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ABSTRACT

Background: The pharyngeal and intraoral airways are closely related to respiration, tongue posture, and craniofacial morphology. Despite the advantages of cone-beam computed tomography (CBCT) in three-dimensional airway assessment, the combined effects of age, sex, skeletal class, and respiratory type on these structures remain unclear. Therefore, this study aimed to evaluate the morphometric and volumetric characteristics of the pharyngeal and intraoral airways using CBCT and to assess the main and interaction effects of these variables.

Materials and Methods: A total of 560 CBCT scans (295 females, 265 males; aged 8–73 years) were retrospectively analyzed. The area and volume of the nasopharyngeal, oropharyngeal, hypopharyngeal and intraoral airways 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. A p-value <0.05 was considered statistically significant.

Results: Age and breathing pattern were the main factors associated with pharyngeal airway dimensions. Total pharyngeal airway volume and area differed significantly by age in both females ($p=0.014$; $p=0.031$) and males ($p=0.004$; $p=0.002$), and by breathing pattern in both sexes (volume: $p=0.025$ and $p=0.002$; area: both $p<0.001$). Nasopharyngeal airway volume showed a significant age-related difference only in males ($p=0.002$), whereas nasopharyngeal airway area differed by age in both females ($p=0.043$) and males ($p=0.008$). Oropharyngeal airway volume was associated with age ($p<0.001$) and breathing pattern ($p=0.034$) in females, and with breathing pattern in males ($p=0.002$). Oropharyngeal airway area differed significantly according to breathing pattern in both sexes (both $p<0.001$) and age in males ($p=0.014$). Hypopharyngeal airway volume was associated with breathing pattern in females ($p=0.042$), and with both age ($p=0.002$) and breathing pattern ($p=0.012$) in males. Intraoral airway measurements showed significant interaction effects in females and significant age-related differences in males (both $p<0.001$).

Conclusion: Pharyngeal airway dimensions were primarily associated with age and breathing pattern, while intraoral airway characteristics showed sex-specific differences, with significant interaction effects in females and age-related variation in males.

Keywords: *Angle's Classification, breathing, cone beam tomography, pharyngeal airway, intraoral airway, anova*

Introduction

The pharynx is a complex fibromuscular tubular structure extending from the skull base to the level of the cricopharyngeal sphincter, located anterior to the cervical vertebral column, typically between the C1 and C6 levels [1, 2]. It is anatomically divided into three interconnected regions—the nasopharynx, oropharynx, and hypopharynx (laryngopharynx)—which play essential roles in respiration, swallowing, and speech [2, 3]. Beyond these fundamental functions, the pharynx and adjacent craniofacial structures are closely associated with dentofacial development, maintenance of airway patency, and functional occlusion [4-6]. Previous studies have demonstrated that sagittal, vertical, and transverse maxillomandibular relationships may influence pharyngeal airway morphology and dimensions, with measurable differences observed among individuals with different skeletal patterns [5, 7, 8]. These variations are clinically relevant, as they may affect craniofacial growth, respiratory efficiency, and overall quality of life [9, 10].

The intraoral airway is defined as the air-containing space between the palatal vault and the dorsal surface of the tongue and represents a three-dimensional parameter reflecting tongue posture and intraoral spatial balance [11]. Although this term is clinically descriptive, there is no consensus in the literature regarding its nomenclature, and related expressions such as low tongue space, oral cavity airway volume, oral cavity air capacity, and tongue space have been used to describe similar anatomical regions [11-14]. Cone-beam computed tomography (CBCT)-based studies have shown that this air-filled intraoral space is closely associated with tongue posture, oral cavity configuration, and upper airway morphology [11–13]. Furthermore, it has been evaluated in relation to dentofacial orthopedic treatment outcomes and tongue–oral cavity volumetric relationships, suggesting its potential role in the assessment of airway dynamics and craniofacial adaptation [11,12]. A recent systematic review highlighted the increasing use of CBCT in evaluating tongue–oral cavity relationships, while also emphasizing the methodological and terminological heterogeneity among studies [14].

CBCT enables three-dimensional visualization and volumetric assessment of both pharyngeal and intraoral airway spaces without the distortion, magnification, and superimposition associated with conventional two-dimensional imaging [15, 16]. In pharyngeal airway analysis, CBCT provides detailed information on airway volume, cross-sectional morphology, and areas of constriction, whereas in intraoral airway evaluation, it allows precise assessment of the spatial relationship between the tongue, palate, and surrounding air space [13]. Previous studies have also demonstrated that CBCT-based measurements can achieve acceptable reliability and reproducibility when standardized imaging and segmentation protocols are applied [17, 18].

To the best of our knowledge, few CBCT-based studies have simultaneously evaluated pharyngeal and intraoral airway structures within a multifactorial analytical framework. Therefore, the present study aimed to comprehensively assess the morphometric and volumetric characteristics of these regions using CBCT. A robust three-way ANOVA model was applied to investigate the main and interaction effects of age, sex, skeletal class, and breathing pattern. The null hypothesis was that these variables would not significantly affect the measured parameters.

Materials and Methods

Ethical Approval

Ethics committee approval for this retrospective study was obtained by Necmettin Erbakan University Faculty of Dentistry, Faculty of Dentistry, Drug and Non-Medical Device Research Ethics Committee on 25.05.2023 with protocol number 2023/299, and the scientific and ethical appropriateness of the study was approved.

Study Population and Population

This retrospective study included CBCT images obtained for diagnostic purposes from patients who presented with various dental complaints between February 2019 and October 2024. A total of 560 CBCT scans from individuals aged 8–73 years were analyzed.

Prior to the study, a power analysis was performed by ANOVA method using the G*Power v3.1.9.7 program to determine the number of individuals to be included in the groups. According to the 95% confidence level (1-α), 95% test power (1-β), Cohen's f=0.303 effect size and multi-way analysis of variance parameters, it was determined that a minimum of 240 individuals should be included in the study, with at least 4 cases (209/60 ≅ 4) in each group. In order to increase the statistical power of the study, it was decided to include more records than the minimum number of cases initially determined.

Inclusion and Exclusion 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. 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

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 radiographs were taken by the same technician according to standard protocols.

Measurement Procedure

The included CBCT images were reviewed by a single observer with three years of experience in oral diagnosis and maxillofacial radiology (BO). Image data were saved in DICOM (Digital Imaging and Communications in Medicine) format and measurements were performed using Dolphin 3D Imaging Software (Dolphin Imaging & Management Solutions®, Chatsworth, CA, USA). Mark points and reference planes were checked in axial, coronal and sagittal planes, and precise measurements were made on three-dimensional models. The observer was blinded to participants' skeletal classification and breathing pattern to minimize measurement bias.

Three-Dimensional Cephalometric Measurements

In the three-dimensional cephalometric analysis, the area and volume of the nasopharyngeal, oropharyngeal, and hypopharyngeal airways, as well as the total airway area and volume, were measured. Intraoral airway area and volume measurements were also taken. Accordingly, the nasopharyngeal airway was referenced as the region within the triangle formed by the points Basion (Ba), Sella (S), and posterior nasal spine (PNS). A line passing through points Ba and S, forming one side of the triangle, was extended to the ANS-PNS line. The oropharyngeal airway was measured as the region between the ANS-PNS line, which is the inferior boundary of the nasopharyngeal airway superiorly, and a line drawn from the most anteroinferior of the 3rd cervical vertebra, parallel to the ANS-PNS line inferiorly. The hypopharyngeal airway was considered as the pharyngeal area whose superior boundary starts from the inferior of the oropharyngeal airway and whose inferior boundary is

a line drawn from the 4th cervical vertebra parallel to the palatal plane. Finally, when calculating the total airway, the area and volume values of the nasopharyngeal, oropharyngeal, and hypopharyngeal airway volumes were added together **(*Figure 1*)** [19]. In intraoral airway assessment, the area and volume of the region between the tongue and the palate were measured **(*Figure 2*)** [11].

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 [20]. 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 3a, 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 3b, d***) [21].

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 [22].

Statistical Analysis

Statistical analyses were performed using JAMOVI software (version 2.3.22). Normality was assessed using the Shapiro–Wilk test. A robust three-way ANOVA model (Walrus package) was applied to evaluate the main and interaction effects of age, sex, skeletal class, and breathing pattern, accounting for potential violations of variance homogeneity. Post hoc comparisons were performed using the Bonferroni test. Quantitative data are presented as trimmed mean ± standard error. Statistical significance was set at $p < 0.05$.

Result

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 (***Table 1***).

Descriptive statistics for all morphometric and volumetric parameters are presented in Table 2. The mean total pharyngeal airway volume was 26551.08 ± 9245.64 mm^3, and the mean area was 10087.92 ± 2539.96 mm^2. Corresponding values for the nasopharyngeal, oropharyngeal, and hypopharyngeal regions, as well as intraoral airway measurements, are summarized in ***Table 2***.

Total pharyngeal airway volume differed significantly by age in both females ($p = 0.014$) and males ($p = 0.004$), and by breathing pattern in both sexes ($p = 0.025$ and $p = 0.002$, respectively), whereas skeletal pattern and interaction terms were not significant (***Table 3***). Similarly, total pharyngeal airway area showed significant differences according to age in females ($p = 0.031$) and males ($p = 0.002$), and according to breathing pattern in both sexes (both $p < 0.001$). Skeletal pattern was not significant, and only females demonstrated a significant age × breathing interaction ($p = 0.04$) (***Table 4***).

Nasopharyngeal airway volume showed no significant differences in females (all $p > 0.05$), whereas in males, a significant age effect was observed ($p = 0.002$) (***Table 5***). Nasopharyngeal airway area differed significantly by age in both females ($p = 0.043$) and males ($p = 0.008$), with no significant effects of breathing pattern, skeletal pattern, or interactions (***Table 6***).

Oropharyngeal airway volume differed significantly by age ($p < 0.001$) and breathing pattern ($p = 0.034$) in females, and by breathing pattern in males ($p = 0.002$), whereas skeletal pattern and interactions were not significant (***Table 7***). Oropharyngeal airway area differed significantly according to breathing pattern in both sexes (both $p < 0.001$) and according to age in males ($p = 0.014$), with no significant effects of skeletal pattern or interactions (***Table 8***).

Hypopharyngeal airway volume differed significantly by breathing pattern in females ($p = 0.042$), and by age ($p = 0.002$) and breathing pattern ($p = 0.012$) in males, with no significant effects of skeletal pattern or interactions (***Table 9***). Hypopharyngeal airway area showed no significant effects in females, whereas in males, only age was significant ($p = 0.015$) (***Table 10***).

Intraoral airway volume and area showed no significant main effects in females; however, significant age × skeletal pattern, breathing × skeletal pattern, and three-way interaction effects were observed (all $p \leq 0.009$). In males, both intraoral airway volume and area differed significantly by age (both $p < 0.001$), with no significant effects of breathing pattern, skeletal pattern, or interactions (***Tables 11*** and ***12***).

Discussion

The present study demonstrated that pharyngeal airway morphology is primarily influenced by age and breathing pattern, whereas skeletal pattern alone was not consistently associated with airway dimensions. These findings were observed across all pharyngeal compartments, although the magnitude of these effects varied between sexes. In contrast, intraoral airway measurements showed a more complex pattern, particularly in females, where significant interaction effects were identified. These findings suggest that upper airway morphology may reflect the combined influence of growth, sex-related craniofacial characteristics, respiratory function, and soft-tissue adaptation rather than sagittal skeletal pattern alone [19, 23, 24].

Larger pharyngeal airway dimensions were observed in males, consistent with previous CBCT- and MRI-based studies [25-27]. Daniel et al. [25] showed that men had significantly larger pharyngeal structures than women, while Malhotra et al. [26] reported that sex-related differences in upper-airway

morphology, particularly airway length and collapsibility, may contribute to distinct airway characteristics between males and females. Diwakar et al. [27] similarly found greater pharyngeal airway volume in males and emphasized the contribution of craniofacial morphology to airway size. These differences may be related to greater craniofacial dimensions and variations in soft-tissue characteristics. However, airway size alone does not necessarily indicate functional stability, as airway patency is also influenced by neuromuscular control and soft-tissue balance [25, 26].

Age-related differences were evident, particularly in males. Significant variations in airway dimensions were observed across age groups, with differences often involving the younger (8–18 years) cohort. These findings are consistent with previous studies demonstrating that airway structures increase during growth and tend to stabilize after puberty [28-32]. Abramson et al.[28] demonstrated age-related changes in upper-airway size using three-dimensional CT, showing that airway structures enlarge with maturation. Tourné[29] emphasized that pharyngeal growth has important physiologic implications and should be considered in orthodontic diagnosis and treatment planning. Tsai[30] and Sheng et al.[31] likewise showed developmental changes in pharyngeal airway depth and related structures from childhood to adulthood. In children, Chianchitlert et al.[32] also reported age-dependent increases in upper pharyngeal airway dimensions, particularly across skeletal types II and III. Together, these observations support the concept that the airway undergoes developmental changes rather than remaining static.

Breathing pattern was another important factor, particularly in total pharyngeal and oropharyngeal measurements. Significant differences between nasal and oral breathers were observed in both sexes, suggesting that respiratory mode may influence airway morphology. Alves et al. [33] reported significant three-dimensional differences in pharyngeal airway dimensions between nasal- and mouth-breathing children. Harari et al. [34] also showed that mouth breathing is associated with dentofacial and craniofacial changes that may secondarily affect airway form. Habumugisha et al. [35] demonstrated differences in pharyngeal airway dimensions and maxillary arch morphology between mouth- and nasal-breathing children with skeletal Class I and II patterns. Collectively, these studies support the view that breathing mode is not merely a functional descriptor, but an important variable that may contribute to structural airway adaptation. At the same time, the relationship between breathing pattern and airway size is not entirely straightforward. Some previous studies have reported smaller airway dimensions in mouth breathers, particularly in children, whereas the present study identified larger values in oral breathers in several pharyngeal variables [33-35]. This apparent discrepancy may be explained by differences in age distribution, growth stage, and duration of functional adaptation. In a sample including older individuals, larger airway values in oral breathers may reflect compensatory enlargement rather than superior airway quality.

In contrast, skeletal pattern classification alone was not significantly associated with most pharyngeal airway variables in either sex. This finding differs from several studies reporting larger airways in Class III subjects and smaller values in Class II individuals [8, 23, 36, 37]. Grauer et al. [23] found that airway shape and volume vary with facial morphology, suggesting a relationship between craniofacial pattern and airway form. Shokri et al. [8], Zheng et al. [36], and Oh et al. [37] also reported significant associations between airway dimensions and sagittal skeletal pattern in CBCT-based analyse. Celikoglu et al. [38] demonstrated differences in pharyngeal airway volume across vertical skeletal patterns, Wang et al. [39] reported narrower airways in adult skeletal Class II subjects with vertical growth tendencies, and Brito et al.[40] found volumetric and morphologic differences among different skeletal Class II patterns. These findings suggest that the effect of skeletal morphology on airway size may be context-dependent, varying according to growth pattern, sex, and the specific airway compartment analyzed. However, the literature remains inconsistent. One possible explanation is that the association between

skeletal class and airway dimensions becomes less evident when age and breathing pattern are considered simultaneously. Airway size is likely influenced by the interaction of multiple factors, including craniofacial growth, tongue posture, soft-tissue adaptation, mandibular position, and respiratory behavior. Under these conditions, the independent effect of sagittal skeletal classification may be attenuated. Therefore, the absence of significant skeletal effects in the present study may reflect the influence of these interacting variables rather than the lack of a true association [8, 23, 27, 36-40].

Another important finding of the present study was the regional variation among airway compartments. The nasopharynx showed fewer associations with breathing pattern, whereas the oropharynx and hypopharynx appeared more functionally responsive. This is anatomically plausible, as these regions are more directly influenced by tongue position, soft palate dynamics, mandibular posture, and neuromuscular adaptations. In contrast, the nasopharyngeal airway is more constrained by surrounding skeletal and soft-tissue structures and may therefore be less sensitive to breathing mode, particularly in adults [19, 23]. These findings highlight the importance of evaluating the upper airway by segments rather than relying solely on total airway measurements, as global values may obscure region-specific behavior and limit the identification of the most affected compartment.

The intraoral airway yielded the most distinctive findings in the present study. In females, intraoral airway volume and area did not differ significantly according to age or breathing pattern as isolated main effects; however, significant age × skeletal pattern, breathing × skeletal pattern, and three-way interaction effects were observed. In males, intraoral airway measurements were primarily influenced by age, with no significant interaction effects. These sex-specific differences suggest that intraoral airway morphology in females may be more sensitive to the combined influence of anatomical and functional factors, whereas in males it appears to be more developmentally driven. This pattern differs from the more consistent findings observed in the pharyngeal compartments. Previous studies have demonstrated that oral cavity volume, tongue volume, and tongue posture are closely interrelated [12, 14, 41]. Ding et al.[41] reported a positive relationship between tongue volume and oral cavity capacity, while Rana et al.[12] showed that the tongue volume/oral cavity volume ratio is associated with upper-airway dimensions. The systematic review by Aflah et al.[14] emphasized the value of CBCT-based volumetric assessment of the tongue and oral cavity in understanding the relationship between oral cavity morphology and upper-airway configuration. More recent reports examining oral cavity–airway relationships after orthognathic procedures also suggest that intraoral volume and upper-airway volume are biomechanically linked [42]. Taken together, these findings suggest that the intraoral compartment may represent a functional region influenced by the interaction among tongue posture, oral cavity capacity, jaw position, and surrounding soft tissues, rather than being solely a passive air space.

In this context, the significant interaction effects observed in females may reflect a relatively more compact intraoral environment in which age, skeletal morphology, and breathing pattern interact to influence available oral space and tongue position. This may help explain why no significant main effects were observed for age or breathing pattern alone, whereas significant effects emerged when these variables were analyzed in combination with skeletal pattern. In males, the predominantly age-related pattern may indicate a more developmentally driven process, with fewer detectable interaction effects. Although this interpretation remains tentative, it appears consistent with previous studies describing the interrelationship between tongue morphology, oral cavity dimensions, and airway space [12, 14, 41, 42].

Limitations

Several limitations should be considered when interpreting the present findings. Although CBCT provides detailed three-dimensional visualization of the airway, it remains a static imaging modality and cannot capture dynamic physiological processes such as airflow, muscle activity, tongue motion, or

pharyngeal collapsibility during function or sleep [19]. Second, airway measurements are also dependent on the segmentation protocols and anatomical boundaries used to define airway subregions, which may affect comparability across studies [19, 43]. Third, the cross-sectional design limits causal interpretation. Fourth, breathing pattern may itself represent a long-term adaptive behavior rather than a fixed biologic trait. Finally, although sex-stratified analyses strengthened the interpretation, future studies with larger subgroup sizes, longitudinal follow-up, and functional respiratory assessment would provide a more comprehensive understanding of how developmental, morphologic, and functional factors interact in shaping airway dimensions.

Conclusion

Taken together, the present findings suggest that airway morphology is influenced by multiple factors and may be better understood within a sex-specific framework. Age-related differences were more pronounced in males, while breathing pattern showed consistent associations with several pharyngeal airway variables. Skeletal pattern alone demonstrated limited explanatory value. In contrast, intraoral airway measurements, particularly in females, showed complex interaction effects that may not be adequately captured by one-dimensional classifications. These findings indicate that CBCT-based airway evaluation should consider age, sex, breathing pattern, and compartment-specific characteristics rather than relying solely on sagittal skeletal classification. Such an approach may be relevant for orthodontic assessment and treatment planning, as well as for understanding variations in airway morphology and function.

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.

Declarations

Abbreviations:

CBCT: Cone Beam Computed Tomography

DICOM: Digital Imaging and Communications in Medicine

Ba: Basion

S: Sella

ANS: Anterior Nasal Spine

PNS: Posterior Nasal Spine

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

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:

Not applicable.

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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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FIGURE LEGENDS

Figure 1. The three-dimensional cephalometric analysis of the nasopharyngeal (red), oropharyngeal (blue), and hypopharyngeal (green) airways is shown. S: Midpoint of the sella turcica; ANS: Anterior Nasal Spine; PNS: Posterior Nasal Spine; Ba: Basion.

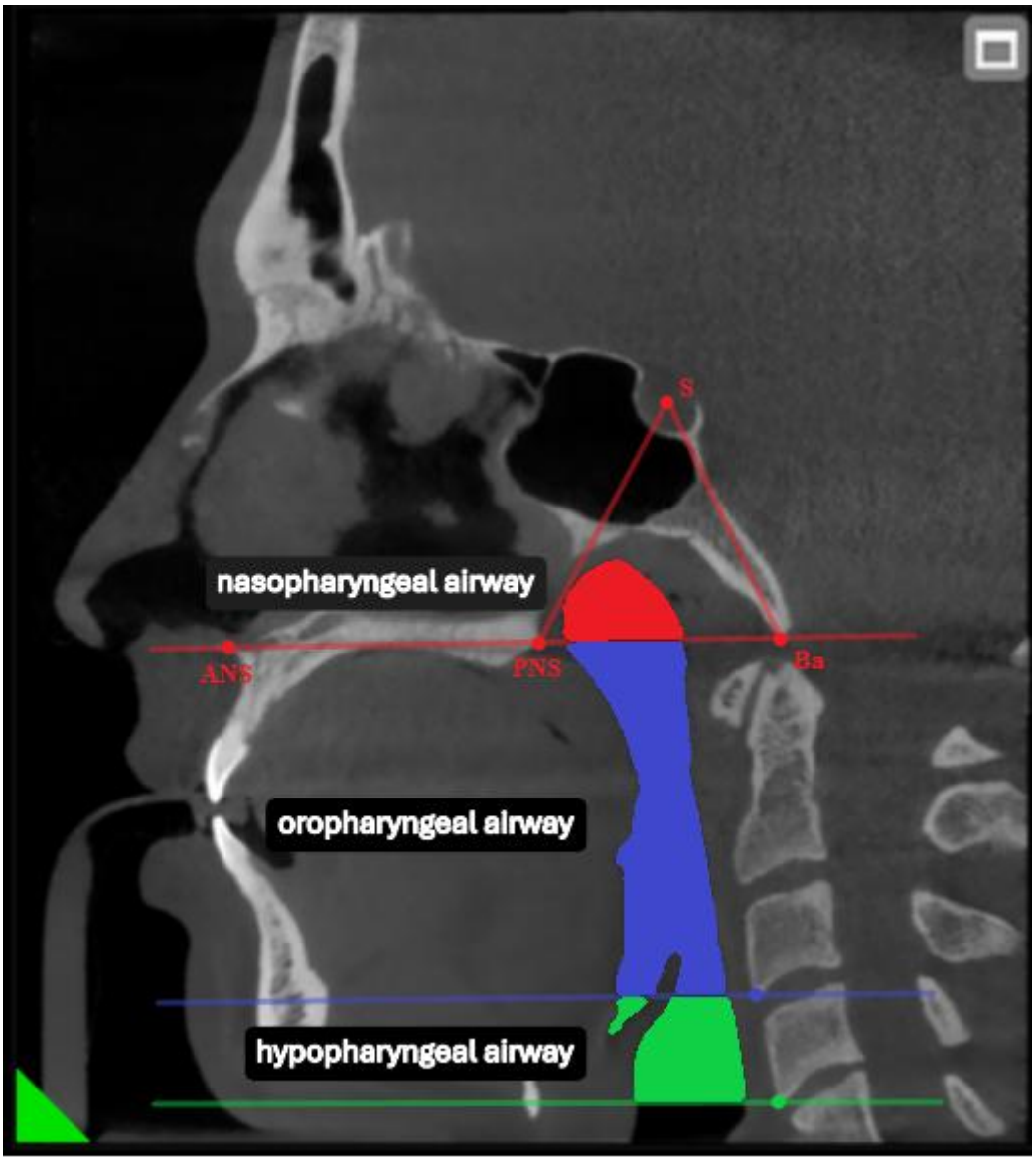


Figure 2. Standardized segmentation of the intraoral airway space (yellow) on sagittal CBCT slice for three-dimensional cephalometric analysis.

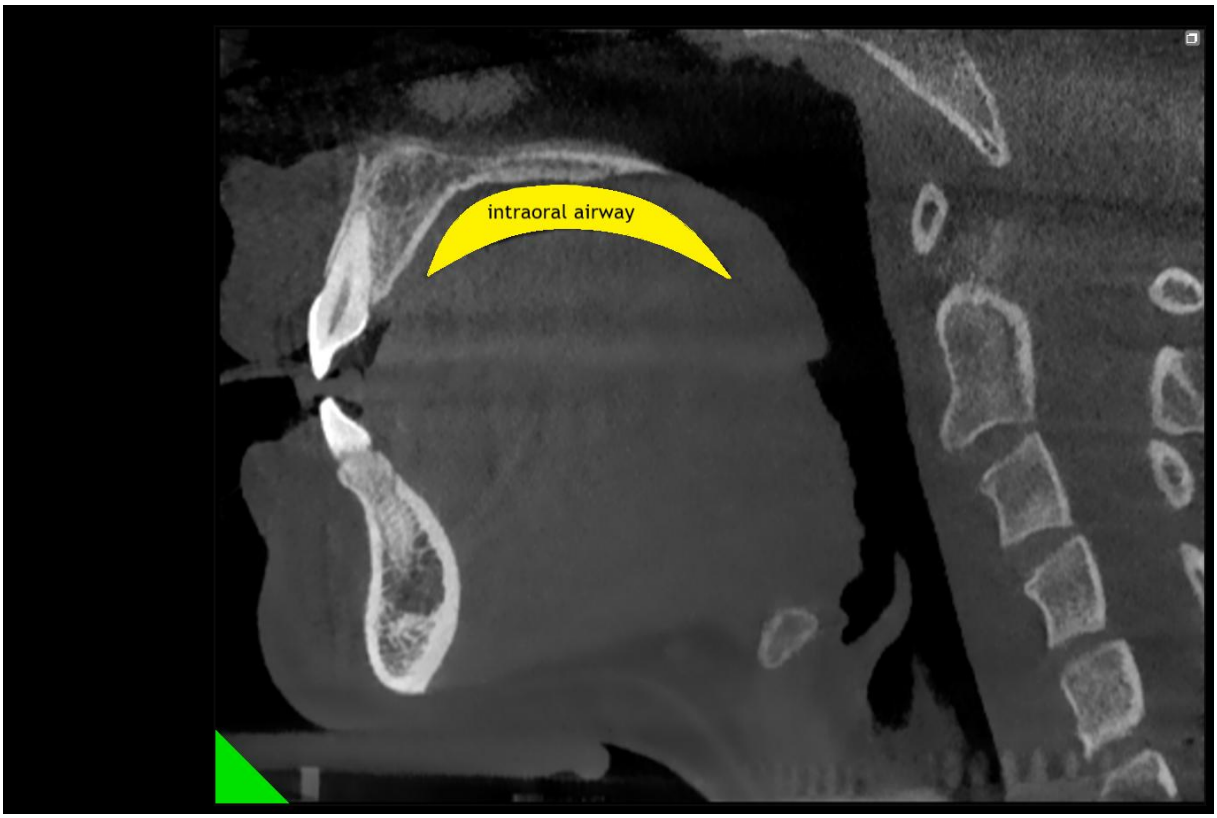
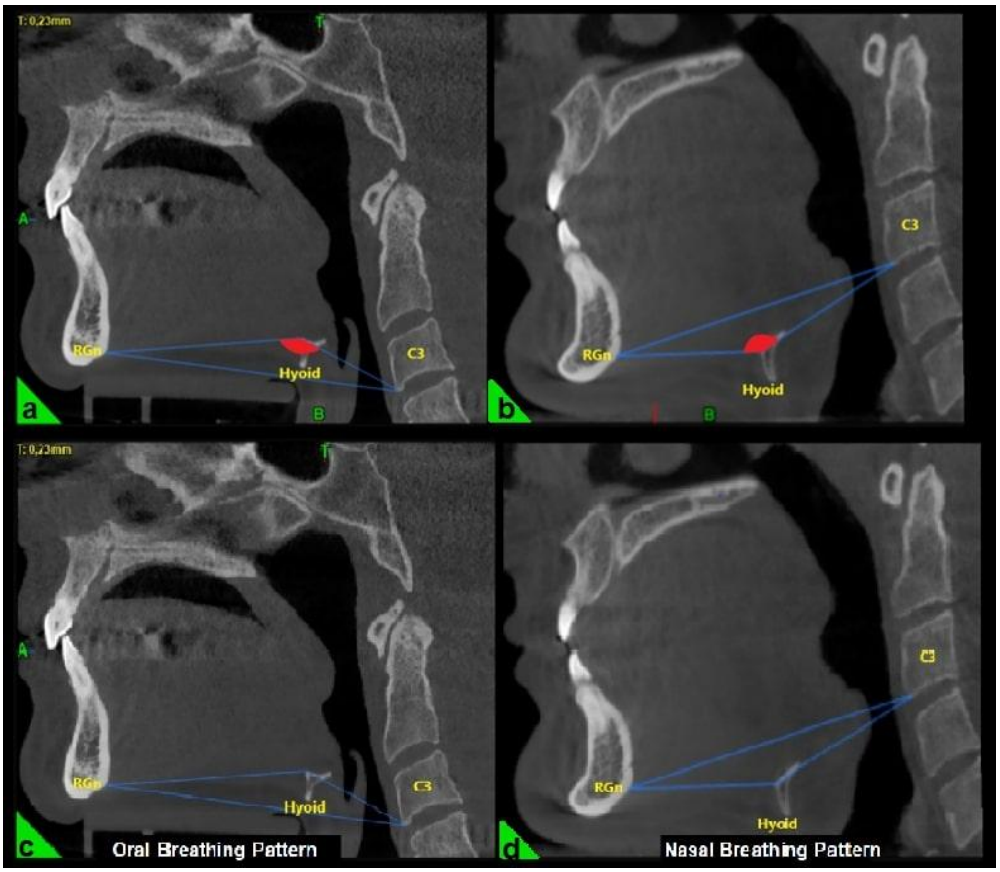


Figure 3. Sagittal CBCT images illustrating the classification of breathing patterns using the hyoid triangle technique. (a, c) Oral breathing pattern: the hyoid bone is positioned above the RGn–C3 plane, forming a negative hyoid triangle. (b, d) Nasal breathing pattern: the hyoid bone is located below 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.


T: 0,23mm
T
A
RGn
Hyoid
C3
B
a
b
c
d
Oral Breathing Pattern
Nasal Breathing Pattern

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