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Original Article

3D Assessment of the Relationship of the Mandibular Buccal Shelf with the Mandibular Canal: A CBCT Retrospective Study

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Main Points

- The site on the mandibular buccal shelf (MBS) adjacent to the distal surface of the second molar is the safest point for micro-implant (MI) insertion in the absence of impacted third molars.
- The wide variation in the distance and angulation between the MBS and the mandibular canal (MC) indicates that the MBS is not entirely safe for MI insertion, regardless of specific locations, recommending analysis of each case individually.
- There is a significant sexual dimorphism in the distance between the MBS and MC, with females exhibiting significantly smaller measurements than males.
- Given the significant anatomical variability, cone-beam computed tomography might be employed as a complementary diagnostic tool to precisely assess the MC position and determine the optimal MI insertion angulation.

ABSTRACT

Objective: This study aimed to evaluate the micro-implant safest insertion site on the mandibular buccal shelf (MBS) without compromising the integrity of the mandibular canal (MC).

Methods: This retrospective investigation included cone-beam computed tomography (CBCT) of 96 Portuguese patients (58 females and 38 males, average age of 25.5±10.2 years). Measurements were taken in four bilateral MBS sites buccal to the mandibular second molar; tangent to the distal surface (7D), distobuccal cusp tip (7CD), buccal groove (7S) and mesiobuccal cusp tip (7CM). The transversal MBS midpoint was also determined, and the maximum angulation from the transversal MBS midpoint was extracted relative to the true vertical plane. Subsequently, the distance from the MBS midpoint to the MC was calculated at this angulation. Descriptive and inferential statistical analyses were performed at $p<0.05$

Results: Significant correlations were observed among several variables and age, sex and bilateral asymmetry ($p<0.05$). The MBS transversal width and the distance from the MBS midpoint to the MC progressively increased in the posterior direction while the angulation decreased.

Conclusion: The most appropriate micro-implant insertion location compared to the other MBS investigated sites, in the absence of impacted third molars, is adjacent to the distal surface of the second molar. This finding is consistent across all age groups, sexes, and insertion sides. However, due to the demonstrated variability, taking a CBCT scan prior to mini-implant insertion might be considered to minimize the risk of injury to the inferior alveolar nerve.

Keywords: CBCT, mandibular buccal shelf, mandibular canal, mini-implants

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INTRODUCTION

Contemporary orthodontics continuously encounters the challenge of developing and implementing novel techniques, materials, and approaches to enhance the effectiveness of orthodontic treatment.[1] Over the years, emerging innovations of orthodontic anchorage systems have been notable, allowing significant advancements therapeutic possibilities. Traditionally, orthodontic anchorage could be achieved using intra-oral and extra-oral modalities. However, both approaches have limitations that might cause anchorage loss, ultimately compromising treatment objectives.[2,3] To reinforce anchorage and achieve predictable treatment results, temporary anchorage devices have emerged in clinical practice, making it possible to obtain a maximum anchorage with no or minimal movement of the anchorage unit.[4] Micro-implants (MIs) have become increasingly prevalent for their ease of placement and removal, low cost, and minimal or no requirement for patient compliance.[5]

The mandibular buccal shelf (MBS) is the vestibular posterior area of the mandible, buccal to the roots of the molars. This platform typically provides adequate bone volume and density for MI placement.[1] The MI is generally inserted nearly vertically, parallel to the molar roots; therefore, an angulated insertion technique may be necessary.[4] However, MBS bone height and thickness variation could compromise MI placement and primary stability. Numerous factors might influence the success and/or failure of MI, including aspects related to the patient (age, sex, skeletal pattern, insertion site, oral hygiene status, and smoking) or linked to the MI used (diameter, insertion technique, angulation, and force applied).[1,6]

Evaluating the approximation of the mandibular canal (MC) to a future MI position is critical to avoid injuring the inferior alveolar nerve (IAN).[7] Since the MC is an intra-osseous canal, radiographs are an essential diagnostic modality to determine the estimated position of an MI relative to the MC. Cone-beam computed tomography (CBCT) allows the determination of the MC location three-dimensionally, reducing the likelihood of causing injuries at the IAN level.[8,9]

Several investigations analysed the most appropriate MBS site for MI placement.[7,10,11] Gandhi et al.[11] compared MBS parameters, among American growing and non-growing patients, concluding that the MBS transversal width increased while its height progressively decreased from the distal root of the first molar to the distal root of the second molar in all three facial patterns without interfering with the MC, regardless of sex and age. In a Brazilian study, Eto et al.[7] reported a similar observation, concluding that the ideal MI placement site in the MBS faces the second molar's distal root, regardless of facial pattern, sex, and age. In a CBCT investigation, Elshebiny et al.[10] virtually placed an MI in MBS and digitally traced the IAN. The authors noted that the cortical bone thickness, MBS transversal width, and MI insertion depth were most favourable vestibular to the distobuccal cusp of the mandibular second molar. Despite these comparable findings, further investigations are necessary due to variations in craniofacial forms, including the MBS, among populations;[11-13] none of the performed studies have sufficiently addressed the potential MI insertion angle that can be employed without risking damage to the MC. Therefore, the primary aim of this study was to evaluate the safest insertion site for MI without compromising the integrity of the MC. Within this context, the following null hypotheses were tested:

- The MBS bone width and the location of the MC in the same region do not vary with respect to patients' age.

- The MBS bone width and the location of the MC in the same region do not vary considering the patients' sex.

- The bone width of the MBS and the location of the MC are symmetrical on both the right and left mandibular sides.

METHODS

This retrospective three-dimensional quantitative investigation was performed at Egas Moniz University Clinic. The research protocol was secured by the Ethics Committee of the Egas Moniz School of Health & Science (approval no.: PT-288/23, date: 30.11.2023), and written consents were obtained from the participants before administering the CBCT scans. This investigation, adhering to the Strengthening the Reporting of Observational Studies in Epidemiology guidelines for observational studies, was performed exclusively on Portuguese patients.[14,15]

Sample Size Calculation

The sample size was determined using the G*Power (v. 3.1.9.7, H.H.U.D., Düsseldorf, Germany). This calculation was informed by the findings of Matias et al.[13] and utilized a significance level of 5% (α=0.05) alongside an 80% power to detect a Cohen's d effect size of 0.6 in the cross-sectional width of the MBS. The sample size calculation indicated that, under these conditions, a minimum of 90 patients were required (n=45 per group for a two-group stratification).

Sample Description and Exclusion/Inclusion Criteria

A total of 1,431 patient records from individuals who attended the Egas Moniz University Clinic between January 2023 and March 2024, and underwent CBCT (exclusively for diagnostic purposes) were reviewed. Portuguese individuals who had CBCT scans showing complete bilateral MBS and mental foramen with full permanent lower dentition were selected. Patients exhibiting syndromes, apparent asymmetry, having a history of previous orthodontic treatment, or radiographic signs of periodontal disease were excluded from the study. Poor-quality CBCT scans were also excluded.

A total of 96 CBCT scans fulfilled the inclusion and exclusion criteria used in this study. Subsequently, the cohort was stratified for age and sex.

Image Acquisition and Processing

The CBCT scans were acquired using Planmeca Viso G7 (Planmeca, Helsinki, Finland) with 120 kV, 5 mA, a large field of view (20x17 cm), an exposure duration of 30 seconds, and a slice thickness of 0.45 mm. Following the protocol of As Low As Diagnostically Acceptable, the CBCT field of view adhered to being indication-oriented and patient-specific.[16] Each CBCT was constructed utilizing the Planmeca Romexis Viewer, V 6.0 software (Planmeca, Helsinki, Finland). The mandible was initially oriented in the three orthogonal planes, with the mental foramen used as a reference point to ensure that the axial plane remained parallel to the occlusal plane. Bilateral measurements were performed in four specific regions of the MBS at the level of the lower second molars (Figure 1): tangent to the distal surface, distobuccal cusp, buccal groove, and mesiobuccal cusp. In cases where the third molar was present in the MBS region, the tangent dimension to the distal surface of the second lower molar could not be obtained.

The superficial transverse midpoint of the MBS was first identified, and then the maximum insertion angle of this point was determined relative to the mandibular canal in the vertical plane. Using this angle, the distance between the midpoint of the MBS and the MC was measured (Figure 2). The transverse width of the MBS was defined as the buccolingual distance from the most buccal bony point of the shelf to the nearest bony point of the adjacent tooth. In cases where the precise position of the MC was unclear, the canal was manually traced using the Planmeca Romexis® 5 software to confirm its location.

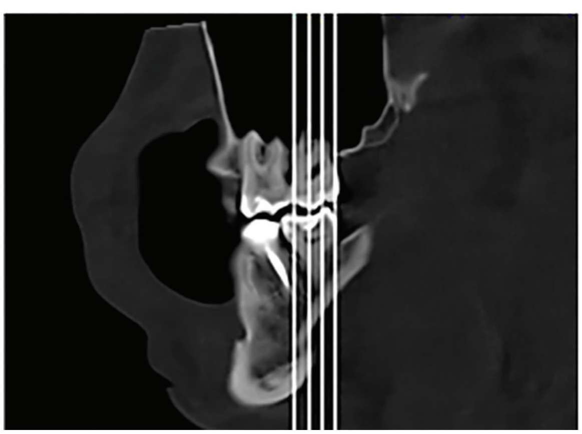

Figure 1. Sagittal view of the CBCT illustrating the four zones analyzed CBCT, cone-beam computed tomography.

Statistical Analysis

Data analyses were performed using the SPSS software (IBM, SPSS Inc,. Chicago USA) v29.0. The normality and homogeneity of variance in the data obtained from the measurements across the different points were investigated using the Shapiro-Wilk and Levene's tests, respectively. Descriptive and inferential statistical methods were applied. In the latter, Student's t-tests were performed. The mean, standard deviation (SD), and 95% confidence intervals (95%) were computed for each variable. The significance level was established at 5% ($p<0.05$).

Reproducibility Study

Around 10% of the cohort (10 cases) was re-examined by the same operator at two-week intervals. Twenty-four measurements on each CBCT (240 measurements in total) were evaluated. The Intraclass Correlation Coefficient (ICC) showed excellent intra-examiner reproducibility between the repeated corresponding measurements (ICC=0.927-0.996).

RESULTS

The total cohort comprised 96 individuals aged 25.5 (±10.2) years, 58 females (60.4%) and 38 males (39.6%) of the total sample. The cohort was stratified into two age groups: ≤22 years old: comprising 49% and >22 years old: encompassing 51%. Table 1 presents the mean, SD, minimum and maximum values of each variable. These mean measurements indicate the progressively increasing transversal width of the MBS in the posterior direction (7CM <7S <7CD <7D), on both the right (7.2 mm <7.3 mm <7.3 mm <7.6 mm) and left sides (6.7 mm <6.9 mm <7.1 mm <7.3 mm) respectively. The maximum value found for the transverse width of the MBS was 12 mm in the area tangent to the distal surface of the second lower right molar, and the minimum value was 2.9 mm in the area adjacent to the mesial cusp of the second lower right molar.

Similarly, the mean distance from the midpoint of the MBS to the closest point of the MC increased progressively towards the posterior region on the right side (12.7 mm <12.9 mm <13.0 mm <13.7 mm) and the left side (12.6 mm <12.8 mm <13.1 mm <13.7 mm). The maximum value observed was 19.6 mm, corresponding to the tangent of the distal surface of the mandibular second molar, and the minimum value was 6.3 mm in the area of the distal cusp of the lower right second molar.

In contrast, the mean insertion angle measurements showed a progressive decrease in the posterior direction, on sides, both the right (10.9°>9.4°>7.0°>4.4°) and left (9.4°>7.9°>6.2°>4.9°). The minimum angulation value was the same at all sites analyzed and was zero degrees. It was noted that the SD for all the angular measurements was high, indicating their disparity and variation compared to the mean values.

Measurement Differences Among Males and Females

The mean MBS transversal width corresponding to the mesial cusp of the mandibular second molar was significantly greater in males (7.8±1.91 mm) compared to females (6.8±1.5 mm) at $p=0.011$. No statistically significant sexual dimorphism was found ($p>0.05$) regarding the angulation possible without interfering with the CM. Regarding the distance from the midpoint of the MBS to the closest point of the CM, statistically significant differences ($p\leq0.05$) were found in all locations, and the average was higher in males than in females (Table 2).

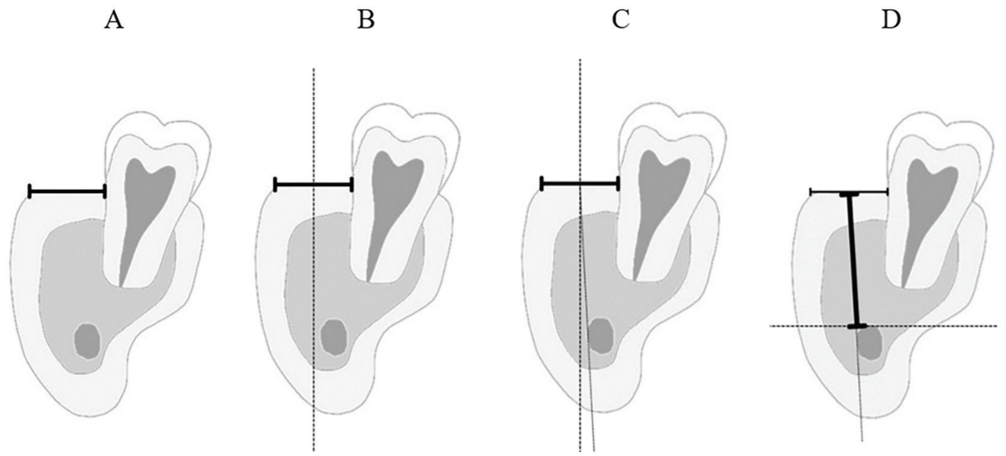

Figure 2. Illustration of the data collection method for the study sample. A: Superficial transverse width of the MBS; B: Midpoint of the initial measurement; C: Maximum angle from the anterior point to the mandibular canal relative to true vertical; D: Distance from the midpoint of the MBS to the nearest point of the mandibular canal

MBS, mandibular buccal shelf

Table 1. Descriptive and comparative measurements of the eight analyzed zones: four zones on the right side and four zones on the left side

		Width of the MBS (mm)		Angle to canal (graus)		Distance to the MC (mm)	
		Mean±SD	Max.-Min.	Mean±SD	Max.-Min.	Mean±SD	Max.-Min.
R	7D	7.6±1.6	12-5.0	4.4±4.9	17.0-0	13.7±2.3	19.4-8.6
	7CD	7.3±1.7	11.78-3.6	7.0±6.1	19.9-0	13.0±2.3	18.9-6.3
	7S	7.3±1.7	11.74-4.5	9.4±6.7	23.7-0	12.9±2.11	18.1-9.1
	7CM	7.2±1.8	11.9-2.9	10.9±7.0	29.7-0	12.7±2.02	17.6-9.0
L	7D	7.3±1.3	11.7-4.2	4.9±4.3	17.6-0	13.7±2.48	19.6-9.5
	7CD	7.1±1.2	9.1-4.0	6.2±5.3	21.8-0	13.1±2.31	17.6-9.5
	7S	6.9±1.2	10.2-4.5	7.9±6.0	12.4-0	12.8±2.33	17.3-6.8
	7CM	6.7±1.5	10.6-3.6	9.4±6.7	25.3-0	12.6±2.40	17.4-10.2

MBS, mandibular buccal shelf; MC, mandibular canal; R, right; L, left; SD, standard deviation; Max., maximum; Min., minimum; 7D, tangent to the distal surface; 7CD, distobuccal cusp tip; 7S, buccal groove; 7CM, mesiobuccal cusp tip.

Table 2. Measurement differences of the eight evaluated sites among males and females (p<0.05)

		Right								Left							
		7D		7CD		7S		7CM		7D		7CD		7S		7CM	
	Sex	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
MBS	Mean	7.7	7.3	7.2	7.1	6.9	7.5	6.8	7.8	7.3	7.3	6.6	6.8	6.8	7.0	6.6	7.2
	P	0.305		0.088		0.053		0.011		0.924		0.560		0.583		0.073	
Angle	Mean	3.7	5.1	6.1	8.2	8.5	10.3	9.5	12.1	3.9	3.6	5.3	6.1	6.9	7.3	8.3	8.4
	P	0.214		0.090		0.146		0.056		0.812		0.463		0.724		0.932	
Distance	Mean	13.2	14.8	13.2	14.6	12.9	14.1	12.6	13.8	13.3	14.7	13.5	14.5	12.9	13.9	12.7	13.7
	P	0.003		0.005		0.006		0.003		0.032		0.047		0.041		0.028	

MBS, mandibular buccal shelf; 7D, tangent to the distal surface; 7CD, distobuccal cusp tip; 7S, buccal groove; 7CM, mesiobuccal cusp tip.

Measurement Differences Between Age Groups

The mean possible insertion angle in relation to the true vertical plane was not influenced by age (p>0.05) except at three locations adjacent to the mandibular left second molar, the mesial cusp (p=0.035), the distal cusp (p=0.049), and the sulcus (p=0.048), which were significantly greater in the older age group than in the younger age group (22 years or younger). Among these values, the minimum noticed angulation was zero in both age groups, and the maximum was 25.3° in the older age group. The MBS transversal width and the distance to the MC were not influenced by age (Table 3).

Measurement Differences Between the Right and Left MBS

There were statistically significant discrepancies between the paired MBS transverse width (right and left sides) in the zones adjacent to the distal (p=0.002) and mesial (p=0.043) cusps of the lower second molars. Furthermore, there were statistically significant differences between the right and left sides of the lower second molars in the zones of the distal cusp (p=0.009), the sulcus (p<0.001), and the mesial cusp (p<0.001) concerning the possible angulation in relation to the true vertical without interfering with the CM. No statistically significant discrepancies were noted on the right and left side corresponding to the distance from the midpoint of the MBS to the closest point to the CM at p>0.05 (Table 4).

DISCUSSION

The primary objective of this retrospective 3D radiographic investigation was to identify the safest sites for MI insertion on an MBS, considering both the MI length and insertion angle to avoid interference with the MC. Additionally, this study aimed to assess the influence of sex, age, and symmetry on an MI insertion site. Understandably, the anatomy and variation of the MBS are of utmost significance for determining the optimal insertion site for an MI; therefore, avoiding iatrogenic complications.

Four distinct vestibular sites in the lower second molar region were explored bilaterally. Previous research has indicated that the lower first molar area has a less favorable bone height relative to the MC, and a narrower MBS width than the lower second molar region. Therefore, it was excluded from this study.[11] Simultaneously, the area tangent to the distal surface of the lower second molars was considered worth investigating since it had not been previously analyzed.[7,11] However, this area was often unclear in cases involving impacted third molars.

For a safe MI placement, the MBS should ideally have a minimum buccal bone width of 5 mm.[17] Our investigation observed a progressive increase in the MBS transverse width bilaterally in a posterior direction, aligning with the

Table 3. Measurement differences of the eight evaluated sites between the two age groups (p<0.05)

		Right								Left							
		7D		7CD		7S		7CM		7D		7CD		7S		7CM	
	Age	≤22	>22	≤22	>22	≤22	>22	≤22	>22	≤22	>22	≤22	>22	≤22	>22	≤22	>22
MBS	Mean	7.6	7.5	7.0	7.3	7.0	7.3	7.0	7.3	7.0	7. 5	6.7	6.6	6.9	7.0	6.7	6.9
	p	0.890		0.267		0.358		0.417		0.185		0.638		0.707		0.551	
Angle	Mean	3.4	4.8	6.1	7.6	8.1	10.3	9.3	11.7	2.7	4.6	4.6	6.7	5.9	8.1	7.0	9.6
	p	0.209		0.179		0.083		0.072		0.075		0.049		0.048		0.035	
Distance	Mean	14.2	13.5	14.2	13.3	13,6	13.0	13.4	12.7	14.0	13.5	14.4	13.4	13.7	13.0	13.4	12.8
	p	0.147		0.082		0.259		0.086		0.256		0.051		0.159		0.144	

MBS, mandibular buccal shelf; 7D, tangent to the distal surface; 7CD, distobuccal cusp tip; 7S, buccal groove; 7CM, mesiobuccal cusp tip.

Table 4. Measurement differences between the right and left MBS (p≤0.05)

		7D		7CD		7S		7CM	
	Side	R	L	R	L	R	L	R	L
MBS	Mean	7.6	7.3	7. 4	6.7	7.3	6.9	7.2	6.7
	p	0.085		0.002		0.084		0.043	
Angle	Mean	4.37	3.71	7.04	6.19	9.36	7.9	10.9	9.4
	p	0.244		0.009		<0.001		<0.001	
Distance	Mean	13.7	13.7	13.0	13.1	12.9	12.8	12.7	12.6
	p	0.977		0.477		0.776		0.925	

MBS, mandibular buccal shelf; 7D, tangent to the distal surface; 7CD, distobuccal cusp tip; 7S, buccal groove; 7CM, mesiobuccal cusp tip.

findings reported in the literature.[7,10,11,18-20] Furthermore, the distance from the MBS midpoint to the closest margin of the MC continuously increased towards the posterior direction, contradicting Gandhi et al.[11] and Eto et al.[7] observations of a lessening in bone height relative to the MC in the posterior direction. On the other hand, Elshebing et al.[10] noted a closer distance of a virtually inserted MI perpendicular to their occlusal plane in a more posterior position corresponding to an approximately vertical orientation, which support our findings that in further posterior regions, the MC is positioned more vertically. Additionally, our study found that female patients demonstrated a shorter distance to the MC in all the examined locations, which aligns with the findings of Eto et al.[7]

Determining the accurate insertion angle is critical for MI's stability and for avoiding contact with the anatomical structures in its vicinity, such as MC. Our analysis revealed significant variability in the angular values obtained, ranging from 29.7° at the vestibular mesiobuccal cusp of the right second molar to zero, the minimum value found across all locations. Although the average values suggest that the MI insertion angle is safer in more anterior regions, the finding of a minimum angle of zero degrees in all locations does not allow us to infer the possible angular capacity for MI insertion in either site. This suggests that each case must be assessed individually.

The MBS undergoes anatomical changes throughout the growth process.[21] Gandhi et al.[11] reported that growing females and males exhibited significantly wider MBS than their corresponding non-growing groups. In the older age group (>22 years), the angular capacities for MI insertion were found to be significantly greater along the mesiobuccal cusp, sulcus, and distobuccal cusp of the left second molar, with a similar corresponding distance available before reaching the MC in both age cohorts. Eto et al.[7] observed that patients aged between 20 and 40 years had significantly greater bone height relative to the MC when compared to other age groups. Gandhi et al.[11] bone height was significantly lower in growing females and males compared to their non-growing counterparts in the three locations studied (distal root of the first molar, mesial root of the second molar, and distal root of the second molar).

Our study noted that the transverse width of the MBS was significantly greater in males only at the mesial cusp of the right second lower molar. Regarding the distance to the CM, females exhibited significantly smaller measurements than males, suggesting the presence of sexual dimorphism associated with these variables. Minor asymmetry is a natural phenomenon present in individuals, influenced by genetic, environmental, or even random factors.[22] This study showed a significantly wider right MBS, vestibular to the mesial and distal lower second molar buccal cusps, than those on the equivalent left side. Furthermore, the possible MI insertion angulation without interfering with the MC was significantly greater at the distal cusp area, buccal groove, and mesiobuccal cusp of the right lower second molar than at the left corresponding sites. However, the distance from the midpoint of the MBS to the closest point of the MC was similar on both mandibular sides.

To maintain hygiene and minimize irritation to the surrounding soft tissue, an MI head should remain at least 5 mm above the level of the soft tissue.[23] In this context, the proposed size for the MI to be inserted into the MBS is 2x12, with a length of 15.8 mm. Based on this recommendation, an MI of approximately 9 to 10 mm in length would be inserted at the bone level. In the present study, the distance between the MI and the MC exhibited significant variability, ranging from 19.6 mm in the area tangent to the distal surface of the left lower second molars to 6.3 mm from the vestibular to the distobuccal cusp of the right lower second molar. The minimum measured values varied from 6.30 mm at the distobuccal cusp of the right second molars to 10.2 mm at the mesiobuccal cusp of the left lower second molars, indicating that the MBS is not entirely safe for MI insertion, regardless of the specific location.

Interestingly, in the absence of impacted third molars, the area tangent to the distal surface of the second molar appears to be the safest area for mini-implant insertion, demonstrating higher average distance values from the MC. This site also presents a more favorable average MBS transverse width. However, the minimum values noticed in this area were 8.6 mm on the right and 9.5 mm on the left, which do not allow it to be considered a completely safe zone, given that the typical bone level insertion length is 10 mm. Due to the above-reported reasons, it might be advisable to obtain a CBCT before MI insertion. However, the patient has to be informed about the increased CBCT radiation hazard and cost and contribute to the decision before inserting an MI, which relies on a 2D orthopantograph, accepting a small risk of possible iatrogenic injury to the MC.

Study Limitations

This study was performed at one center with limitations embedded in its retrospective design. More prospective multicenter investigations are recommended to consolidate the findings of our study.

CONCLUSION

Based on the analyzed data, the optimal location for MI insertion in the MBS, in the absence of impacted third molars, is the area adjacent to the distal surface of the second molar. This holds regardless of age, sex, or side of insertion. Our results indicate that this region not only has a greater MBS transverse width but also a longer distance to the MC. Nonetheless, given the observed variability in results, it is advisable to utilize CBCT as an adjunctive diagnostic tool for an MI insertion on MBS. CBCT enables a thorough examination of the MC position and aids in determining the feasible angulation across various mandibular bone structure regions, thereby mitigating the risk of injuries to the IAN.

Ethics

Ethics Committee Approval: The research protocol was secured by the Ethics Committee of the Egas Moniz School of Health & Science (approval no.: PT-288/23, date: 30.11.2023).

Informed Consent: Written consents were obtained from the participants before administering the CBCT scans.

Footnotes

Author Contributions: Concept - P.M.P., I.B.; Design - P.M.P., L.P., I.B.; Data Collection and/or Processing - J.F., L.P., J.B.; Analysis and/or Interpretation - J.F., I.B.; Literature Search - J.F., J.B.; Writing - J.F., P.M.P., L.P., I.B.

Conflict of Interest: The authors have no conflicts of interest to declare.

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