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CBCT-Based Morphometric and Volumetric Assessment of the Tongue, Soft Palate, and Palatal Height in Relation to Skeletal Class and Breathing Pattern

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Abstract

Objectives

This study aimed to evaluate the influence of skeletal class, breathing mode, age, and sex on the morphometric and volumetric features of the soft palate, tongue, and palatal height using cone-beam computed tomography(CBCT).

Materials and Methods

A total of 560 CBCT scans (295 females, 265 males; aged 8–73 years) were retrospectively analyzed. Soft palate length, width, angle, and volume; tongue height, width, area, and volume; and palatal height values were measured using Dolphin 3D software. Participants were categorized by skeletal class (I, II, III), breathing pattern (nasal/oral), and age group. Data were analyzed using robust three-way ANOVA and Bonferroni post hoc tests.

Results

In females, soft palate length ($p < 0.001$), width ($p = 0.002$), and volume ($p < 0.001$) showed significant age-related differences. Additional differences were found in soft palate width by breathing type ($p = 0.041$) and skeletal pattern ($p = 0.004$), as well as in tongue height ($p = 0.024$), tongue volume ($p = 0.017$), and tongue area ($p = 0.033$). In males, age significantly affected soft palate length ($p < 0.001$), tongue length ($p = 0.036$), tongue volume ($p < 0.001$), and tongue area ($p = 0.004$), with a notable breathing–skeletal interaction for soft palate length ($p = 0.029$). Palatal height was significantly influenced by breathing type in females ($p = 0.04$) and by both age ($p < 0.001$) and breathing type in males ($p = 0.01$).

Conclusion

Age, sex, breathing and skeletal patterns significantly influence soft palate, tongue, and palatal height morphology.

Clinical Relevance:

From a clinical standpoint; incorporating these parameters into orthodontic and surgical planning may help anticipate airway changes associated with growth, breathing habits, and skeletal discrepancies.

Introduction

The tongue and soft palate are two key anatomical structures that play a crucial role in maintaining upper airway patency and oral–maxillofacial function [1, 2]. Their morphometric and volumetric characteristics are closely associated with craniofacial development, occlusal balance, and breathing function [1]. Even minor alterations in the dimensions of these structures may compromise airway stability and influence maxillomandibular relationships, underscoring their importance in orthodontic and maxillofacial assessment [2].

The tongue is involved in essential functions such as breathing, deglutition, mastication, and articulation. Alterations in its posture or size can markedly affect airway dimensions and skeletal relationships [1, 2]. Likewise, the soft palate contributes to velopharyngeal closure and phonatory resonance, and its elongation or volumetric changes have been strongly linked to obstructive sleep apnea [3]. Beyond these two structures, palatal height has recently gained attention as a determinant of transverse maxillary development and airway morphology, with mouth breathers frequently exhibiting narrower and deeper palatal vaults[4, 5].

Sexual dimorphism and skeletal discrepancies further modulate these relationships. CBCT-based studies have consistently demonstrated larger tongue and soft palate volumes in males [6, 7], while skeletal Class II and III malocclusions have been associated with altered tongue posture and velar morphology [8, 9]. Breathing mode is another critical determinant, as mouth breathing has been linked with increased palatal height, elongated soft palates, and compromised tongue posture [10, 11]. However, most prior studies have evaluated these parameters in isolation or within limited populations, providing only a partial understanding of their combined effects.

Cone-beam computed tomography (CBCT) has become the preferred imaging modality for such evaluations, as it enables three-dimensional analysis with relatively low radiation exposure and high diagnostic accuracy [12, 13]. Despite these advantages, few studies have simultaneously examined the tongue, soft palate, and palatal height across age, sex, skeletal class, and breathing type within a single multifactorial framework.

To our knowledge, no previous CBCT-based study has simultaneously assessed the tongue, soft palate, and palatal height using a multifactorial robust ANOVA approach. Based on this background, the present study aimed to comprehensively evaluate the morphometric and volumetric features of these structures using CBCT. A three-way robust ANOVA model was applied to analyze the main and interaction effects of age, sex, skeletal class, and breathing type. We hypothesized that these parameters would show significant differences according to skeletal class and age, display sex-specific patterns, and reveal multifactorial interactions not detectable through univariate analyses. The null hypothesis stated that skeletal class, breathing type, and age would not significantly affect the measured parameters.

Methods

Ethical Approval

Ethics approval for this retrospective study was obtained from the Necmettin Erbakan University Faculty of Dentistry, Drug and Non-Medical Device Research Ethics Committee on 05.25.2023 (Protocol no: 2023/299), confirming its scientific and ethical appropriateness.

Study Population and Power Calculation

CBCT images obtained for diagnostic purposes from patients attending the Department of Oral and Maxillofacial Radiology, Necmettin Erbakan University, between February 2019 and October 2024, were retrospectively analyzed.

A priori power analysis was performed using G*Power v3.1.9.7 with ANOVA parameters set at a 95% confidence level (1–α), 95% power (1–β), and an assumed medium effect size (Cohen's f = 0.30) [14]. The minimum required sample size was 240. To further strengthen statistical power, a larger cohort of 560 scans was included.

Inclusion Criteria:

The study included patients aged ≥ 8 years with no congenital or acquired craniofacial anomalies, history of craniofacial trauma or surgery, cleft lip/palate, systemic syndromes, or missing teeth affecting occlusion, and with CBCT images of optimal diagnostic quality allowing clear identification of reference points.

Exclusion Criteria:

Patients were excluded if they had congenital or acquired craniofacial anomalies, a history of craniofacial trauma or surgery, cleft lip/palate, systemic syndromes, missing teeth affecting occlusion, suboptimal CBCT image quality, or unclear reference points.

CBCT Acquisition Protocol

In this retrospective study, CBCT images of 560 male and female patients aged 8-73 years with high diagnostic quality who met the inclusion criteria were analyzed. The CBCT images used in the study were obtained with Morita 3D Accuitomo 170 and NewTom GiANO 3D devices. The Morita 3D Accuitomo 170 (J Morita MFG Corp., Kyoto, Japan) was operated at 90 kVp and 5 mA, with an irradiation time of 17.5 seconds, 0.25 mm voxel size, 140 mm × 100 mm FOV, 360° data acquisition and no additional filtering. The NewTom GiANO 3D device (Verona, Italy) was operated at 90 kVp and 10 mA, with an irradiation time of 18 seconds, 0.15 mm voxel size, 140 mm × 100 mm FOV, 360° data acquisition and no additional filtering. Both devices were calibrated before each patient, and imaging was performed by the same technician following standardized protocols. As two different CBCT systems were used, potential variability in voxel size was minimized by calibration; however, this factor is acknowledged as a methodological limitation [15].

Measurement Procedure

All scans were saved in DICOM format and analyzed with Dolphin 3D Imaging Software (Dolphin Imaging & Management Solutions®, Chatsworth, CA, USA). Measurements were performed on 3D reconstructions in sagittal, axial, and coronal views. A single examiner (B.O.-3 years' experience) performed the measurements, blinded to skeletal class and respiratory type to minimize bias. Measurement reliability was assessed by repeating all measurements on 50 randomly selected scans after two weeks. Inter-observer reliability was tested by a second examiner (16 years' experience). Intraclass correlation coefficients (ICC) >0.90 were considered excellent [16].

Three-Dimensional Cephalometric Measurements

In the three-dimensional cephalometric analysis; the length, width, and angle values of the soft palate were measured. Accordingly, the soft palate length was measured as the distance between the posterior nasal spine (PNS) and the most distal point of the soft palate (P) **(Figure 1a)**[17]. The soft palate width was measured as the distance between the SP1 point, which defines the anterior border of the soft palate, and the SP2 point, which defines the posterior border of the soft palate (**Figure 1b**)[18]. The soft palate angle was measured as the angle between the line drawn from the anterior nasal spine (ANS) to the PNS and the line drawn from the posterior nasal spine (PNS) to the most distal point of the soft palate (P)**(Figure 1c)**[17].

Figure 1. Sagittal CBCT images show the soft palate length (a), soft palate width (b), and soft palate angle (c). PNS: Posterior nasal spine, point determining the posterior border of the hard palate; P: The most extreme point of the soft palate; SP1: Point determining the anterior border of the soft palate; SP2: Point determining the posterior border of the soft palate; ANS: Anterior nasal spine; PNS: Posterior nasal spine; P: The most extreme point of the soft palate.

The soft palate volume was calculated as the volume encompassed within the sagittal boundaries of the soft palate, extending from the PNS to the P **(Figure 2b)**[19]. The height, width, area, and volume values of the soft tissue of the tongue were measured. Tongue height was measured as the length of the vertical bisector from the dorsal surface of the tongue to the line between the base of the epiglottis and the tip of the tongue. Tongue width was measured as the length between the base of the epiglottis (the base of the epiglottis is the point where the epiglottis and the base of the tongue intersect) and the tip of the tongue **(Figure 2a)** [20]. Tongue area and volume were calculated as the cross-sectional area and volume defined by lines connecting the most superior and anterior point of the tongue dorsum and hyoid bone corpus (H), the base of the epiglottis (EB), the most distal point of the tongue (Tt), and the most posterior point of the mandibular symphysis (RGn) **(Figure 2b)** [19].

Figure 2. Sagittal CBCT images show tongue height and width (a), and the borders of the tongue (red) and soft palate (green). Tt: Point defining the tip of the tongue; RGn: Most posterior-inferior point of the mandibular symphysis; H: Center of the hyoid bone; Ep: Epiglottis.

The palatal height value was measured as the distance from the mid-deepest point of the palate to the line connecting the distolingual tubercles of the upper first molars **(Figure 3)** [21].

Figure 3. Coronal CBCT section shows palatal height.

Participant Grouping Criteria

Sex-based categorization was applied in this study. A total of 560 CBCT scans were analyzed, comprising 295 female and 265 male patients. Participants ranged in age from 8 to 73 years and were stratified into five age groups for subgroup analysis: 8–18 years, 19–29 years, 30–40 years, 41–51 years, and over 52 years.

Skeletal classification was determined by calculating the ANB angle on sagittal sections of the CBCT images using Dolphin 3D software (Dolphin Imaging & Management Solutions®, Chatsworth, CA, USA), based on the principles of Steiner analysis [22]. The ANB angle was obtained by subtracting the SNB (sella–nasion–point B) angle from the SNA (sella–nasion–point A) angle, which reflect the anteroposterior relationship of the maxilla and mandible to the cranial base. All measurements were performed on mid-sagittal slices aligned with standard cephalometric reference planes. Based on the measured ANB values, patients were categorized into three skeletal classes: Class I (ANB angle between 0° and 4°), Class II (ANB > 4°), and Class III (ANB < 0°).

The breathing pattern of each participant was classified as either nasal or oral based on the “hyoid triangle” technique, applied to sagittal CBCT sections using Dolphin 3D software (Dolphin Imaging & Management Solutions®, Chatsworth, CA, USA). This method involves constructing a triangle using three anatomical landmarks: the anterior-inferior point of the third cervical vertebra (C3), the most anterior point of the hyoid bone, and the retrognathion (RGn). In this configuration, the RGn–C3 line serves as the base, and a triangle is formed by connecting these three points. When the hyoid bone is positioned above the RGn–C3 plane, the triangle has a superior vertex and is considered a “negative triangle,” indicating an oral breathing pattern (**Figure 4a, c**). Conversely, when the hyoid lies below the RGn–C3 line, the triangle takes on a “positive” configuration, which is indicative of nasal breathing (**Figure 4b, d**) [23].

Figure 4. Sagittal CBCT images illustrating the classification of breathing patterns using the hyoid triangle technique. (a, c) Oral breathing pattern: the hyoid bone is positioned above the RGn–C3 plane, forming a negative hyoid triangle. (b, d) Nasal breathing pattern: the hyoid bone is located below the RGn–C3 plane, forming a positive hyoid triangle. RGn: Most posterior-inferior point of the mandibular symphysis; Hyoid: Center of the hyoid bone; C3: Anterior-inferior point of the third cervical vertebra.

To assess measurement reliability, 50 CBCT scans were randomly selected for both intra- and inter-observer evaluations. Intra-observer reliability was assessed by having the primary examiner (BO), with three years of experience in oral and maxillofacial radiology, repeat all measurements after a two-week interval. For inter-observer reliability analysis, a second examiner (GM), with sixteen years of experience in the same field, independently performed the same measurements on the selected scans. Both observers followed identical measurement protocols. Intraclass correlation coefficients (ICC) were

calculated for both assessments, and values above 0.90 were considered indicative of excellent agreement [24].

Statistical Analysis

Data analysis was performed with JAMOVI V2.3.22 (The Jamovi Project, Sydney, Australia). Compliance with normal distribution was evaluated by Shapiro-Wilk test. For the comparison of non-normally distributed data according to age, respiratory and skeletal pattern groups, three-way Robust ANOVA was applied using the Walrus package. Multiple comparisons were performed with the Bonferroni post-hoc test. Effect sizes (η^2) were reported for significant results Analysis results are reported as pruned mean ± standard error of the mean for quantitative data. Statistical significance level was accepted as $p<0.05$.

Results

A total of 560 participants (295 females, 265 males) with a mean age of 33.74 ± 14.96 years were included. Of these, 28.6% (n = 160) were oral breathers and 71.4% (n = 400) were nasal breathers (***A1***).

Descriptive statistics for all morphometric and volumetric parameters are summarized in ***A2***. The mean soft palate length was 36.33 ± 5.10 mm, width 9.94 ± 2.10 mm, angle 127.10° ± 8.18°, and volume 3627.67 ± 2322.75 mm^3. The mean tongue length was 74.31 ± 8.10 mm, height 34.46 ± 6.18 mm, area 12,642.85 ± 2307.14 mm^2, and volume 103,123.76 ± 22,266.33 mm^3, while the mean palatal height measured 18.97 ± 4.84 mm.

In females, soft palate length varied significantly across age groups ($p < 0.001$), showing an overall increase with age. Multiple comparisons revealed that the nasal-breathing Class I group aged 8–18 years had significantly shorter soft palates than the oral-breathing Class I group aged 30–40 years. No main effects of breathing type or skeletal class were detected ($p = 0.43$ and $p = 0.35$, respectively). However, the three-way interaction of age, breathing, and skeletal pattern was significant ($p = 0.016$) (***A3***). In males, length was also affected by age ($p < 0.001$), and a breathing × skeletal pattern interaction ($p = 0.029$) indicated that nasal-breathing Class III males exhibited shorter soft palates than nasal-breathing Class I counterparts.

Soft palate width in females differed significantly with age ($p = 0.002$), being greater in the 41–51-year group than in the 8–18 and 19–29-year groups. Significant effects of both breathing type ($p = 0.041$) and skeletal pattern ($p = 0.004$) were observed, with wider soft palates in oral breathers and Class II females. In males, no significant differences were found for any factor or interaction ($p > 0.05$) ***(Table 1).***

In both females and males, no significant differences were found in soft palate angle according to age, breathing type, or skeletal pattern, and no significant interaction effects were observed (all $p > 0.05$) ***(A4)***.

Soft palate volume exhibited a strong age effect in females ($p < 0.001$), increasing markedly from adolescence to middle age. The 8–18 and 19–29-year groups had significantly lower volumes than all older groups. Breathing type and skeletal class had no significant influence ($p = 0.67$ and $p = 0.713$,

respectively). In males, neither age nor breathing nor skeletal pattern yielded statistically significant differences ***(A5)***.

In females, tongue length did not differ significantly among age groups, breathing types, or skeletal classes ($p > 0.05$). In males, tongue length varied significantly across age groups ($p = 0.036$), though post-hoc comparisons did not reveal specific pairwise differences, suggesting a general trend of increasing tongue length with age ***(A6)***.

Tongue height in females differed significantly across skeletal classes ($p = 0.024$), being greater in Class II than in Class I and III, but showed no effects of age or breathing type ($p = 0.48$ and $p = 0.67$). No significant differences were observed in males ($p > 0.05$) ***(Table 2)***.

Tongue volume exhibited the most consistent age-related variation in both sexes. In females, tongue volume increased significantly with age ($p < 0.001$), and significant differences were also detected among skeletal classes ($p = 0.017$), with Class II showing greater volumes than Class I. In males, age was again highly significant ($p < 0.001$), with markedly lower tongue volumes in the 8–18-year group compared to older age groups, while breathing and skeletal pattern effects remained nonsignificant ***(Table 3)***.

Tongue area followed a pattern similar to tongue volume. In females, it differed significantly across age groups ($p < 0.001$) and skeletal classes ($p = 0.033$), with larger areas in Class II females. In males, tongue area also differed with age ($p = 0.004$), being smaller in younger groups and larger in adults, while breathing type and skeletal class showed no significant differences ***(Table 4)***.

In females, palatal height did not differ significantly by age ($p = 0.051$), but oral breathers showed greater palatal height than nasal breathers ($p = 0.04$). Skeletal pattern had no significant effect ($p = 0.555$). In males, palatal height increased significantly with age ($p < 0.001$), especially between the 8–18 and 30–40/41–51 age groups, and was higher in oral breathers than nasal breathers ($p = 0.01$). Skeletal pattern effects were not significant in either sex ***(Table 5).***

Discussion

This study provided a comprehensive evaluation of the morphology of the soft palate, tongue, and palatal height in relation to sex, age, breathing type, and skeletal pattern. By systematically comparing our findings with previous reports, both consistent and divergent results were identified, offering new insights into the complex and multifactorial determinants of craniofacial morphology.

Soft palate morphology demonstrated clear sex-related differences, as males exhibited greater length, width, and volume compared with females. These findings corroborate earlier studies by Kollias and Krogstad (1999)[25], Awati et al. (2020)[26], and Lin et al. (2008)[27], which consistently reported sexual dimorphism in velar dimensions. Interestingly, no significant sex-based differences were detected in palatal angle, suggesting that angular parameters may be more sensitive to postural adaptations rather

than intrinsic anatomical variance. Age-related analyses revealed a progressive increase in length in both sexes, with significant volumetric enlargement observed primarily in females. Similar trends were previously reported by Chalkoo et al. (2016)[28], Deepa and Ramnarayan (2013)[29], Verma et al. (2014)[30], and Jayaprakash et al. (2019)[31], who emphasized continuous morphometric alterations across adulthood. In contrast, other studies, such as Nagaraj et al. (2016)[32] and Crowley et al. (2021)[33], suggested stabilization of velar dimensions after early adulthood. These contrasting results highlight that velar growth may be influenced by population-specific, methodological, or functional factors. Skeletal pattern exerted limited influence on the soft palate, with significant differences observed only in females for width. Previous studies[34-36] reported distinct variations across malocclusion classes, suggesting that methodological differences, including three-dimensional imaging and sample heterogeneity, may explain the discrepancies. Breathing type demonstrated a more notable impact in females, as oral breathers exhibited greater soft palate width, supporting the findings of Matsuo et al. (2010)[37] and Bakor et al. (2011)[38], who linked oral breathing with transversal palatal alterations. Taken together, these findings underline that sex and breathing mode may exert synergistic effects on velar morphology, while skeletal classification alone may be less decisive.

The tongue exhibited marked sexual dimorphism, as males presented significantly greater length, height, area, and volume compared with females. This observation is in accordance with CT- and CBCT-based studies by Abraham et al. (2023)[39], Ding et al. (2018)[7], Uysal et al. (2013)[2], and Iwasaki et al. (2019)[8]. Zhao et al. (2021)[10] additionally identified BMI as an independent determinant, further underscoring the multifactorial regulation of tongue size. The role of sex hormones, particularly the anabolic effect of testosterone, and sex-specific craniofacial growth trajectories, may explain the observed disparities. Age was another determinant, as tongue area and volume significantly increased with advancing age. While some investigations[40, 41] have described age-related muscle atrophy and volumetric decline, others such as Rana et al. (2020)[42] suggested more pronounced reductions in thickness. Skeletal pattern further influenced tongue morphology, with Class III subjects and hyperdivergent individuals presenting larger tongue volumes, in line with Iwasaki et al. (2019)[8] and Tseng et al. (2021)[9]. These results confirm that tongue morphology is closely integrated with skeletal structure and should be incorporated into orthodontic and airway evaluations. Surprisingly, no significant differences were observed between nasal and oral breathers in our sample, in contrast with Azevêdo et al. (2016)[43] and Engelke et al. (2010)[44], who highlighted changes in tongue posture associated with mouth breathing. This discrepancy may be attributable to temporal variations in breathing habits, environmental influences, or the sensitivity of imaging protocols.

Palatal height analysis also revealed significant associations with sex and age. Consistent with Šidlauskienė et al. (2024)[45] and Araby et al. (2023)[46], males exhibited greater values, which have been attributed to genetic and hormonal influences, particularly post-pubertal testosterone effects. Age-related increases were significant in males but not in females, corroborating the reports of Eslami Amirabadi et al. (2018)[47] and Mei et al. (2023)[13]. Skeletal classification, however, did not reveal any significant effect, in agreement with Kairalla et al. (2022)[48], who reported no direct association, and Saadeh & Ghafari (2023)[49], who emphasized vertical rather than sagittal influences. Notably, breathing

pattern demonstrated a consistent effect across sexes, as oral breathers exhibited significantly greater palatal height compared with nasal breathers. This finding supports earlier studies by Souki et al. (2009) [4], Lione et al. (2014)[50], and Harari et al. (2010)[11], which demonstrated that chronic oral breathing promotes a narrower and deeper palatal vault. These results underline the importance of recognizing oral breathing habits early in clinical practice to prevent maxillary constriction and related malocclusions.

When the combined effects of age, sex, skeletal pattern, and breathing mode were considered, significant interactions were limited. Notably, soft palate length in females demonstrated a significant interaction among multiple variables, whereas tongue and palatal height parameters did not. This finding suggests that while individual factors exert strong influences, their combined or synergistic effects may not always reach statistical significance, likely due to adaptive compensations and the multifactorial nature of craniofacial development. The limited evidence in the literature addressing combined factor interactions highlights the originality of this study, as it provides a simultaneous assessment of these variables rather than focusing on isolated effects. From a clinical standpoint, the simultaneous evaluation of the soft palate, tongue, and palatal height provides a more integrative understanding of upper airway morphology. Incorporating these parameters into orthodontic and surgical planning may help anticipate airway changes associated with growth, breathing habits, and skeletal discrepancies, ultimately contributing to more functional and stable treatment outcomes.

This study has several limitations that should be considered when interpreting the findings. First, its retrospective design inherently limits control over participant positioning, muscle activity, and breathing function during CBCT acquisition. Because all measurements were derived from static three-dimensional images, dynamic variables such as tongue motion, airway collapsibility, and real-time breathing patterns could not be assessed. Second, although calibration procedures were applied, two different CBCT devices with distinct voxel resolutions were used, which may have introduced minor variability in image scaling and segmentation accuracy. Third, breathing type classification was based on anatomical indicators and clinical history rather than objective airflow measurements, which could have led to misclassification in borderline cases. Fourth, skeletal classification relied solely on sagittal parameters (ANB angle), without integrating vertical or transverse skeletal components that might influence soft-tissue morphology. In addition, the sample was drawn from a single institution with a demographically homogeneous population, limiting the generalizability of the results across different ethnic and geographic groups. Finally, the cross-sectional nature of the study precludes causal inference; longitudinal or functional imaging studies would be required to confirm the observed associations and temporal changes.

Future research should aim to overcome the current study's limitations by incorporating dynamic and functional imaging modalities, such as cine-MRI or four-dimensional CBCT, to evaluate tongue and soft palate movements during actual breathing and swallowing. Objective airflow or polysomnographic measurements should also be integrated to validate breathing classification and its clinical implications. Moreover, longitudinal investigations following craniofacial growth trajectories could clarify the temporal

sequence between skeletal development, soft-tissue adaptation, and airway morphology. Finally, multi-center studies with diverse populations and standardized voxel calibration protocols are recommended to enhance generalizability and establish normative reference data for different age and sex groups.

Conclusion

Taken together, this study demonstrated that age, sex, and breathing pattern significantly influence craniofacial soft-tissue morphology. Soft palate dimensions and tongue size increased progressively with age, showing more pronounced changes in males. Tongue morphometry exhibited distinct sex-related differences, with larger volumes and dimensions in males compared with females. Palatal height increased significantly with age in males but remained relatively stable in females, and was also affected by breathing type, with oral breathing associated with greater palatal height and reduced transverse expansion. Overall, by simultaneously evaluating the soft palate, tongue, and palatal height, this study provides a novel and comprehensive contribution to the literature, emphasizing the importance of age-, sex-, and breathing-related factors in craniofacial assessment.

Abbreviations

CBCT: Cone Beam Computed Tomography

DICOM: Digital Imaging and Communications in Medicine

ANS: Anterior Nasal Spine

PNS: Posterior Nasal Spine

EB: Epiglottis Base

P: Most distal point of the soft palate

Tt: Tip of the Tongue

H: Hyoid bone corpus

ICC: Intraclass Correlation Coefficient

RGn: Retrognathion

C3: Third Cervical Vertebra

ANB: A–Nasion–B Angle

SNA: Sella–Nasion–A Angle

SNB: Sella–Nasion–B Angle

Declarations

Data Availability

The datasets generated and/or analyzed during the current study are not publicly available due to institutional data privacy policies but are available from the corresponding author on reasonable request.

Conflict of Interest:

The authors declare no competing interests.

Ethics Approval and Consent to Participate:

All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments. The study was approved by the Ethics Committee of the Faculty of Dentistry, Necmettin Erbakan University (Approval No: 2023/299). Written informed consent was obtained from all participants.

Consent for Publication:

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Authors' Contributions

B.O. carried out the CBCT measurements, performed intra-observer reliability tests, conducted statistical analyses, and drafted the initial version of the manuscript. G.M. was responsible for the overall study conception and design, supervised the methodological framework, performed inter-observer measurements, and contributed substantially to the interpretation of the findings. M.Y. assisted in data collection, organization of patient records, and contributed to the literature review. A.E. provided methodological input, guided the structuring of the results and discussion sections, and critically revised the manuscript for intellectual content. All authors read, revised, and approved the final manuscript.

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Tables

Tables are available in the Supplementary Files section.

Figures

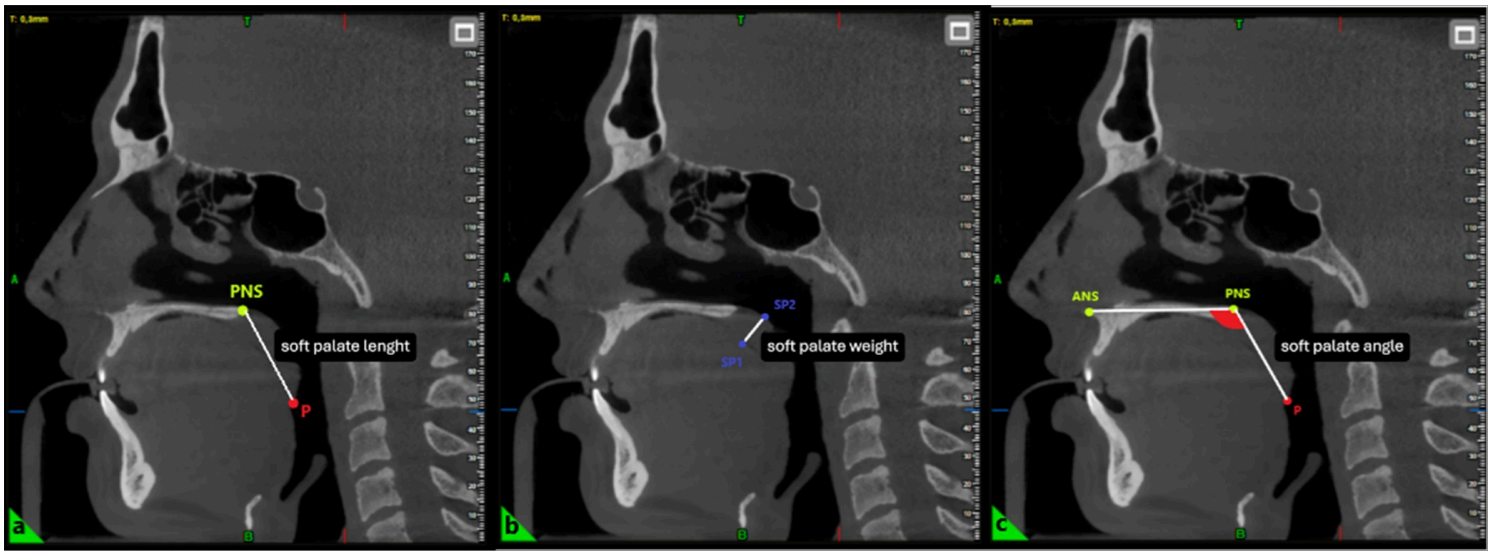


Figure 1

Sagittal CBCT images show the soft palate length (a), soft palate width (b), and soft palate angle (c). PNS: Posterior nasal spine, point determining the posterior border of the hard palate; P: The most extreme point of the soft palate; SP1: Point determining the anterior border of the soft palate; SP2: Point determining the posterior border of the soft palate; ANS: Anterior nasal spine; PNS: Posterior nasal spine; P: The most extreme point of the soft palate.

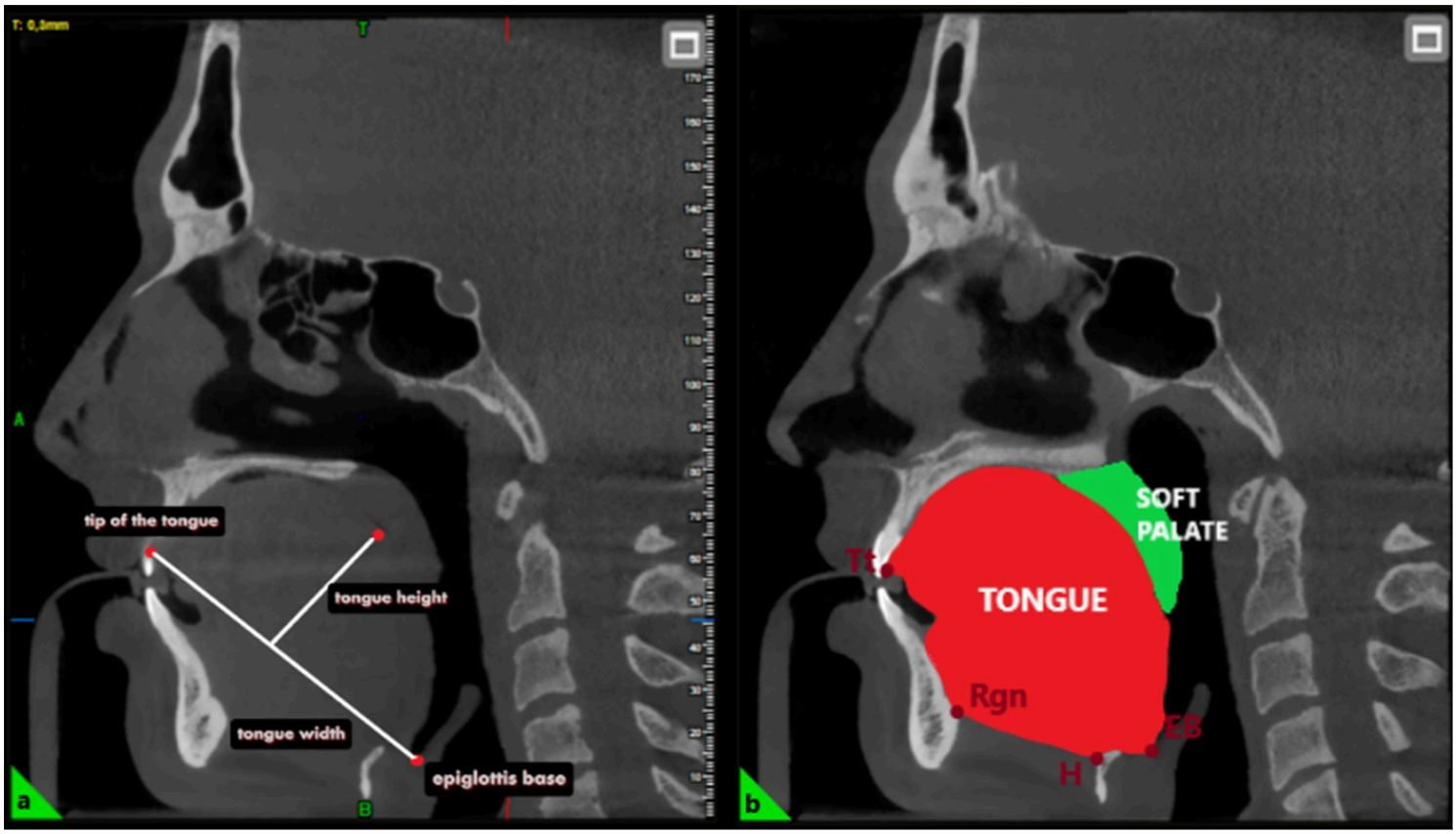


Figure 2

Sagittal CBCT images show tongue height and width (a), and the borders of the tongue (red) and soft palate (green). Tt: Point defining the tip of the tongue; RGn: Most posterior-inferior point of the mandibular symphysis; H: Center of the hyoid bone; Ep: Epiglottis.



Figure 3

Coronal CBCT section shows palatal height.

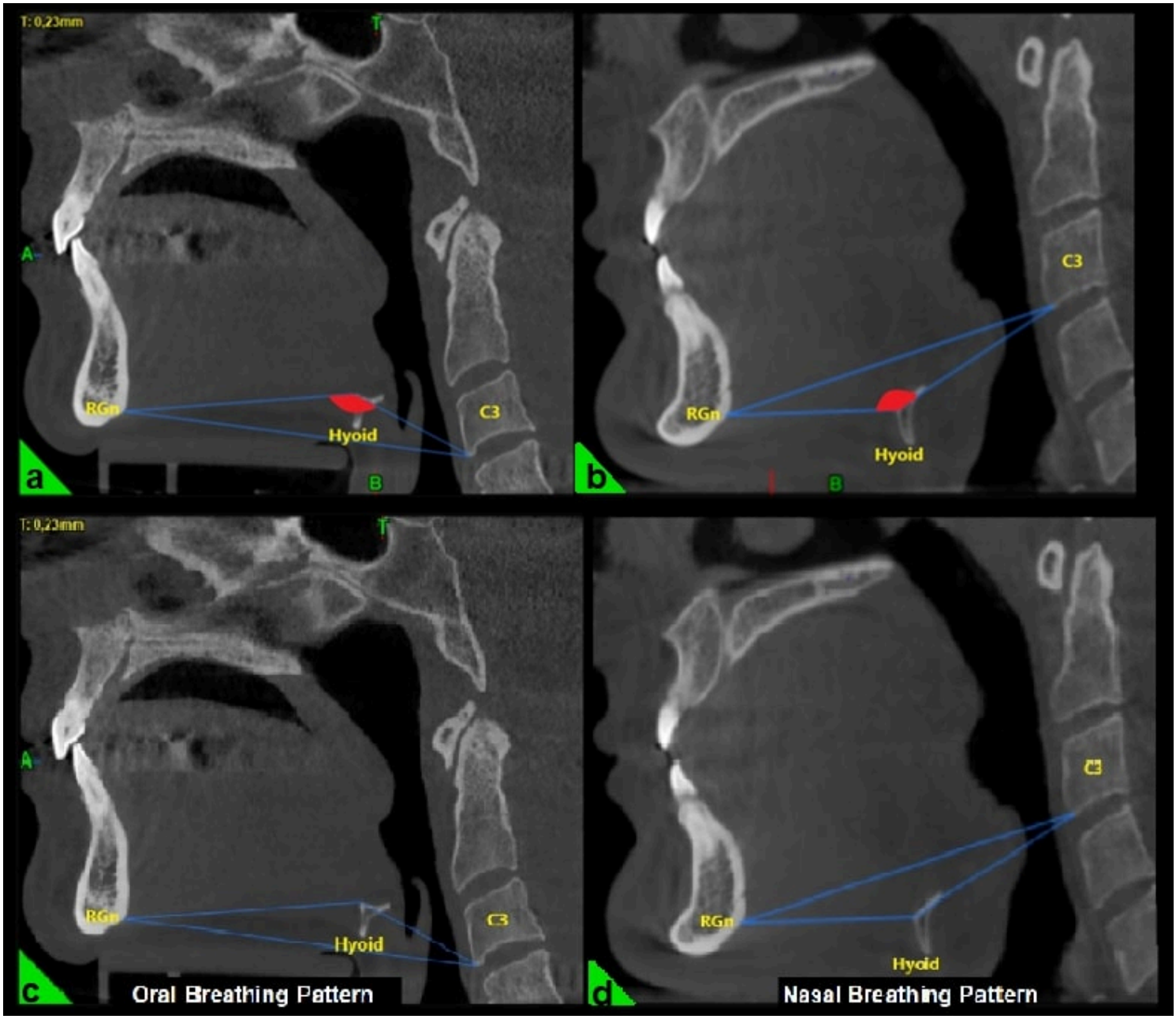


Figure 4

Sagittal CBCT images illustrating the classification of breathing patterns using the hyoid triangle technique. (a, c) Oral breathing pattern: the hyoid bone is positioned above the RGn–C3 plane, forming a negative hyoid triangle. (b, d) Nasal breathing pattern: the hyoid bone is located below the RGn–C3 plane, forming a positive hyoid triangle. RGn: Most posterior-inferior point of the mandibular symphysis; Hyoid: Center of the hyoid bone; C3: Anterior-inferior point of the third cervical vertebra.

Supplementary Files

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