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"Assessment of mandibular buccal shelf dimension in different vertical facial growth pattern and its clinical implication for buccal shelf bone screw insertion - a cross-sectional study"

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Abstract

Background:
The mandibular buccal shelf (MBS) has emerged as a reliable extra-alveolar site for orthodontic skeletal anchorage. However, anatomical variations influenced by facial growth patterns may affect the quantity of available bone and the stability of bone screws.
Objective:
To evaluate MBS dimensions in individuals with different vertical facial growth patterns and identify the most favourable site for bone screw insertion using cone-beam computed tomography (CBCT).
Materials and Methods:
A cross-sectional CBCT study was conducted on 90 subjects aged 18–30 years, divided equally into three groups according to facial growth pattern: average, horizontal, and vertical growers. CBCT scans were analyzed using CS 3D imaging software. Transverse buccal cortical bone thickness was measured at 6 mm and 11 mm apical to the cementoenamel junction (CEJ), while vertical bone dimensions were assessed at 4 mm and 5 mm apical to the CEJ from the mesial aspect of the mandibular first molar to the distal aspect of the second molar. Statistical analysis included ANOVA, Tukey's post hoc test, paired t-test, and independent t-test, with significance set at $p < 0.05$.
Results:
Mandibular buccal shelf dimensions varied significantly among facial growth patterns ($p < 0.001$). Horizontal growers exhibited the greatest overall MBS dimensions (8.98 ± 2.00 mm), followed by average growers (6.92 ± 2.04 mm), while vertical growers demonstrated the least bone availability (5.06 ± 2.14 mm). Males showed significantly greater composite MBS dimensions than females (7.67 ± 2.88 mm vs. 6.30 ± 2.09 mm; $p = 0.039$). No significant differences were observed between right and left sides, indicating bilateral symmetry. Both transverse and vertical dimensions increased progressively in the posterior direction, with the greatest measurements recorded at the distal aspect of the mandibular second molar, particularly at the 11 mm level from the CEJ.
Conclusion:
Mandibular buccal shelf dimensions are significantly influenced by facial growth pattern and gender. Horizontal growers possess the most favourable bone characteristics for skeletal anchorage, whereas vertical growers exhibit comparatively reduced bone availability. The distal aspect of the mandibular second molar represents the most suitable site for MBS bone screw insertion across all facial growth patterns. CBCT-based evaluation is recommended for individualized treatment planning and optimal selection of insertion sites and screw dimensions.

Introduction

The attainment of absolute anchorage i.e, no displacement within the anchorage unit, has consistently represented a fundamental challenge in orthodontic biomechanics, with treatment outcomes being critically dependent on the adequacy of anchorage control. Following Kanomi R's introduction of orthodontic mini -implants in 1997, there has been a paradigm shift toward skeletal anchorage systems. This technique has gained widespread acceptance owing to its ability to provide near absolute anchorage, along with advantages such as minimally invasive placement and removal, and relative cost-effectiveness.[1]

Orthodontic skeletal anchorage allows the clinician to maintain absolute anchorage throughout the course of treatment.[2] Mini-implants are inserted into various anatomical locations based on the biomechanics employed. The commonly favoured sites include the palate, lingual aspect of the maxillary alveolar process, retromolar area, and the buccal alveolar processes of both the maxilla and mandible.[3] Lately, the mandibular buccal shelf (MBS) is considered as a viable extra-alveolar site for bone screw insertion. Positioned bilaterally in the posterior section of the mandibular body, the MBS is situated buccal to the roots of the first and second molars and anterior to the oblique line of the mandibular ramus.[4] MBS has been Suggested as a dependable source of extra-alveolar (E-A) anchorage, mini-implants in MBS are recommended for retracting the entire mandibular arch. This approach aims to address severe crowding, protrusion, and mandibular prognathism without the need for orthognathic surgery.[5]

Vertical facial morphology plays a significant role in growth prediction, anchorage systems, bite force, and various functions. The close association between facial vertical dimensions and morphological changes influenced by genetics, coupled with disrupted oral respiratory functions during childhood that impact bone development, logically results in variations in cortical bone thickness among individuals with different facial heights.[2] Studies have demonstrated that individuals with hypodivergent growth patterns tend to exhibit greater cortical bone thickness in the mandibular buccal shelf region compared to hyperdivergent individuals. This can be attributed to stronger masticatory musculature and increased functional loading, which promote bone apposition and density. Conversely, hyperdivergent individuals often have thinner cortical bone and reduced bone density, potentially compromising mini-implant stability.[6] Despite the growing body of evidence supporting the use of the mandibular buccal shelf as an anchorage site, there remains considerable variability in anatomical dimensions among individuals. Factors such as age, sex, growth pattern, and ethnic background can influence bone morphology.

Cone-beam computed tomography (CBCT) has been accessible for more than a decade, offering 3-dimensional imaging with minimal distortion. While extra-alveolar mini-implants are frequently employed, various imaging exams are now available for guiding their installation. Establishing a selection criterion can furnish the orthodontist with valuable information to enhance their decision-making process.[7] Given the importance of skeletal pattern in influencing bone morphology, evaluating the mandibular buccal shelf dimensions in different vertical facial growth patterns is of particular relevance.

Therefore, the present study aims to assess the dimensions of the mandibular buccal shelf in individuals with different vertical facial heights to identify the optimal locations on MBS for the insertion of bone screw. Understanding these variations will aid clinicians in selecting appropriate insertion sites, determining optimal screw dimensions and angulation, and ultimately enhancing treatment efficiency and stability.

Material and methods

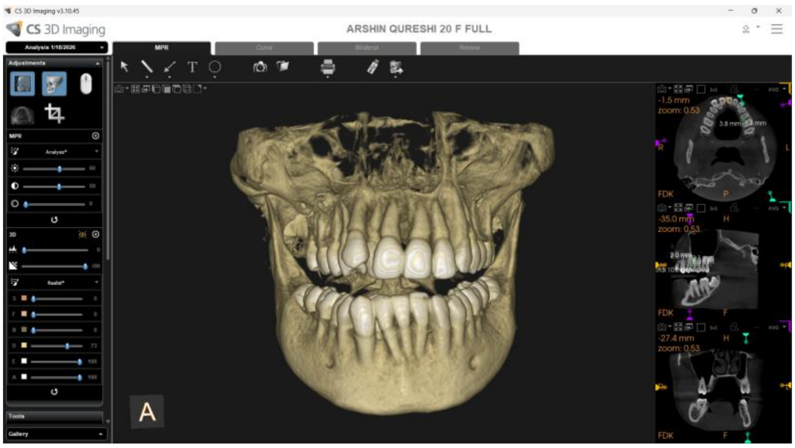
This cross-sectional CBCT study evaluated mandibular buccal shelf (MBS) dimensions in transverse and vertical planes. A total of 338 patients reporting to the Department of Orthodontics and Dentofacial Orthopedics, People's University, were screened based on predefined inclusion and exclusion criteria. Individuals aged 18–30 years with a full complement of teeth up to the second molars, no history of craniofacial trauma or surgery, and no previous orthodontic treatment were included. Patients with orthognathic surgery, prostheses, congenitally missing teeth, or grossly decayed teeth (excluding third molars) were excluded. 90 eligible subjects were selected and divided into three groups according to facial growth pattern: Average growers (Group A, n=30), Horizontal growers (Group B, n=30), and Vertical growers (Group C, n=30), with 15 males and 15 females in each group.

The variation in facial height among patients was assessed using the:

1. Mandibular Plane Angle (SN-GoGn)
2. Mandibular Plane Angle (GoMe-FH)
3. Gonial angle
4. Basal Plane angle

CBCT scans were obtained using a CS 9600 Carestream unit; Kodak Carestream Health, Rochester, NY, USA (Fig 1) (120 kVp, 6.3 mA, 0.3-mm voxel size, 12 × 10 cm field of view) and analyzed using CS 3D imaging v3.10.21 software. The acquired CBCT datasets were meticulously analyzed, and standardized measurements were performed bilaterally in the mandibular arch, specifically extending from the mesial root of the mandibular first molar to the distal root of the mandibular second molar, thereby ensuring consistency and reproducibility across all evaluated samples.

Fig. 1 CS 9600 Carestream CBCT machine.



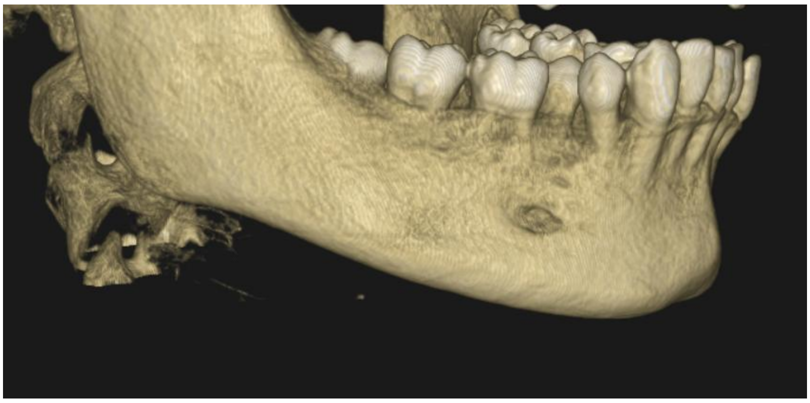


Figure 2. A Full Mouth CBCT scan; B. Area of interest (Mandibular buccal Shelf)

Transverse buccal cortical bone thickness was measured at apical levels of 6 mm and 11 mm from the CEJ (Figs 4A and 4B). From these two, horizontal lines were drawn towards the outermost part of cortical bone. These reference points were selected based on clinical relevance, as 6 mm approximates the minimum standard mini-implant length, whereas extra-alveolar mini-implant commonly exceed 10 mm in length.

Vertical buccal bone thickness was further evaluated at 4 mm and 5 mm apical to the CEJ. This was measured by drawing two horizontal reference points at 4 and 5 mm from CEJ (Fig.5A). From these two points, two vertical lines were drawn towards the lower most part of the cortex (Fig.5B), enabling precise characterization of cortical bone availability within clinically significant insertion zones.

The measurement protocol employed in this study is based on the methodology reported by Vargas et al. (2020)[7].

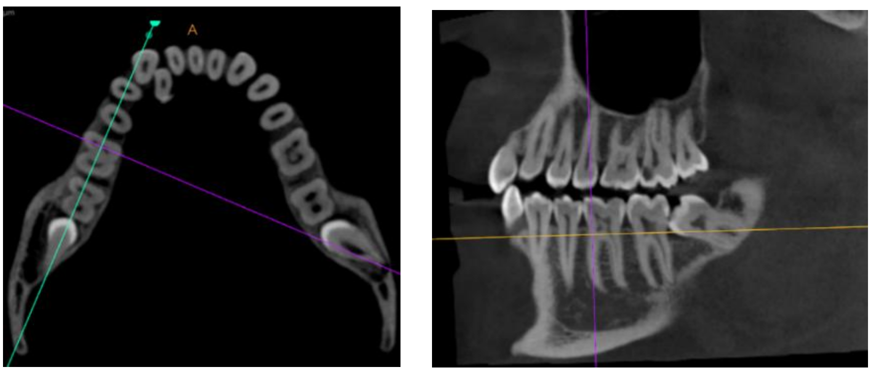


Fig. 3 Visualization procedure for the mandibular buccal shelf (MBS):

(A) Green line passes through the furcation areas;
(B) Pink line follows the long axis of the mesial root of the first molar;

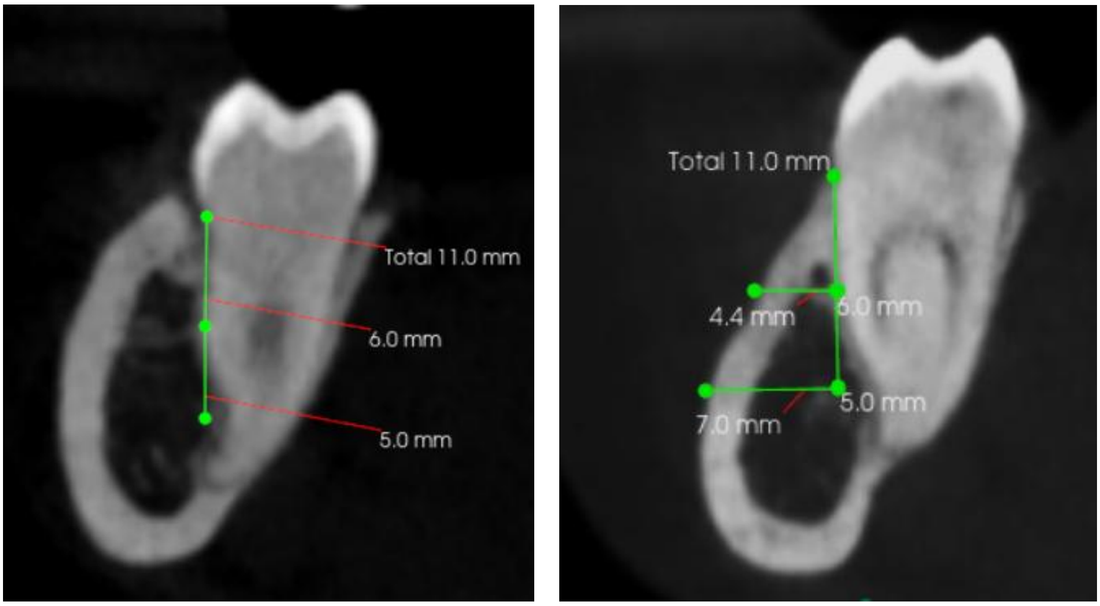


Fig. 4 A. Vertical lines were drawn at distances of 6 mm and 11 mm apically from the cementoenamel junction; B. Two perpendicular lines were then drawn from those points , extending up to the buccal cortical bone.

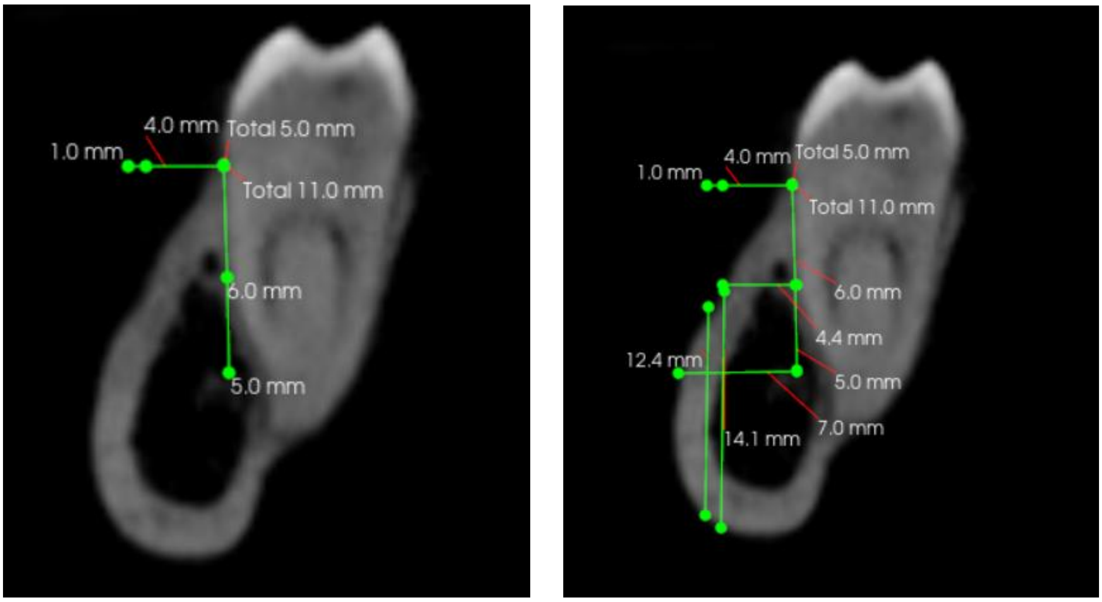


Fig. 5A Horizontal lines were drawn 4 mm and 5 mm from the cementoenamel junction point; B. Two perpendicular lines were then drawn from those points , extending up to the lower border of mandibular cortex.

Statistical analysis:

Data were analyzed using SPSS version 25.0. Descriptive statistics were expressed as mean ± standard deviation and frequency (%). Intergroup comparisons were performed using one-way ANOVA followed by Tukey's post hoc test. Paired t-test was used for right–left side comparisons, and independent samples t-test for gender-based comparisons. Associations between categorical variables were assessed using the chi-square test. Intraobserver reliability was evaluated using Kappa statistics. A p-value <0.05 was considered statistically significant.

Results

The findings indicated that mandibular buccal shelf (MBS) dimensions are affected by factors such as facial growth pattern, gender, and the specific measurement site. Individuals with a horizontal growth pattern exhibited the highest mean values, followed by those with an average growth pattern, while the vertical growth pattern showed the lowest values. Males generally demonstrated greater composite MBS dimensions than females, and this difference was statistically significant overall. At the same time, the right and left sides showed almost equal values, indicating that the mandibular buccal shelf dimensions were bilaterally symmetrical in this study.

MBS dimensions increased in the posterior direction, that is, from the mesial aspect of the first molar toward the distal aspect of the second molar. Both the horizontal and vertical measurements were greatest in the second molar distal region, especially at the 11H level, indicating that this area provided the most favourable bone support for bone screw placement. Based on the available bone dimensions, the distal aspect of the mandibular second molar was the ideal site for mandibular buccal shelf bone screw insertion in all three groups. Among the three facial growth patterns, the horizontal group offered the best bone availability and allowed the greatest insertion angle range and screw length, whereas the vertical group showed comparatively lower bone dimensions and would require more cautious clinical selection.

Table 1. Comparison of composite MBS dimension between right and left sides

Group	Right	Left	p value

	Mean	SD	Mean	SD	t value	
Average	6.92	2.04	6.98	2.05	0.00	1.000 (NS)
Horizontal	8.98	2.00	8.99	1.99	0.00	1.000 (NS)
Vertical	5.06	2.14	5.09	2.12	0.00	1.000 (NS)
Overall	6.99	2.59	7.01	2.58	0.00	1.000 (NS)

Graph 1. Comparison of composite MBS dimension between right and left sides

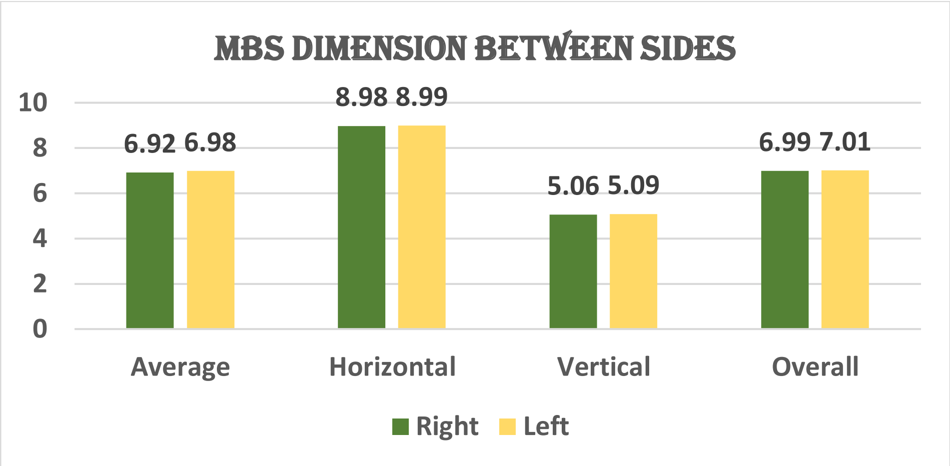


Table 2. Comparison of composite MBS dimension between males and females

Group	Male Mean	Male SD	Female Mean	Female SD	t value	p value
Average	7.47	2.15	6.36	1.87	1.23	0.233 (NS)
Horizontal	9.95	2.33	8.00	0.96	2.44	0.031*
Vertical	5.60	2.46	4.53	1.73	1.12	0.280 (NS)
Overall	7.67	2.88	6.30	2.09	2.11	0.039*

Graph 2: Comparison of composite MBS dimension between males and females

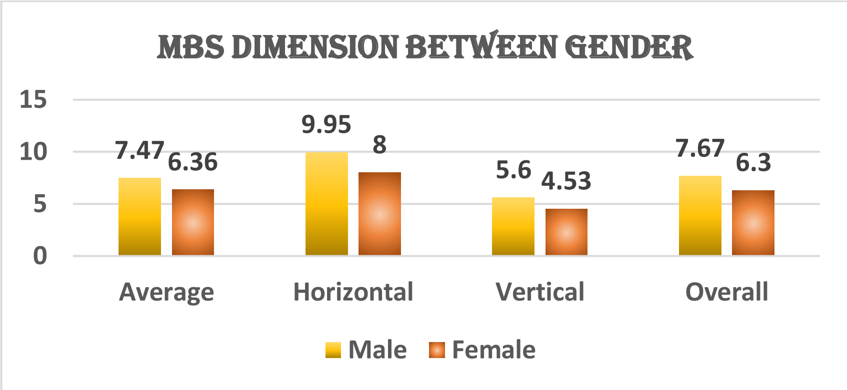


Table 3. Composite MBS dimension according to facial growth pattern

Growth pattern	Mean	SD	F value	p value
Average	6.92	2.04	18.02	<0.001*
Horizontal	8.98	2.00		
Vertical	5.06	2.14		

Graph 3: Composite MBS dimension according to facial growth pattern

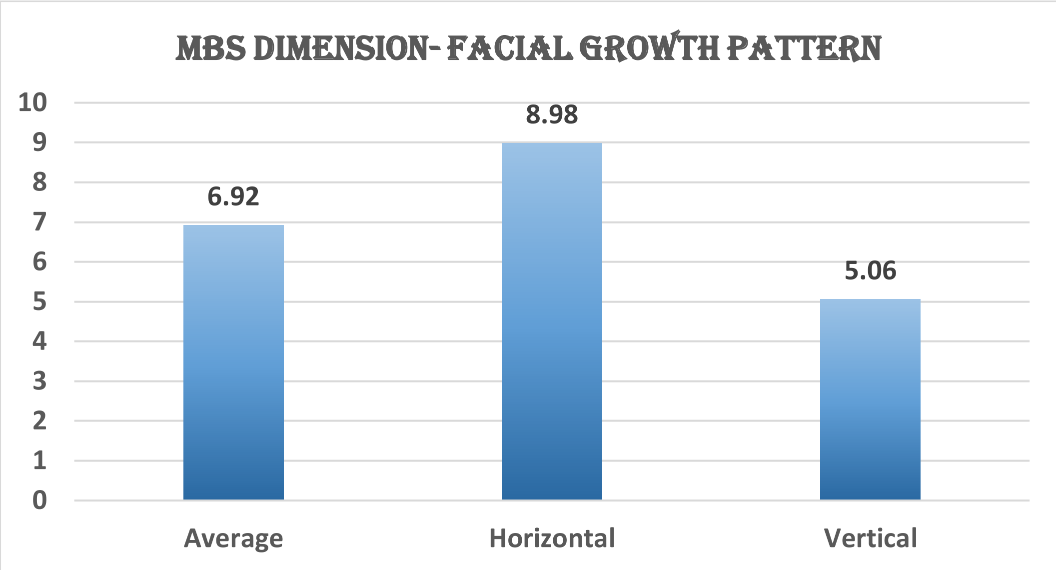


Table 4. Post hoc comparison of composite MBS dimension

Comparison	p value
Average vs Horizontal Growers	0.008*
Average vs Vertical Growers	0.024*
Horizontal vs Vertical Growers	<0.001*

Table 5. MBS dimensions at 16 measurement points according to facial growth pattern

Measurement point	Average Growers		Horizontal Growers		Vertical Growers		F value	p value
	Mean	SD	Mean	SD	Mean	SD		
6H/1MM	1.22	0.98	1.75	0.61	1.09	0.80	3.69	0.031*
6H/1MD	2.38	1.29	3.15	0.83	1.81	0.76	9.16	<0.001*
6H/2MM	3.16	1.42	5.01	0.85	2.67	0.75	27.73	<0.001*
6H/2MD	5.01	0.96	7.10	0.62	3.88	0.80	82.47	<0.001*
11H/1MM	1.54	1.17	2.56	1.05	1.55	0.94	6.07	0.004*

11H/1MD	3.43	1.06	4.38	1.03	2.79	1.01	12.11	<0.001*
11H/2MM	4.77	1.09	6.47	0.99	4.06	1.02	28.67	<0.001*
11H/2MD	5.89	0.92	7.58	0.75	5.02	0.75	51.53	<0.001*
4V/1MM	1.76	5.32	5.47	6.94	0.45	1.82	5.10	0.009*
4V/1MD	10.29	5.72	12.85	6.48	5.06	5.59	8.94	<0.001*
4V/2MM	15.53	4.04	17.89	2.24	12.41	5.98	7.94	<0.001*
4V/2MD	19.24	2.74	20.34	2.36	16.24	4.34	8.45	<0.001*
5V/1MM	1.46	4.38	3.46	5.83	0.79	3.46	1.78	0.178 (NS)
5V/1MD	5.01	5.92	9.78	6.38	2.95	4.78	7.46	0.001*
5V/2MM	12.28	4.83	16.25	2.40	7.39	5.80	18.87	<0.001*
5V/2MD	17.70	3.00	19.61	2.27	12.84	6.41	13.25	<0.001*

1MM = first molar mesial; 1MD = first molar distal; 2MM = second molar mesial; 2MD = second molar distal; 6H and 11H = horizontal measurements at 6 mm and 11 mm from CEJ; 4V and 5V = vertical measurements at 4 mm and 5 mm from CEJ

Table 6. Change in MBS thickness in posterior direction at 6 mm from CEJ

Site	Mean	SD	F value	p value
1MM	1.35	0.84	107.12	<0.001*
1MD	2.45	1.12		
2MM	3.62	1.45		
2MD	5.33	1.56		

Table 7. Change in MBS thickness in posterior direction at 11 mm from CEJ

Site	Mean	SD	F value	p value
1MM	1.88	1.15	126.20	<0.001*
1MD	3.53	1.21		
2MM	5.10	1.44		
2MD	6.16	1.34		

Table 8. Change in MBS vertical dimension in posterior direction at 4 mm from CEJ

Site	Mean	SD	F value	p value
1MM	2.56	5.50	106.58	<0.001*
1MD	9.40	6.69		
2MM	15.28	4.85		
2MD	18.61	3.65		

-Table 9. Change in MBS vertical dimension in posterior direction at 5 mm from CEJ

Site	Mean	SD	F value	p value
1MM	1.90	4.72	84.12	<0.001*
1MD	5.91	6.33		
2MM	11.97	5.79		
2MD	16.72	5.10		

Table 10. Clinically favorable site, suggested insertion angle, and optimal screw length for MBS bone screw placement

Growth pattern	Most favorable site	Mean transverse thickness at favorable site (mm)	Mean vertical dimension at favorable site (mm)	Suggested insertion angle	Suggested screw length
Average Growers	2MD at 11H	5.89	19.24	30°–40°	10 mm
Horizontal Growers	2MD at 11H	7.58	20.34	30°–45°	10–12 mm
Vertical Growers	2MD at 11H	5.02	16.24	20°–30°	10 mm

Discussion

The present study evaluated the MBS dimensions in relation to facial growth pattern, gender, and anatomical site, with the aim of identifying the most favourable location for buccal shelf bone screw insertion. The findings of this study are largely consistent with existing literature and provide further clinical insight into the optimal utilization of extra-alveolar anchorage.

One of the key findings of the present study was the significant variation in MBS dimensions among different facial growth patterns. Subjects with a horizontal (hypodivergent) growth pattern demonstrated the greatest bone dimensions, followed by average growers, while vertical growers showed the least bone availability. These findings are in agreement with the study by Gandhi et al. (2021)[8], which reported that MBS width and height vary significantly with facial type, with hypodivergent individuals showing more favourable bone characteristics for mini-implant placement. Similarly, CBCT-based studies have indicated that low-angle patients tend to exhibit denser cortical bone and increased bone thickness, enhancing primary stability of mini-implant.[9] Campoy et al. (2025)[10] noted reduced bone thickness in hyperdivergent individuals, suggesting potential limitations in these patients. Eto VM et al. (2023)[11] and Ramasamy et al. (2023)[12] observed greater cortical bone thickness in horizontal or hypodivergent individuals, while vertical growers showed comparatively reduced thickness. Gaffuri et al. (2020)[13] establish that vertical facial pattern is an important determinant of alveolar bone morphology, with hypodivergent individuals showing more favourable cortical bone characteristics.

The present study found that males exhibited significantly greater MBS dimensions compared to females. This observation aligns with general anatomical principles, as males typically have larger skeletal structures and greater cortical bone thickness. The findings of the present study are in agreement with a study by Gandhi et al. (2021)[8] demonstrating statistically significant differences in MBS dimensions between males and females, with males showing increased bone width and height. These differences can be attributed to sexual dimorphism in bone morphology, hormonal influences, and differences in muscle mass and functional loading. Eto VM et al. (2023)[11] concluded that females demonstrated significantly reduced buccal shelf bone thickness and height compared to males. Flores-Villamarín EP et al. (2025)[14] reported that males exhibited significantly greater horizontal and vertical MBS dimensions compared to females. Clinically, this suggests that mini-implant placement in females may require more careful evaluation of bone availability, particularly in borderline cases or in vertical growers. However, contrary to the present study, studies by Ozdemir et al (2013)[2], Aleluia RB et al (2021)[6] and Karim et al (2022)[15] have found no statistically significant differences in MBS between genders.

Another important finding was the lack of significant differences in MBS dimensions between the right and left sides. This is in agreement with the findings other studies demonstrating no statistically significant differences in MBS between the right and left sides.[6,10,16,17,18] Although limited studies explicitly focus on bilateral comparison, CBCT-based analyses typically assume symmetry in anatomical measurements, providing lack of an asymmetry. Therefore, the findings of this study support the reliability of using either side for mini-implant placement, provided other anatomical conditions are favourable.

A consistent trend observed in this study was an increase in MBS dimensions from the first molar region toward the second molar region at 6 mm and 11 from the CEJ. The distal aspect of the mandibular second molar exhibited the greatest bone width and height, particularly at higher levels such as 11 mm from the cementoenamel junction. The findings of the present study are in agreement with studies by other studies**.** Elshebiny et al. (2018)[3] found that the buccal shelf at the level of the second molar distobuccal cusp provides optimal conditions for mini-implant placement due to favourable cortical thickness and bone depth. Vargas et al. (2020)[7] reported that MBS thickness increases posteriorly, making the second molar region the most suitable site for mini-implant insertion. Liu H et al (2019)[19] in CBCT analyses have demonstrated that the buccal bone thickness increases progressively from the premolar region to the molar region.

Based on the findings of this study, the distal aspect of the mandibular second molar was identified as the most favourable site for mini-implant insertion across all facial growth patterns. This is consistent with the results of Aleluia R.B. et al. (2021)[6] and Abhijith et al. (2024)[17] which consistently highlights this region as the ideal location for extra-alveolar anchorage.

Escobar-Correa et al. (2021)[20] demonstrated that the mandibular buccal shelf constitutes a highly favourable osseous site for mini-implant insertion, exhibiting optimal bone characteristics, particularly in the region distal to the mandibular second molar root, where enhanced cortical thickness and bone volume contribute to improved anchorage stability. Vargas et al. (2020)[7] noted that the optimal insertion site lies buccal to the distal root of the second molar. Finite element analysis by Khosravi et al. (2025)[21], further support this finding by demonstrating that mini-implant placed distal to the second molar exhibit more favourable stress distribution and biomechanical stability**.**

The clinical success of mini-implant depends on several factors, including bone density and thickness[4], insertion site, angulation, and screw dimensions. The present study reinforces the importance of selecting an appropriate anatomical site to maximize stability and minimize complications.

The increased bone dimensions in the distal second molar region allow for:

- Increased screw length (8-12 mm)
- Optimal screw diameter (2 mm)
- Wider range of insertion angles (30°- 45°)

This is particularly advantageous in achieving stable anchorage for complex orthodontic movements such as distalization of the mandibular dentition.

According to the present study, optimal screw length is 10-12 mm. This is in agreement with Fan et al. (2025)[22] concluding that a maximum insertion length ≤ 12 mm and a maximum insertion angle ≤ 28° for placing mini-implants safely in the MBS. Sarul et al (2022)[23] recommended larger miniscrews (length 10 mm, diameter 1.8–2.0 mm) are the anchorage of choice for the MBS, although they may be associated with increased soft tissue irritation. C Mathews et al. (2021)[24] reported that, for the South Indian population, a miniscrew with dimensions of approximately 2 × 10 mm or smaller is considered appropriate for placement. Most studies indicate that 12 mm is the optimal length for the MBS; however, lengths ranging from 10 mm to 14 mm may be selected based on the specific characteristics of each patient.[25] Chang C et al. (2016)[26] reported that the angulation of the miniscrew at the optimal TAD position is approximately 38°, suggesting that the screw should be inserted at a similar angle relative to the MBS surface to closely match the axial inclination of the molar.

Conclusion

- MBS dimensions were significantly influenced by facial growth pattern, gender, and anatomical location.
- Horizontal growers exhibited the greatest bone availability, while vertical growers showed the least.
- Males demonstrated larger MBS dimensions than females, and no significant differences were observed between the right and left sides.
- Bone dimensions increased posteriorly, with the greatest horizontal and vertical measurements recorded at the distal aspect of the mandibular second molar, particularly at the 11 mm level. This region appears to be the most favourable site for buccal shelf bone screw placement across all facial growth patterns.

Credit authorship contribution statement

Amitabh Kallury, Chandrika Dubey, Rajesh Kumar Balani: Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization. Akshay Agarwal: Material and method, CBCT measurements. Surabhi Lata: Writing – Original draft, Data curation. Lokesh Gyamlani: Original draft, Data curation.

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