.3 mA, and a field of view (FOV) of 12 × 10. Image assessment was performed under dim lighting conditions using the Carestream 9600 CBCT scanner. CS 3D Imaging v3.10.21 Software was used to measure interradicular safe zone.

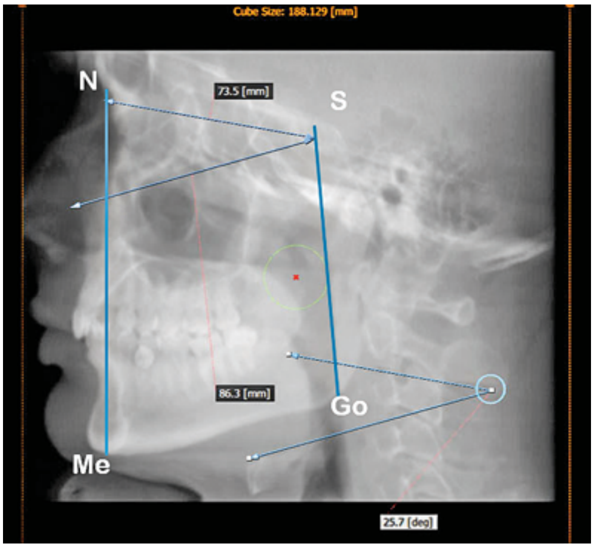


Figure 1: Measurements of facial patterns: 1) Anterior cranial base (sella [S] to nasion [N]) and mandibular plane (gonion to menton), 2) Face height index, the ratio of posterior face height to anterior face height using the measurements of distance from sella (S) to gon ion (Go) divided by the distance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

Image Orientation and Reference Points

Sagittal sections were obtained in the mandibular posterior region, specifically between the second premolar and first molar, and were oriented along the long axis of the second premolar. Along this reference axis, four standardized levels were identified at 3 mm, 5 mm, 8 mm, and 11 mm apical to the cemento-enamel junction (CEJ), following the root contour of the second premolar. (Fig 2)

Measurement Procedure

At each predefined level, corresponding axial sections were generated. The following measurements were recorded at each level:

1. Mesiodistal interradicular distance (Fig 3.A)
2. Buccolingual alveolar bone width (Fig 3.B)

Thus, while the reference points were established on sagittal sections, all linear measurements were performed on the corresponding axial images to ensure accuracy in assessing interradicular space and alveolar bone dimensions.

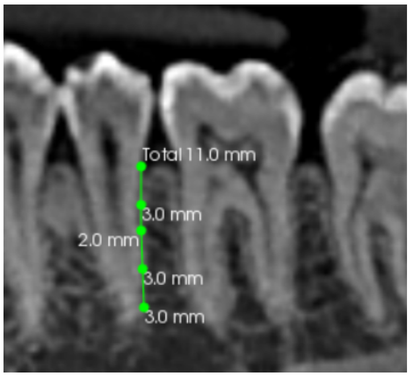


Fig 2. Sagittal view of the mandibular CBCT image. Sequential polyline parallel to root of second Premolar at 3, 5, 8, 11 mm from the CEJ.

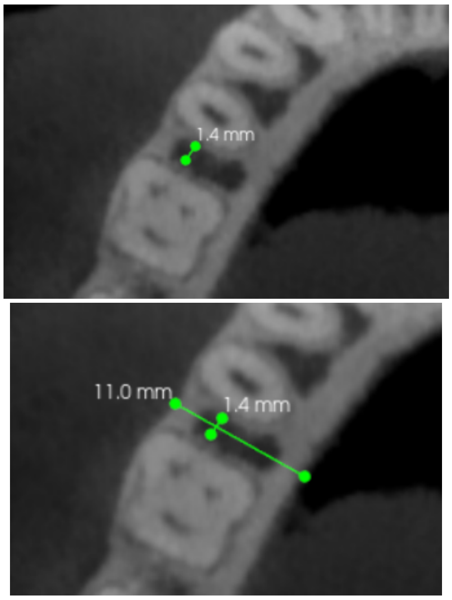


Fig 3.A, Measurement of the narrowest interradicular distance; **B,** distance between the buccal and lingual cortical bone surface.

STATISTICAL ANALYSIS

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 interradicular and buccolingual bone thickness in mandibular posterior region.

For intra-group comparisons (i.e., comparison of measurements at different distances from the CEJ within the same gender), one-way analysis of variance (ANOVA) was employed. Post hoc multiple comparison tests were performed to identify pairwise differences between levels, and results were denoted using superscript letters, where identical superscripts indicated no statistically significant difference.

For inter-group comparisons (i.e., comparison between males and females), the independent samples t-test was used. A p-value of less than 0.05 was considered statistically significant. Highly significant results were denoted where $p < 0.001$. All analyses were performed separately for different growth patterns (horizontal, average, and vertical) to assess the influence of skeletal pattern on buccolingual bone width and interdental distances.

RESULTS

The present study evaluated the buccolingual (BL) bone width and interradicular (IR) distances at varying levels from the cementoenamel junction (CEJ) (3 mm, 5 mm, 8 mm, and 11 mm), with comparisons made across genders and different growth patterns.

Interradicular Distance of mandibular cortical bone surface between 2nd PM and 1st Molar in Males and Females

The interradicular distance demonstrated a consistent increase from coronal to apical levels. In males, the mean IR distance increased from 1.50 ± 0.60 mm at 3 mm to 3.40 ± 1.05 mm at 11 mm. In females, it increased from 1.63 ± 1.55 mm to 2.96 ± 0.81 mm over the same range. This increase was statistically significant across different levels from the CEJ ($p < 0.001$). Pairwise comparisons revealed significant differences between most levels, with some overlap between adjacent levels. [Graph 1]

Buccolingual Bone Width of mandibular cortical bone surface between 2nd PM and 1st Molar in Males and Females

The mean buccolingual bone width showed a progressive increase with increasing distance from the CEJ in both males and females. At 3 mm, the mean BL width was 10.67 ± 1.05 mm in males and 10.27 ± 1.69 mm in females. This increased to 12.24 ± 1.42 mm in males and 11.71 ± 1.40 mm in females at 11 mm.

Statistically significant differences were observed across the different CEJ levels within both genders ($p < 0.001$). Post hoc comparisons indicated that the increase in BL width was significant between most levels, although some adjacent levels showed no statistically significant difference. [Graph 2]

Gender Differences in Horizontal Growth Pattern

In individuals with a horizontal growth pattern, no statistically significant gender differences were observed in buccolingual bone width at any level from the CEJ ($p > 0.05$). For interradicular distance, no significant differences were observed at 3 mm and 5 mm. However, at 8 mm, a statistically significant difference was noted ($p = 0.047$), with males showing slightly higher values. At 11 mm, the difference approached significance ($p = 0.052$), but did not reach statistical significance. [Table 1]

Gender Differences in Average Growth Pattern

In the average growth pattern group, both buccolingual and interradicular measurements did not show statistically significant differences between males and females at any distance from the CEJ ($p > 0.05$). Although males generally exhibited slightly higher mean values compared to females, these differences were not statistically significant, indicating comparable bone dimensions between genders in this growth pattern. **[Table 2]**

Gender Differences in Vertical Growth Pattern

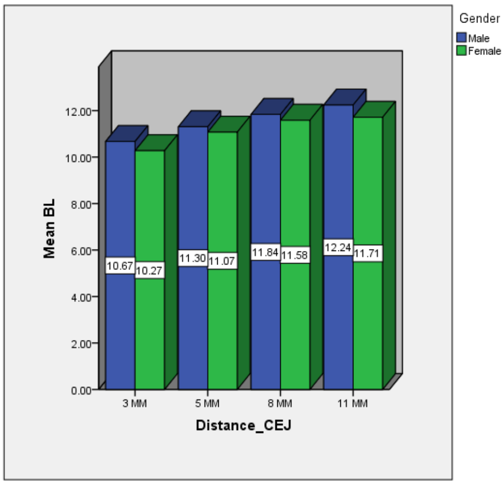
In subjects with a vertical growth pattern, no statistically significant gender differences were observed for either buccolingual bone width or interradicular distance at any level from the CEJ ($p > 0.05$). Both BL and IR values increased with increasing distance from the CEJ, consistent with the trends observed in other growth patterns. However, inter-gender differences remained statistically insignificant. [Table 3]

Comparison of Interradicular Distance and Buccolingual Bone Width Across Gender and Vertical Facial Patterns

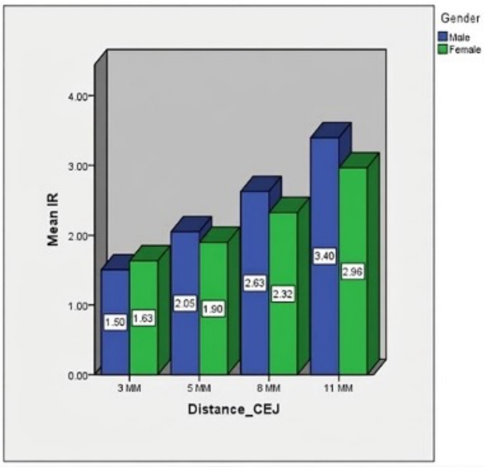
In males, both buccolingual (BL) and interradicular (IR) bone distances showed a consistent increase from 3 mm to 11 mm from the CEJ across all growth patterns. The horizontal and average growth patterns demonstrated comparatively higher BL and IR values than the vertical pattern, with the vertical pattern showing lower measurements especially at coronal levels. Statistically significant differences ($p < 0.001$) were observed at 3 mm for both BL and IR measurements, indicating notable variation among growth patterns in males. [Table 4]

In females, a similar increasing trend in BL and IR distances was observed with increasing distance from the CEJ across all growth patterns. However, the vertical growth pattern consistently exhibited lower values compared to horizontal and average patterns.

Unlike males, the differences among growth patterns in females were not statistically significant ($p < 0.001$), suggesting relatively uniform bone dimensions irrespective of growth pattern. [Table 5]



Graph 1: The comparison of the Buccolingual bone among various distances from CEJ among gender



Graph 2: The comparison of the narrowest interradicular distances among various distances from CEJ among genders

Table 1: The comparison of the distances between the buccolingual and interradicular bone among genders at various distances from CEJ in horizontal growth pattern

Distance from CEJ	Gender	BL Mean	BL Standard Deviation	P value	IR Mean	IR Standard Deviation	P value
3 MM	Male	10.79	1.30	0.518	1.53	.47	0.491
	Female	10.27	2.74		2.01	2.62	
5 MM	Male	11.42	1.28	0.981	2.11	.49	0.093
	Female	11.41	1.79		1.83	.39	
8 MM	Male	11.93	1.41	0.957	2.65	.49	0.047*
	Female	11.89	1.89		2.33	.36	
11 MM	Male	12.27	1.48	0.626	3.41	.70	0.052
	Female	11.98	1.76		2.92	.63	

Table 2: The comparison of the distances between the buccolingual and interdental bone among genders at various distances from CEJ in average growth pattern

Distance from CEJ	Gender	BL Mean	BL Standard Deviation	P value	IR Mean	IR Standard Deviation	P value
3 MM	Male	10.92	.81	0.227	1.77	.81	0.563
	Female	10.57	.76		1.62	.54	
5 MM	Male	11.77	1.01	0.179	2.25	.81	0.609
	Female	11.26	1.00		2.11	.58	
8 MM	Male	11.73	1.43	0.654	2.65	.82	0.583
	Female	11.93	1.15		2.51	.72	
11 MM	Male	12.76	1.03	0.247	3.56	1.36	0.425
	Female	12.08	1.03		2.93	1.48	

Table 3: The comparison of the distances between the buccolingual and interradicular bone among genders at various distances from CEJ in vertical growth pattern

Distance from CEJ	Gender	BL		P value	IR		P value
		Mean	Standard Deviation		Mean	Standard Deviation	
3 MM	Male	10.31	.94	0.317	1.22	.32	0.667
	Female	9.98	.81		1.27	.27	
5 MM	Male	10.73	1.25	0.685	1.79	.36	0.709
	Female	10.55	1.14		1.75	.32	
8 MM	Male	12.17	2.10	0.147	2.35	.24	0.302
	Female	10.93	1.27		2.13	.40	
11 MM	Male	11.69	1.58	0.675	3.21	1.04	0.463
	Female	11.50	1.22		3.00	.82	

Table 4: The comparison of the distances between the buccolingual and interradicular bone among genders at various distances from CEJ in various growth patterns among males

Growth pattern	Distance from CEJ	BL			IR		
		Mean	Standard Deviation	P value	Mean	Standard Deviation	P value
Horizontal	3 MM	10.79	1.30	<0.001**	1.53	.47	<0.001**
	5 MM	11.42	1.28		2.11	.49	
	8 MM	11.93	1.41		2.65	.49	
	11 MM	12.27	1.48		3.41	.70	
Average	3 MM	10.92	.81	<0.001**	1.77	.81	<0.001**
	5 MM	11.77	1.01		2.25	.81	
	8 MM	11.73	1.43		2.65	.82	
	11 MM	12.76	1.03		3.56	1.36	
Vertical	3 MM	10.31	.94	<0.001**	1.22	.32	<0.001**
	5 MM	10.73	1.25		1.79	.36	
	8 MM	12.17	2.10		2.35	.24	
	11 MM	11.69	1.58		3.21	1.04	

Table 5: The comparison of the distances between the buccolingual and interradicular bone among genders at various distances from CEJ in various growth patterns among females

Growth pattern	Distance from CEJ	BL			IR		
		Mean	Standard Deviation	P value	Mean	Standard Deviation	P value
Horizontal	3 MM	10.27	2.74	<0.001**	2.01	2.62	<0.001**
	5 MM	11.41	1.79		1.83	.39	
	8 MM	11.89	1.89		2.33	.36	
	11 MM	11.98	1.76		2.92	.63	
Ave	3	10	.76	<0.	1.	.54	<0.

rage	MM	.57		001 **	62		001 **
	5 MM	11.26	1.00		2.11	.58	
	8 MM	11.93	1.15		2.51	.72	
	11 MM	12.08	.95		2.93	1.48	
Vertical	3 MM	9.98	.81	<0.001 **	1.27	.27	<0.001 **
	5 MM	10.55	1.14		1.75	.32	
	8 MM	10.93	1.27		2.13	.40	
	11 MM	11.50	1.22		3.00	.82	

DISCUSSION

In contemporary orthodontic practice, mini-implants are extensively employed as a source of temporary anchorage, effectively preventing unwanted tooth movement, particularly anchorage loss.[20] Implant site selection is often complex, as it demands adequate interradicular space, appropriate clearance from adjacent roots and vital anatomical structures, and favourable alveolar bone density and thickness.[21]

In recent years, cone-beam computed tomography (CBCT) has been introduced and successfully utilized for the evaluation of three-dimensional structures, volumetric measurements, and the bony architecture, including the morphology of cortical bone in the maxillomandibular complex.[16] Cone-beam computed tomography is favoured for volumetric assessment in mini-screw placement planning due to its capacity for three-dimensional visualization, economic feasibility, and reduced radiation burden.[22]

A progressive increase in buccal and lingual cortical bone thickness, along with interradicular distances is observed as the measurement point moves apically from the cemento-enamel junction.[21,23] These findings are consistent with the present study, which demonstrated that as the distance from the cemento-enamel junction increases, both interradicular distance and the distance between the buccal ang lingual cortical bone surface between mandibular second premolar and 1st molar also increase. Findings from a previous study indicate that, within the interradicular space between the second premolar and first molar, sites situated approximately 10 mm apical to the cemento-enamel junction are deemed safe for mini-implant placement.[24]

Vertical facial morphology represents a critical factor in orthodontic assessment, impacting growth prediction, anchorage strategy, bite force, and functional performance. Given its association with genetically and functionally mediated bone remodelling during development, it is plausible that cortical bone thickness in the maxilla and mandible varies among different facial growth patterns. Increased alveolar cortical bone thickness has been associated with enhanced primary stability and improved clinical success rates. Additionally, a significant association exists between cortical bone thickness and vertical growth patterns, with evidence indicating that individuals with vertical growth patterns typically present reduced cortical bone thickness compared to those with normal or horizontal growth patterns.[16]

Based on CBCT measurements obtained in the present study, the posterior interdental region of the mandible between the second premolar and first molar demonstrated indicate that in males, horizontal and average growth patterns exhibited significantly greater interradicular and buccolingual bone dimensions than the vertical growth pattern, with statistically significant differences evident at the coronal level (3 mm). These results suggest that vertical facial growth pattern may influence bone availability in males, particularly in the coronal region. In contrast, in females, although a similar trend of increasing bone dimensions was observed, intergroup differences were not statistically significant, indicating a relatively homogeneous distribution of interradicular and buccolingual bone irrespective of vertical facial morphology.

CONCLUSION

Within the limitations of the present CBCT-based study, it can be concluded that both mesiodistal interradicular distance and buccolingual alveolar bone width between the mandibular second premolar and first molar increase progressively from 3 mm to 11 mm from the cementoenamel junction across all vertical facial growth patterns.

In male subjects, horizontal and average growth patterns demonstrated comparatively greater interradicular and buccolingual bone dimensions than the vertical growth pattern, with statistically significant differences observed at the coronal level (3 mm). This indicates that vertical growth pattern may influence bone availability in males, particularly in the coronal region. In female subjects, although a similar increasing trend in bone dimensions was observed, no statistically significant differences were noted among the different growth patterns, suggesting relatively consistent interradicular and buccolingual bone availability irrespective of vertical facial type.

Clinically, the findings suggest that deeper levels (8 mm and 11 mm) provide more favorable sites for mini-implant placement in both genders, provided that individual anatomical variations are carefully evaluated using CBCT. However, individualized assessment using three-dimensional imaging remains essential to ensure safe and predictable insertion of mini- implants, minimizing the risk of root injury and implant failure, thereby enhancing the effectiveness of orthodontic mini-implants.

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