



Original Article

Comparison of Premaxillary Dimensions in Patients with Palatally and Buccally Impacted Maxillary Canines and Those with Normally Erupted Canines: A Retrospective Cone-Beam Computed Tomography Study

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Main Points

- Patients with impacted maxillary canines exhibit increased premaxillary height, depth, and volume compared to those with normally erupted canines.
- Premaxillary width does not differ significantly between impacted and non-impacted groups.
- Palatal canine impaction is associated with a significantly greater premaxillary volume than in buccal impaction.

ABSTRACT

Objective: Research into the etiology of maxillary canine impaction (MCI) has focused primarily on the transverse dimensions of the maxilla in the premolar and molar regions. The aim of this study was to evaluate and compare premaxillary width, height, depth, and volume -assessed using cone-beam computed tomography (CBCT)- among individuals with palatal MCI, buccal MCI, and normally erupted maxillary canines.

Methods: This retrospective study utilized CBCT records of patients with MCI. A total of 45 subjects were divided into three groups of 15 subjects each. Group I (palatal canine impaction), Group II (buccal canine impaction), and Group III (control group of normally erupted canines). Premaxillary width, height, depth, and volume were measured in axial, coronal, and sagittal planes using Horos software. All measurements were performed by a single calibrated examiner. One-way ANOVA with Tukey post-hoc analysis was applied; statistical significance was set at $p < 0.05$.

Results: Premaxillary height, depth, and volume were significantly greater in both palatal canine impaction (Group I) and buccal canine impaction (Group II) groups compared to controls (Group III). The increase was greatest in Group I, and this difference among the three groups was statistically significant ($p = 0.04$ for height, 0.0005 for depth, and 0.04 for volume). Premaxillary width did not differ significantly among groups ($p = 0.38$). Post-hoc analysis revealed that premaxillary depth was significantly greater in both palatal and buccal impaction groups than in controls ($p = 0.021$ and 0.002 , respectively), while premaxillary volume was significantly greater in the palatal than in the buccal canine impaction group ($p = 0.03$).

Conclusion: The findings of this study suggest that three-dimensional premaxillary morphology, as assessed by CBCT -particularly increased depth and volume- may be associated with MCI, with a more pronounced effect in palatal impaction. Premaxillary width did not demonstrate a significant association. These results indicate that localized anterior maxillary skeletal characteristics, rather than transverse maxillary deficiency alone, may influence the eruptive pathway of maxillary canines. These findings represent associations and do not establish causality. Prospective studies with larger sample sizes are warranted to validate these findings and to explore their clinical implications for early orthodontic intervention.

Keywords: Palatal canine impaction, premaxilla, impacted canines, cone-beam computed tomography, craniofacial complex, maxillary dimension

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INTRODUCTION

Maxillary canines have the longest developmental period and undergo a complex process from their origin to achieving complete occlusion.¹ Following impacted third molars, impaction of the permanent maxillary canine is the second most common type of tooth impaction.² Numerous factors can contribute to this condition, including genetics,³ discrepancies in arch length,⁴ a lengthy eruption path,⁵ and alterations in the surrounding environment caused by hard tissue structures, soft tissue lesions, or developmental anomalies such as the reduced length or absence of the lateral incisor.⁶

Buccal canine impaction is generally associated with insufficient arch length.⁷ However, the etiology of palatal canine impaction remain largely unknown. Two prominent theories have been proposed regarding its etiology: the guidance theory and the genetic theory.⁸ The guidance theory posits that maxillary canines erupt following the roots of the lateral incisors, which serve as guides. If the lateral incisor roots are missing, canines may not erupt properly and may become impacted.⁹ Conversely, the genetic theory suggests that hereditary factors are involved in palatal canine impaction.¹⁰ Additionally, researchers have investigated the connection between maxillary morphology and the frequency of palatal canine impaction.¹¹

Previous studies have suggested that craniofacial structure may be indicative of permanent canine impaction. This could be associated with the fact that the maxilla and palate originate from the neural crest cells, as do the dental epithelial cells. Additionally, variations in the expression of genes such as *MSX*, *PAX9*, and members of the *HOX* gene family seem to influence the development of both the midface and the teeth.¹²

A canine tooth might be positioned palatally if there is additional space in the maxillary bone, which can result from overdevelopment at the base of the maxilla, the absence of lateral incisors, or the stimulated eruption of adjacent teeth. In such cases, the canine becomes palatally impacted.¹³ Abnormal development of the maxillary-premaxillary suture can similarly alter the eruption trajectory of the maxillary canine.¹⁴

Previous research has analysed the lateral cephalograms of patients with palatal canine impaction and found that these patients often have a longer premaxilla.¹⁵

The advent of cone-beam computed tomography (CBCT) has enabled more accurate and objective three-dimensional assessment of craniofacial structures. Diagnostic tools for detecting canine impaction that utilise CBCT, including the KPG index¹⁶ and Easy Box¹⁷, have been developed for effective diagnosis and treatment planning to determine the position and treatment difficulty. Prior literature has focused on the transverse dimension of the maxilla in the premolar and molar region in maxillary canine impaction (MCI).¹⁸⁻²¹ As limited studies have specifically evaluated the three-dimensional morphology of the premaxilla using CBCT in patients with

impacted maxillary canines previously, the present study aimed to assess and compare the dimensions of the premaxilla in individuals with palatally and buccally impacted, and normally erupted maxillary canines. It was hypothesised that patients with palatally impacted canines would exhibit greater premaxillary dimensions compared to patients with buccally impacted canines and to non-impacted controls, suggesting a potential aetiological role of localized premaxillary morphology in palatal canine impaction.

METHODS

Ethical Approval

This retrospective observational study was approved by the Sri Ramachandra Institute of Higher Education and Research Ethics Committee for Student Projects (approval no: CSP/25/JAN/155/26, date: 27.03.2025). The research was carried out in accordance with the principles outlined in the Declaration of Helsinki (1964) and its subsequent revisions, current ethical standards, and the ALARA principle.

Sample

CBCT scans of the maxilla were collected from the archives of the Department of Orthodontics according to the following inclusion and exclusion criteria.

Inclusion Criteria

1. Subjects with a full complement of permanent dentition (except the impacted maxillary canine in the impaction groups) with or without third molars are visible on CBCT images.
2. No sex restrictions were applied.
3. Patients with retained/exfoliated deciduous teeth whose permanent successors had not yet erupted.
4. For the impaction groups, maxillary canines were classified as palatally or buccally impacted based on their three-dimensional position relative to the dental arch and alveolar process on CBCT images.
5. The control group consisted of patients with normally erupted maxillary canines and no history of dental impaction, who were matched for age and sex.

Exclusion Criteria

1. Low-quality radiographs.
2. Patients undergoing orthodontic treatment.
3. Individuals younger than 13 years of age.
4. Patients with cleft palate and any other congenital anomaly.
5. Cases in which impaction was attributable to local or secondary causes, such as odontomas, cysts, supernumerary teeth, or tumours
6. Patients with a history of traumatic dental injuries and any other factor affecting the natural path of eruption.

The sample size was calculated based on the study by Servais et al.²² Assuming a power of 80%, a total sample size of 45 subjects was determined to be sufficient to detect the expected difference between groups.

Following institutional ethical approval, CBCT records obtained between June 2021 and January 2025 were retrospectively reviewed. Patient records, including medical and dental histories, were examined consecutively to identify individuals with impacted maxillary canines. Age- and sex-matched controls without dental impaction (excluding third molars) were selected from the same database.

A total of 45 subjects (24 females and 21 males; age range, 17-30 years) met the inclusion criteria and were allocated to three groups: palatal canine impaction (n=15), buccal canine impaction (n=15), and control (n=15). In the palatal impaction group, 12 subjects had Class I malocclusion, 2 had Class II malocclusion, and 1 had Class III malocclusion. In the buccal impaction group, 13 subjects had Class I malocclusion, 1 had Class II malocclusion, and 1 had Class III malocclusion. All subjects in the control group exhibited Class I malocclusion.

The presence of palatal or buccal canine impaction in the subjects was verified using CBCT. If the diagnosis remained unclear, the senior author reviewed the records; if no agreement was reached, the individual was excluded from the study.

Each CBCT scan included the complete maxilla and mandible, with a field of view of 155x95 mm² and a voxel size of 0.25x0.25x0.25 mm. The DICOM datasets were imported and analysed using Horos software (Horos project, Geneva, Switzerland) on a Macintosh computer (MacBook Pro, Apple Computer, Inc., Cupertino, California). Quantifications were derived using the digital ruler feature in the multisector reconstruction module of the Horos software. The slice thickness was 5 mm. The segmentation of the region of interest (ROI) was performed using the closed polygon tool in Horos software. The ROI was manually delineated on each axial slice according to the cortical boundaries of the premaxilla. No fixed gray-value or Hounsfield unit threshold was applied because of the known variability of CBCT gray values. Instead, cortical boundaries were visually identified on each slice to ensure consistent anatomical segmentation while excluding adjacent anatomical structures.

The segmented ROIs from all axial slices were aggregated by the software to calculate the total premaxillary volume using slice-by-slice planimetric integration. All measurements were performed using a standardised protocol with a consistent inter-slice interval across all subjects.

Measurements

Premaxilla Width

Premaxillary width was measured as the distance between the alveolar bone at the distal surfaces of the right and left maxillary lateral incisors at the midpoint between the labial and palatal

cortical plates on the mid-axial section. The mid-axial section was taken between the inferior border of the palate and the crestal bone separating the two maxillary central incisors (Figure 1).

Premaxillary Height

On the midsagittal section, a horizontal reference line connecting the anterior nasal spine (ANS) and posterior nasal spine and a perpendicular line from the alveolar crest of the visible maxillary central incisor were drawn. Premaxillary height was defined as the distance between the alveolar crest and the point of intersection of the horizontal and the vertical lines (Figure 2).

Premaxillary Depth

The premaxillary depth was measured as the distance from the external vestibular cortex to the internal lingual cortex at three vertical reference points on the external vestibular cortex: (a) 1 mm below the cemento-enamel junction, (b) two-thirds of the root level, and (c) at the level of the ANS, oriented perpendicular to the long axis of the central incisor in the midsagittal section (Figure 3).

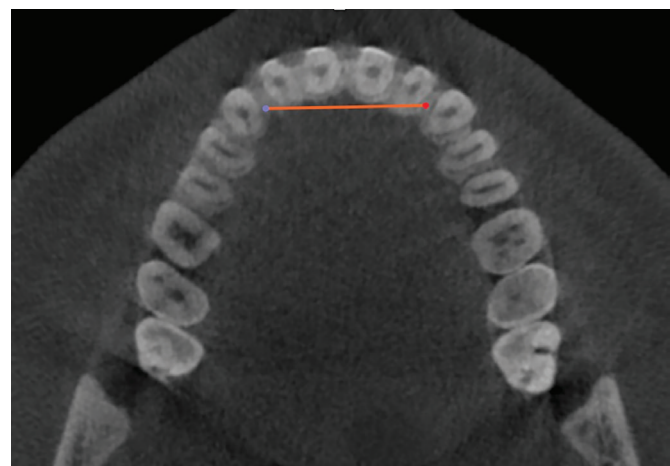


Figure 1. Measurement of the width of the premaxilla.

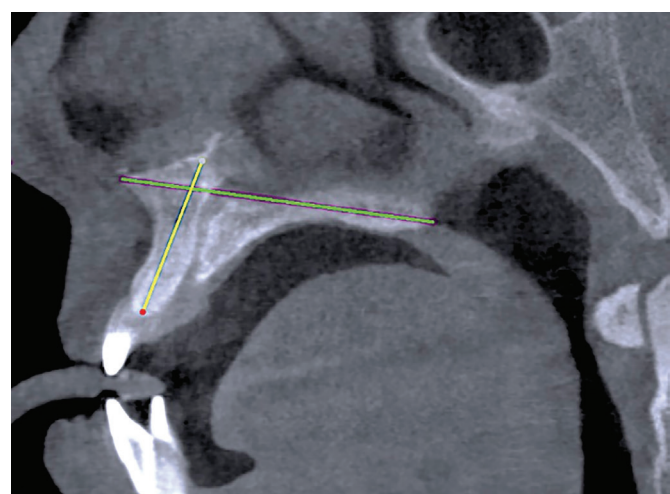


Figure 2. Measurement of the height of the premaxilla.

Premaxillary Volume

The ROI was defined by the following boundaries: laterally, the cortical bone distal to the maxillary lateral incisors bilaterally; and anteroposteriorly, from the ANS to a level corresponding to two-thirds of the length of the nasopalatine canal. A closed polygon tool was used to manually delineate the ROI on consecutive short axial slices, followed by manual planimetry to calculate volume. For each slice, the boundary of the depicted area was traced by completing a closed polygon, ensuring the final point coincided with the initial point. After delineation of all slices encompassing the full extent of the target region, volumetric analysis was performed to obtain the total bone volume (Figure 4).

All measurements for each variable were repeated by the same operator on 10 randomly selected samples after 20 days, and the intraclass correlation coefficient (ICC) was calculated to assess the reliability of the method.

Statistical Analysis

All statistical analyses were performed using R Software (version 4.2.2). Intra-examiner reliability was assessed using the ICC. A single examiner was used to eliminate inter-examiner variability. The Shapiro-Wilk test was performed to assess whether the data were normally distributed. Differences among the three groups were assessed using one-way analysis of variance, followed by Tukey’s honestly significant difference post-hoc test for pairwise comparisons. Statistical significance was set at $p < 0.05$. In addition to p-values, Cohen’s d was calculated for pairwise comparisons to assess the magnitude of differences between groups. Effect sizes were interpreted as small (0.2), moderate (0.5), and large (≥ 0.8).

RESULTS

Intra-examiner reliability was high for all parameters, with ICC values ranging from 0.989 to 0.998 (Table 1). Descriptive data on canine impaction type and premaxillary dimensions are presented in Table 2. Premaxillary height, depth, and volume were greater in both the palatal and buccal canine impaction groups than in controls (Table 2). The increase was greatest in the palatal impaction group and was statistically significant among the three groups ($p=0.04$ for height, $p=0.0005$ for depth, and $p=0.04$ for volume). There was no significant difference in premaxilla width among the three groups ($p=0.38$) (Figure 5, Table 2).

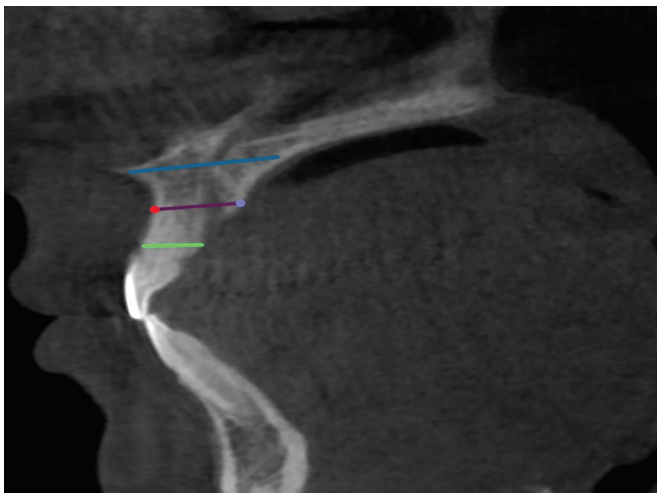


Figure 3. Measurement of the depth of the premaxilla.

Table 1. Intra-examiner reliability		
Premaxilla dimension	ICC	95% CI
Height	0.996	(0.980, 0.996)
Width	0.996	(0.994, 0.999)
Depth	0.989	(0.957, 0.993)
Volume	0.998	(0.996, 0.999)

ICC, intraclass correlation coefficient; CI: confidence interval.

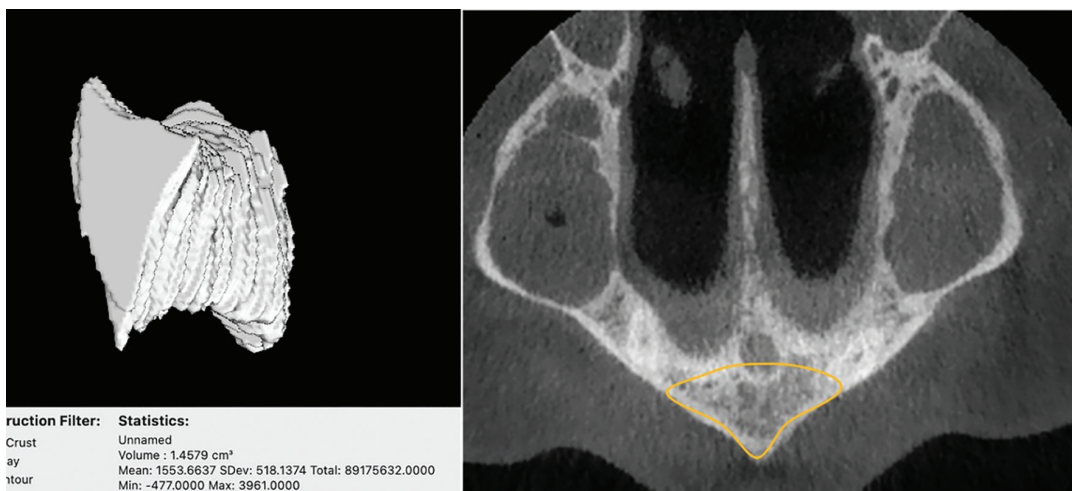


Figure 4. Measurement of the volume of the premaxilla.

Post-hoc analyses demonstrated premaxillary height was significantly greater in the palatal impaction group than in the control group ($p=0.03$) (Table 3, Figure 6). Similarly, premaxillary depth was significantly greater in the palatal impaction group than in the control group ($p=0.02$) (Table 3, Figure 7). Premaxillary depth was also significantly greater in the buccal impaction group compared to controls ($p=0.002$). Premaxillary volume was significantly greater in the palatal

impaction group than in the buccal canine impaction group ($p=0.03$) (Table 3, Figure 8).

Effect size analysis revealed large effects for premaxillary depth and volume, particularly between palatal impaction and control groups (Cohen's $d=0.78-1.08$). Premaxillary height showed a large effect size between the palatal impaction and control groups ($d=1.01$), whereas premaxillary width showed only small effect sizes across comparisons (Table 3).

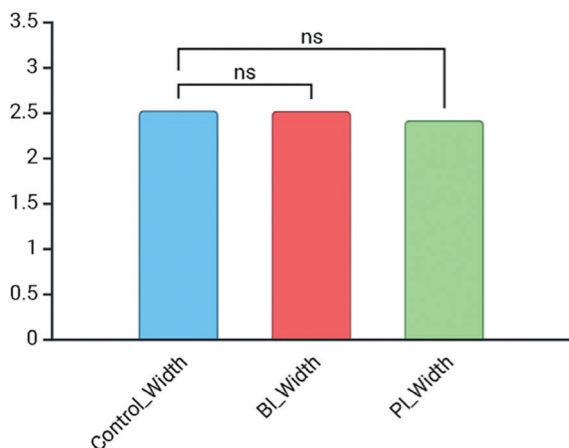


Figure 5. Post-hoc Tukey's multiple comparison test for width of the premaxilla.

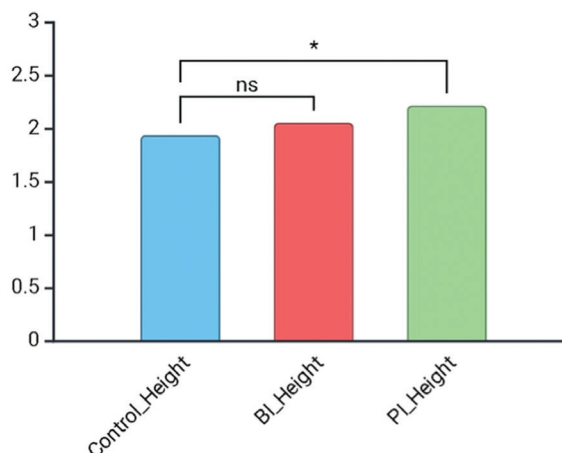


Figure 6. Post-hoc Tukey's multiple comparison test for height of the premaxilla.

Table 2. One-way ANOVA for comparison of mean premaxillary dimensions between three groups

Premaxilla dimension	Group I P		Group II B		Group III C		p-value
	Mean	SD	Mean	SD	Mean	SD	
Height	2.22 cm	0.29	2.05 cm	0.31	1.94	0.26	0.04*
Width	2.42 cm	0.24	2.52 cm	0.26	2.53	0.19	0.38
Depth	4.05 cm	0.70	3.99 cm	0.46	3.47	0.22	0.0005*
Volume	2.24 cm ³	0.72	1.68 cm ³	0.32	1.78 cm ³	0.49	0.04*

*The significance level was set at $p<0.05$. ANOVA, analysis of variance; SD, standard deviation.

Table 3. Post-hoc comparison of mean premaxillary dimensions between groups

Measurement	Comparison	p-value	Mean difference	95% CI of difference	Cohen's d
Height	Control vs. Buccal	0.53	0.116	0.377-0.145	0.39
	Control vs. Palatal	0.03	0.278	0.539-0.016	1.01*
	Buccal vs. Palatal	0.29	0.162	0.423-0.099	0.58
Width	Control vs. Buccal	0.99	0.0005	0.203-0.215	0.18
	Control vs. Palatal	0.43	0.107	0.102-0.319	0.22
	Buccal vs. Palatal	0.47	0.101	0.108-0.310	0.09
Depth	Control vs. Buccal	0.002	0.516	0.868-0.169	0.97*
	Control vs. Palatal	0.021	0.575	1.077-0.075	1.08*
	Buccal vs. Palatal	0.989	0.060	0.618-0.497	0.10
Volume	Control vs. Buccal	0.889	0.098	0.292-0.488	0.25
	Control vs. Palatal	0.146	0.46	1.023-0.116	0.78
	Buccal vs. Palatal	0.038	0.558	1.090-0.025	1.01*

*Cohen's d values were interpreted as small (0.2), moderate (0.5), and large (0.8). The significance level was set at $p<0.05$. CI, confidence interval.

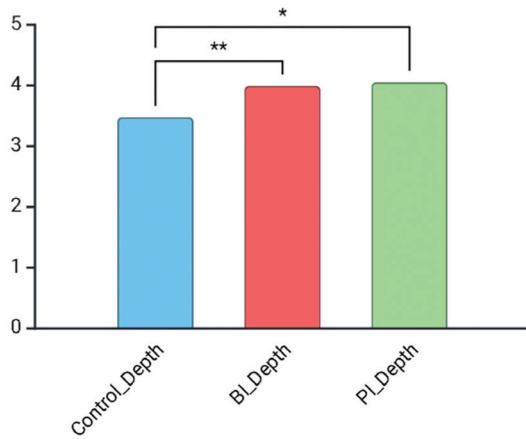


Figure 7. Post-hoc Tukey's multiple comparison test for depth of the premaxilla.

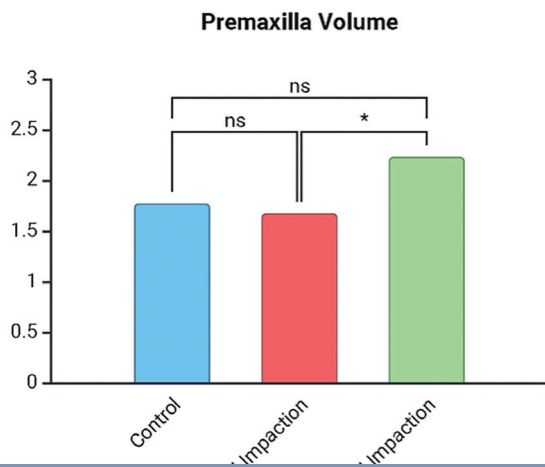


Figure 8. Post-hoc Tukey's multiple comparison test for volume of the premaxilla.

DISCUSSION

Historically, the etiology of palatal canine impaction has been attributed to genetic factors, particularly mutations involving the *MSX1* and *PAX9* genes, or to inadequate eruptive guidance caused by morphological alterations of the maxillary lateral incisor.^{9,23,24} Although premaxillary dimensions have been proposed as a potential etiological factor, this region remains relatively unexplored in orthodontic literature. The present study addressed this gap by comparing premaxillary dimensions in patients with palatal canine impaction, buccal canine impaction, and normally erupted canines, and it demonstrated distinct three-dimensional morphological variations, particularly associated with palatal impaction.

Previous studies have largely focused on transverse maxillary dimensions and their relationship with palatal canine impaction, with conflicting results. Alshalawi et al.¹² reported reduced maxillary arch width in patients with palatally

displaced canines, whereas Hong et al.⁶ found no association with transverse width and instead emphasized lateral incisor morphology. Several studies have similarly reported no significant differences in mesiodistal tooth size, arch length-tooth size discrepancy, basal maxillary width, or arch form between the impaction and control groups.²⁵⁻³¹ In contrast, Mehta et al.³² suggested that increased palatal depth, combined with reduced maxillary incisor width, may predispose to palatal impaction. Mucedero et al.³³ reported that individuals with palatally displaced permanent canines did not exhibit maxillary transverse constriction or significant variation in palatal vault morphology. While Kim et al.⁸ reported a deeper palatal vault in palatal compared with buccal canine impaction.

Notably, most previous studies evaluated palatal morphology distal to the canine region. Given the close developmental and eruptive relationship between the maxillary canine and lateral incisor, assessment of the premaxilla is clinically relevant. In the present study, premaxillary width did not differ significantly among groups. However, the premaxillary depth and height were greater in both the palatal and buccal impaction groups compared with controls, although no significant differences were observed between the palatal and buccal impaction groups. These findings partially contrast with those of Athanasiou et al.,¹⁵ who reported a significant increase in sagittal premaxillary dimension; however, that study relied on lateral cephalograms and did not evaluate three-dimensional morphology.

Although increases in premaxillary depth and height did not reach statistical significance in all pairwise comparisons, these changes may nonetheless have clinical implications. Even modest increases in sagittal or vertical dimensions can influence the spatial orientation of the developing canine, potentially altering its eruptive pathway by increasing palatal bone resistance or reducing the effectiveness of lateral incisor guidance. Such morphological variations may also impact surgical exposure, orthodontic traction mechanics, and anchorage planning in clinically complex cases.

A key finding of the present study was that premaxillary volume was significantly greater in palatal than in buccal canine impaction. This increase likely reflects the combined effect of increased depth and height, suggesting that localized three-dimensional skeletal morphology of the premaxilla, rather than generalized space deficiency, may play a more prominent role in palatal canine impaction. The absence of significant differences in premaxillary width further supports the notion that sagittal and vertical dimensions are more influential than transverse dimensions in the etiology of palatal impaction.

From a biomechanical perspective, increased premaxillary volume may influence the eruption trajectory of the maxillary canine by altering the spatial relationships and resistance patterns within the anterior maxilla. Increased premaxillary depth may position the developing canine germ palatally relative to the dental arch, while increased vertical height

can modify the eruption vector by increasing the distance the canine must traverse before reaching the occlusal plane. These morphological changes may reduce the effectiveness of lateral incisor guidance, as described by guidance theory, thereby predisposing the canine to palatal deviation during eruption. Furthermore, increased osseous volume within the premaxillary region may create greater resistance along the labial eruption pathway, further favoring palatal deviation. Although the present findings do not establish a direct causal relationship, they suggest that premaxillary morphology may act as a contributing biomechanical factor influencing the direction of canine eruption.

These factors may compromise the guidance mechanism described by Becker et al.,⁹ predisposing the canine to palatal displacement. Recent CBCT-based studies support this interpretation. Firincioglu et al.³⁴ demonstrated greater skeletal variation in palatal compared with buccal impactions. Likewise, the studies of Gudelevičiūtė et al.³⁵ and Sharhan et al.³⁶ identified significant anterior maxillary skeletal differences between impacted and non-impacted canines. Collectively, these findings reinforce the role of localised premaxillary morphology in palatal canine impaction.

The present findings support the hypothesis that increased premaxillary depth, height, and volume may contribute to an altered eruptive direction of the maxillary canine. Experimental evidence suggests that mutations in genes such as *MSX1* and *PAX9*, which are associated with palatal canine impaction, may also influence anterior maxillary development, particularly in the anteroposterior dimension.²⁴ Future studies integrating three-dimensional skeletal analysis with genetic and longitudinal eruption data are needed to clarify causal relationships.

Clinical Implications

Although impacted maxillary canines are conventionally evaluated based on three-dimensional position, proximity to adjacent roots, and available arch space, the findings of the present study suggest that premaxillary morphology may represent an additional anatomical factor, particularly in cases of palatal impaction. Increased premaxillary depth and volume may alter the spatial relationship between the lateral incisor and canine tooth germ, potentially compromising eruptive guidance.^{7,9}

This observation is supported by recent CBCT-based studies that have reported significant anterior maxillary skeletal variations in patients with impacted canines.³⁴⁻³⁶

Premaxillary dimensions assessed on CBCT should therefore be regarded as adjunctive indicators of risk rather than standalone predictive parameters. Advanced CBCT-based indices such as the KPG index¹⁶ and Easy Box¹⁷ have further highlighted the importance of three-dimensional evaluation in assessing canine impaction and treatment complexity.

Although specific threshold values cannot be established from the present data because of the limited sample size, patients exhibiting increased anterior maxillary volume and sagittal depth may benefit from closer radiographic monitoring and early interceptive measures during the mixed dentition phase.

It should be emphasized that the morphological differences identified in this study are associative rather than definitively causal. Longitudinal studies incorporating skeletal morphology, eruption timing, and genetic markers are required to establish clinically applicable predictive models.

Study Limitations

The relatively small sample size limits the generalisability of the findings; therefore, the results should be interpreted with caution and regarded as preliminary, despite adequate statistical power reported in prior literature. Volumetric measurements were obtained by manual ROI delineation on axial CBCT slices with a 5-mm inter-slice interval, which may have introduced partial-volume effects. However, identical imaging and measurement protocols were applied across all groups, permitting valid intergroup comparisons. Impacted canines were classified solely as buccally or palatally impacted without further classification according to severity parameters, as the primary objective was to assess premaxillary morphology rather than impaction complexity. Future studies incorporating larger samples, longitudinal designs, genetic data, and three-dimensional severity indices are warranted to further elucidate these relationships.

CONCLUSION

Both buccal and palatal canine impaction groups showed increased premaxillary depth compared with controls. In addition, premaxillary height and volume were increased in the palatal impaction group, with premaxillary volume being significantly greater than that observed in the buccal impaction group.

The findings suggest that localized three-dimensional variations in premaxillary morphology, particularly increased depth and volume, may be associated with palatal MCI. These results support the concept that premaxillary morphology may represent an important anatomical factor influencing canine eruption patterns.

Ethics

Ethics Committee Approval: Approved by the Sri Ramachandra Institute of Higher Education and Research Ethics Committee for Student Projects (approval no: CSP/25/JAN/155/26, date: 27.03.2025).

Informed Consent: This retrospective observational study.

Footnotes

Author Contributions: Surgical and Medical Practices - J.T., B.S., V.K.; Concept - J.T., B.S., V.K.; Design - J.T., B.S., V.K.; Data Collection and/or Processing - J.T., B.S., V.K.; Analysis and/or Interpretation - J.T., B.S., V.K.; Literature Search - J.T., B.S., V.K.; Writing - J.T., B.S., V.K.

Conflict of Interest: No conflict of interest was declared by the authors.

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