RESEARCH ARTICLE

A 3D Analysis of Pharyngeal Airway Space in Adults with Different Mandibular Growth Pattern - A Retrospective Study

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ABSTRACT

Introduction: The pharyngeal airway space (PAS) is a vital anatomical region involved in breathing, speech, and swallowing. Its dimensions height, width, and depth impact airflow with narrowing contributing to respiratory limitations and conditions like obstructive sleep apnea (OSA). The upper airway's structure is influenced by surrounding skeletal and soft tissue components, including the soft palate, which may contribute to airway obstruction. The use of 3D imaging in dentistry more specifically cone beam computer tomography (CBCT) has increased considerably in the last years, making possible the evaluation of anatomical structures and analysis of pharyngeal space morphology, because of its high spatial resolution , adequate contrast between the soft tissues and empty space and the relative low dose radiation compared to multi slice computer tomography, Three-dimensional (3D) imaging can be used to enable better volume rendering, image reconstruction, and evaluation of the position of the jaws in direct relation to the airway

Methodology: This study aimed to examine PAS dimensions in relation to mandibular growth patterns using CBCT scans from 102 adult participants aged 21–50 years. Subjects were grouped into Class I, II, and III mandibular growth patterns. Parameters such as velar length and width, pharyngeal depth, height, volume, mandibular distance, gonial angle, and airway space at C1–C3 vertebral levels were measured.

Results: Participants with Class II growth patterns had lower pharyngeal width, height, and space compared to those with Class I and III (p-values: 0.01, <0.001, 0.02). Mandibular distance and gonial angle also differed significantly across the three growth patterns (p=0.01). Similarly, anteroposterior (AP) distance and maximum width at C1, C2, and C3 levels showed significant differences among the growth patterns (p<0.05).

Conclusion: CBCT proved effective for assessing the airway in relation to jaw structure. Although limited by its retrospective design and lack of clinical sleep data, the study provides valuable insights into skeletal influences on airway size, supporting its use in diagnosis and treatment planning.

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INTRODUCTION

Pharyngeal airway space (PAS) is the part of the throat through which air passes from the nose and mouth to the lungs that is that acts as a passageway linking the mouth and nose to the esophagus and trachea. It helps with both breathing, speaking and swallowing [(1,2)]. Agur AM et al in 2009 stated that the pharynx is about 13 cm long and shaped like a half-cylinder. Its widest part is in the lower portion, called the laryngopharynx, measuring approximately 4.1 cm in males and 3.6 cm in females. [(3)]

The pharynx is mainly made up of three constrictor muscles (superior, middle, and inferior), covered by fascia, with the prevertebral fascia providing support to the posterior wall. [(4)]

Toro-Tobon et al stated that Studies using ultrasound showed that the pharynx changes shape during breathing: it becomes wider front-to-back during deep inhalation and wider side-to-side during deep exhalation [(5)]. This dynamic change helps accommodate airflow during breathing. The nasopharynx houses the adenoids on its upper back wall and the openings of the Eustachian tubes on its side walls. These tubes help equalize pressure between the middle ear and the atmosphere. The oropharynx includes the palatine and lingual tonsils, which are part of the immune system's first line of defense against ingested or inhaled pathogens. The laryngopharynx leads to the esophagus and contains the piriform sinuses, which guide food away from the airway during swallowing.

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Parameters

Different planes	Parameters
Sagittal	ANS to PNS distance:
	Shortest pharyngeal airway space
	Pharyngeal height, width & volume
	Gonial angle
	Velar length & width
Axial	Mandibular distance
	At the level of C1 vertebra (Antero posterior and Maximum width)
	At the level of C2 vertebra (Antero posterior and Maximum width)
	At the level of C3 vertebra (Antero posterior and maximum width)

A narrowed airway restricts airflow and affects respiratory function. Understanding the role of skeletal and soft tissues, including the soft palate, is key to recognizing airway physiology and causes obstruction [8,9].
Early intervention can guide development and prevent abnormalities such as mandibular hypoplasia, retrognathism, and high palatal vaults. The duration of obstruction correlates with the severity of these changes [10,11]. Chronic mouth breathing often caused by nasal blockages due to a deviated septum or enlarged adenoids can lead to a tongue position. This altered posture may contribute to a narrowing of the upper jaw (maxilla) and results in dental irregularities [12].
Craniofacial growth's impact on airway size is vital for orthodontic diagnosis and treatment. Obstructive sleep apnea (OSA), caused by upper airway collapse during sleep, affects 2%–4% of adults and is linked to pharyngeal narrowing [13]. Maxillomandibular advancement improves airway space by moving the soft palate, tongue, and related tissues forward, while mandibular retrusion narrows it [14-16].
The soft tissue stretching hypothesis suggests that individuals adjust head posture to compensate for airway limitations. This can apply mechanical forces on growing facial bones, affecting craniofacial development [17].
Cone beam computed tomography (CBCT) provides detailed 3D imaging of the maxillofacial region with lower radiation, allowing precise airway assessment [18]. It enhances visualization of airway volume and jaw positioning [19].
3D analysis is used to evaluate pharyngeal airway morphology across different growth patterns. Parameters measured in axial and sagittal planes include mandibular distance at C1–C3 vertebrae levels, ANS to PNS distance, pharyngeal width and height, shortest airway space, velar dimensions, gonial angle, and airway volume. The goal is to correlate craniofacial structures with airway dimensions for better clinical understanding.

Table 1. Characteristics of study population

		n (%)
Age	20-30 years	34 (33.3)
	31-40 years	34 (33.3)
	41-50 years	34 (33.3)
Gender	Male	57 (55.8)
	Female	45 (44.2)
Mandibular growth pattern	Class I	44 (43.13)
	Class II	49 (48.03)
	Class III	9 (8.8)

METHODOLOGY

In this retrospective study we assessed various parameters to examine their relationship with pharyngeal airway measurements. The study sample was about 102 participants. The study participants consist of 34 individuals in each age group: 21-30 years, 31-40 years, and 41-50 years. The sample included 57 males and 45 females. Among the participants, 44 (43.13%) had a Class I mandibular growth pattern, 49 (48.03%) had a Class II growth pattern, and 9 (8.8%) had a Class III growth pattern.
The various parameters included in the study are ANS to PNS distance, Velar length, Velar width, Pharyngeal width, Pharyngeal height, Pharyngeal volume, Shortest distance of pharyngeal airway space, Mandibular distance, Gonial angle, At the level of C1 vertebra (AP distance, Maximum width of the pharyngeal airway), At the level of C2 vertebra (AP distance, Maximum width of the pharyngeal airway), At the level of C3 vertebra (AP distance, Maximum width of the pharyngeal airway).

Inclusion Criteria

CBCT images having good resolution and image clarity

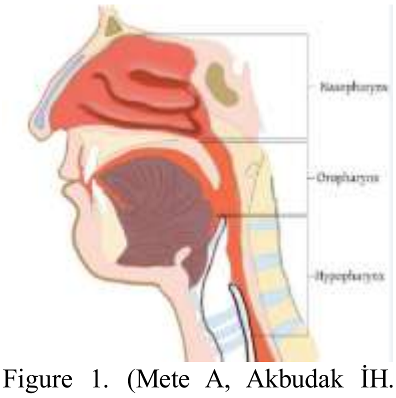


Figure 1. (Mete A, Akbudak İH. Functional anatomy and physiology of airway.
InTracheal intubation 2018 Jul 25. IntechOpen.)[6]

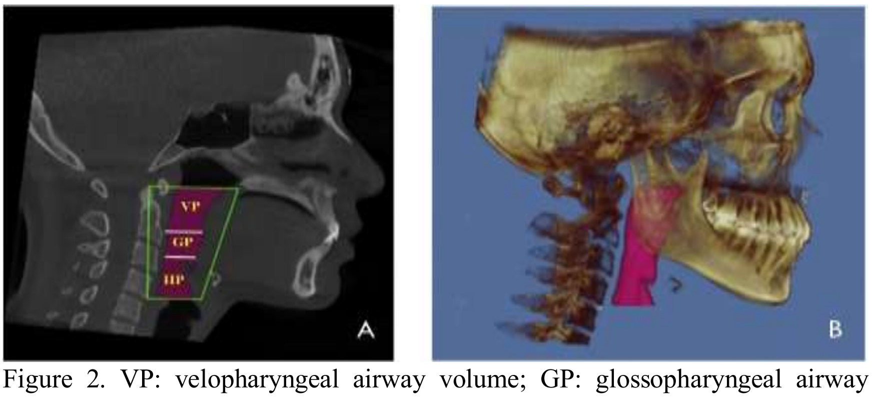


Figure 2. VP: velopharyngeal airway volume; GP: glossopharyngeal airway volume; HP: hypopharyngeal airway volume (Tseng YC, Tsai FC, Chou ST, Hsu CY, Cheng JH, Chen CM. Evaluation of pharyngeal airway volume for different dentofacial skeletal patterns using cone-beam computed tomography. Journal of Dental Sciences. 2021 Jan 1;16(1):51-7.) [7]

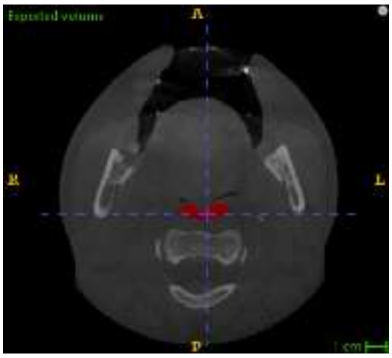


Figure 3. Axial section of Pharyngeal airway space

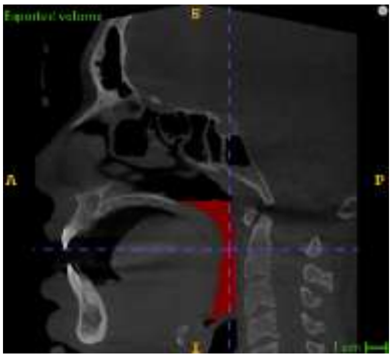


Figure 4. Sagittal section of pharyngeal airway space

Figure 5. Coronal section of pharyngeal airway space

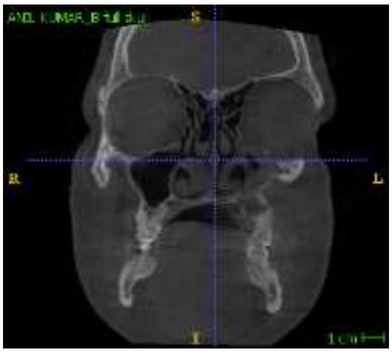


Figure 6. Coronal View: The Midsagittal plane was oriented to the midline of the 3D image, aligning the Crista Galli and anterior nasal spine, and the axial plane was oriented through both Infraorbital skeletal margin landmarks

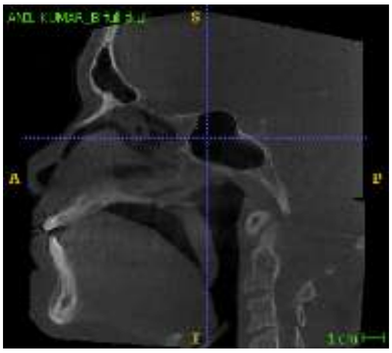


Figure 7. Sagittal view: The Frankfurt horizontal plane (FH) was parallel to the axial plane, placing it through the right porion and right infraorbital landmarks. The right side of the patient jaw was assessed, to avoid patient asymmetry

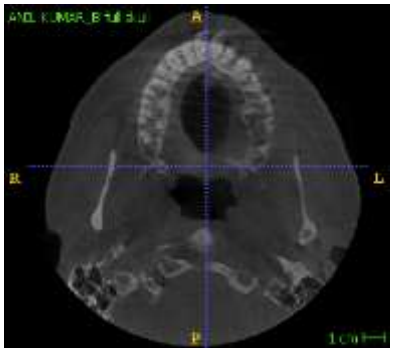


Figure 8. Axial View: The External auditory meatus was oriented and it was verified that neither mandible was present

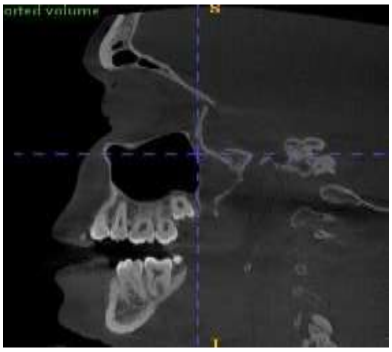


Figure 9. Class I Molar relation - Mesiobuccal cusp of the maxillary first molar occludes with the mesio buccal groove of the mandibular first molar

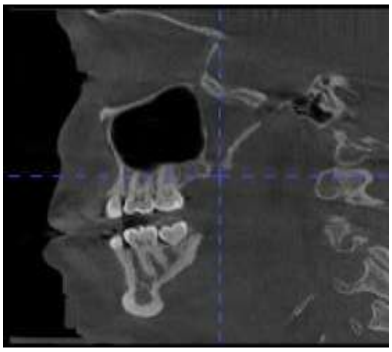


Figure 10. Class II Molar relation - Distobuccal cusp of maxillary first molar occludes with the mesio buccal groove of mandibular first molar

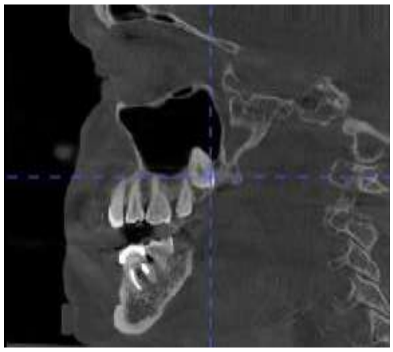


Figure 11. Class III Molar relation - Mesiobuccal cusp of maxillary first molar occludes interdentally between first and second mandibular molar

Age – 20 to 50 years
Full skull CBCT images without any distortion and artifacts

Exclusion Criteria

History of orthognathic surgery
History of tonsillectomy, adenoidectomy
History of Craniofacial trauma
Patients with Craniofacial syndromes

All images were obtained from the PLANMECA PROMAX CBCT Machine and assessed with ITK Snap Software.

Slice thickness - 350 µm 1 Pixel to 403 Pixels

The methodology was designed, tabulated and validated by the study investigator, senior radiologist with average experience of 9 and 20 years in the specialty.

RESULTS

All analyses were carried out using Statistical Package for Social Sciences (version 26, IBM, Chicago, USA). Continuous variables were expressed either as mean ± standard deviation (SD). Categorical variables were

Table 2. Comparison of pharyngeal airway space parameters between different mandibular growth patterns

	Mandibular growth pattern			
	Class I	Class II	Class III	p-value
ANS to PNS distance	48.4±1.25	47.29±1.46	48.57±1.82	0.01*
Velar length	34.65±1.51	34.12±1.51	37.41±1.22	<0.001*
Velar width	9.47±0.94	8.76±0.81	8.98±0.66	0.001*
Pharyngeal height	53.11±4.09	51.54±1.50	55.35±1.86	<0.001*
Pharyngeal width	24.14±0.57	22.44±0.50	24.21±0.49	0.001*
Pharyngeal volume	14924±1321.5	14121±1419.09	14456±1411.9	0.02*
Shortest distance of pharyngeal space	7.38±0.92	7.45±1.35	6.85±0.78	0.01*

One Way ANOVA; *p-value<0.05 – statistically significant

Table 3. Comparison of mandibular distance and gonial angle between mandibular growth patterns

	Mandibular growth pattern			
	Class I	Class II	Class III	p-value
Mandibular distance	58.93±5.93	55.92±6.14	60.96±4.31	0.01*
Gonial angle	41.45±1.22	43.40±1.27	36.13±2.45	0.01*

One Way ANOVA; *p-value<0.05 – statistically significant

expressed as n and %. As data followed normal distribution and homogeneity of variances were present between the groups, One Way ANOVA and Independent sample t-test was used for intergroup comparisons. A p-value of less than 0.05 was considered as significant.

There were about 34 of them in 21-30, 31-40 and 41-50 years respectively. The study had 51 males and 51 females. Among th study participants, about 44 (43.13%) of them had Class I mandibular growth pattern, about 49 (48.03%) of them had Class II growth pattern and 9 (8.8%) of them had Class III growth pattern.

The study participants with Class II mandibular growth pattern had significantly lower pharyngeal width, pharyngeal height and pharyngeal space than participants with Class I and Class III growth pattern (p-value=0.01, p-value<0.001, p-value=0.02).

There were significant differences in mandibular distance and gonial angle between Class I, II and III mandibular growth patterns (p-value=0..01)

There were significant differences seen in AP distance, maximum width at the level of C1, C2 and C3 vertebra among participants with different growth patterns (p-value<0.05)

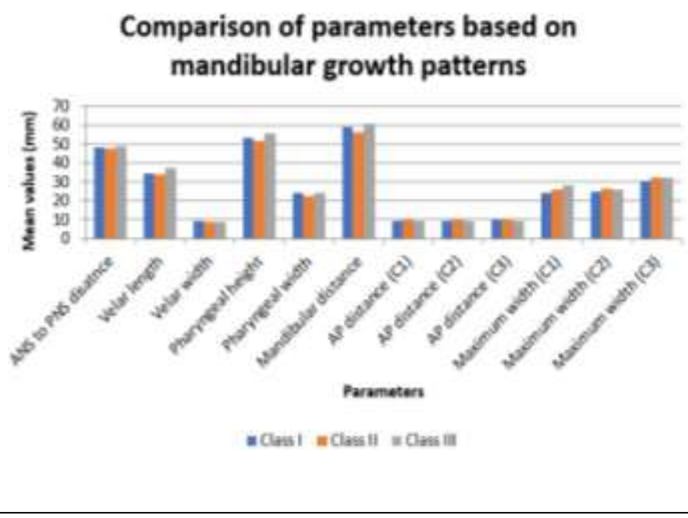
DISCUSSION

The evaluation of 3D pharyngeal airway dimensions using CBCT across varying mandibular growth patterns revealed notable anatomical differences. The distance from the anterior nasal spine (ANS) to the posterior nasal spine (PNS) which reflects the hard palate's length was greatest in Class III subjects (48.57 ± 1.82 mm), pointing toward maxillary advancement or compensatory growth, aligning with Aboudara et al.'s findings that highlighted maxillary length as a factor influencing upper airway structure [20].

Velar length was also significantly increased in Class III individuals (37.41 ± 1.22 mm), likely serving as a compensatory adaptation to preserve velopharyngeal function in the presence of mandibular prognathism. This observation corresponds with Iwasaki et al., who reported that soft palate characteristics vary based on skeletal pattern and affect the retropalatal airway [21].

Conversely, velar width was narrowest in Class II participants (8.76 ± 0.81 mm), possibly indicating nasopharyngeal restriction. This supports El and Palomo's findings that Class II profiles often exhibit diminished oropharyngeal dimensions [22].

Pharyngeal height was most pronounced in Class III cases (55.35 ± 1.86 mm), likely due to the anterior positioning of the mandible stretching the airway vertically consistent with Alves et al.'s findings [23]. Meanwhile, the narrowest pharyngeal width was seen in Class II subjects (22.44 ± 0.50 mm), likely related to mandibular retrusion and a backward tongue posture, echoing results from



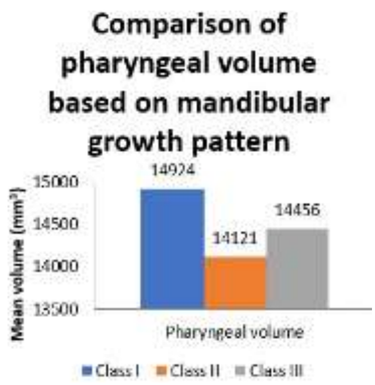


Table 4. Comparison of maximum width and AP distance between mandibular growth patterns

		Mandibular growth pattern			
		Class I	Class II	Class III	p-value
At the level of C1 vertebra	AP distance	9.27±1.46	9.92±1.01	9.15±2.23	0.01*
	Maximum width	24.33±1.78	26.05±2.43	28.24±1.23	0.01*
At the level of C2 vertebra	AP distance	9.27±1.63	9.92±1.01	9.15±1.21	0.01*
	Maximum width	24.51±3.40	26.40±4.26	25.88±3.8	0.04*
At the level of C3 vertebra	AP distance	9.90±3.02	10.21±2.7	9.22±2.9	0.03*
	Maximum width	30.27±2.9	32.12±2.31	31.88±1.95	0.02*

One Way ANOVA; *p-value<0.05 – statistically significant

Gungor and Turkkahraman, who noted reduced transverse airway dimensions in such cases [24].

In terms of volume, Class I individuals showed the highest pharyngeal volume (14,924 ± 1321.5 mm³), while Class II had the lowest (14,121 ± 1419.09 mm³), suggesting mandibular retrognathism may be linked to volumetric airway reduction, aligning with Grauer et al.'s conclusions [25].

Although Class III cases displayed both increased airway height and volume, they also exhibited the smallest minimum pharyngeal distance (6.85 ± 0.78 mm), implying a focal area of narrowing likely due to soft tissue adaptations. This supports Zeng et al.'s observations that such adaptations can cause critical constriction despite overall volumetric increases [26].

Notable differences were also observed in mandibular anatomy. Class III individuals had the longest mandibular body length (60.96 ± 4.31 mm), followed by Class I (58.93 ± 5.93 mm) and Class II (55.92 ± 6.14 mm), with a statistically significant p-value of 0.01. This reflects the influence of forward mandibular growth on airway dimensions, a finding that supports Aboudara et al.'s claims about mandibular influence on craniofacial and airway morphology [20].

Gonial angle measurements also varied significantly. Class II had the highest angle (43.40 ± 1.27°), Class I was intermediate (41.45 ± 1.22°), and Class III showed the lowest (36.13 ± 2.45°), also with a significant p-value (0.01). These patterns indicate vertical growth tendencies in Class II and horizontal growth patterns in Class III, aligning with the observations of Gungor and Turkkahraman [24].

Airway measurements at cervical vertebral levels (C1–C3) showed significant differences between skeletal classes. At the C1 level, the anteroposterior (AP) airway space was largest in Class II (9.92 ± 1.01 mm), despite these individuals having the smallest overall airway volume. This discrepancy suggests localized dimensional increases don't necessarily equate to improved airway function, consistent with Zeng et al.'s findings [26].

The widest transverse dimension at C1 was observed in Class III (28.24 ± 1.23 mm), followed by Class II (26.05 ± 2.43 mm) and Class I (24.33 ± 1.78 mm), again statistically significant (p=0.01). This suggests that forward mandibular positioning may facilitate better transverse airway expansion, as previously noted by Grauer et al. [25]

Similar trends continued at the C2 level: Class II had the greatest AP distance (9.92 ± 1.01 mm), but the relationship between localized dimension and total airway volume remained inconsistent (p=0.01), once more aligning with Zeng et al.'s findings [26]. Transverse width at C2 was also greatest in Class II (26.40 ± 4.26 mm), followed by Class III (25.88 ± 3.8 mm), and lowest in Class I (24.51 ± 3.40 mm), with a significant p-value (0.04), likely reflecting individual variation in mid-pharyngeal structure.

At the C3 level, the AP diameter remained largest in Class II (10.21 ± 2.7 mm), followed by Class I (9.90 ± 3.02 mm), and Class III (9.22 ± 2.9 mm), with p=0.03. The maximum width was also greatest in Class II (32.12 ± 2.31 mm), followed by Class III (31.88 ± 1.95 mm), and lowest in Class I (30.27 ± 2.9 mm), with p=0.02. These results reinforce the notion, as per El and Palomo, that while Class II individuals may show localized enlargement in airway sections, their overall airway function may still be compromised due to skeletal and soft tissue imbalances [22].

Uniqueness of This Study

The comparison of mandibular distance and gonial angle across different mandibular growth patterns (Class I, Class II, and Class III) revealed that Class II mandibular growth patterns are characterized by a shorter mandibular distance and a more obtuse gonial angle, whereas Class III growth patterns demonstrate a greater mandibular distance and a more acute gonial angle.

One added note on this study is that, it is the first of its kind

Study Inference

Early assessment of patients at risk for obstructive sleep apnea is crucial, as skeletal patterns significantly influence airway dimensions. Individuals with Class II malocclusion typically present with a constricted pharyngeal airway, whereas those with Class III patterns tend to exhibit a broader airway. Recognizing these differences aids in orthodontic treatment planning supporting the use of mandibular advancement in Class II cases and mandibular setback in Class III cases to optimize both airway function and skeletal balance.

CONCLUSION

The study concludes the relationship between mandibular growth patterns and pharyngeal airway space can aid in early identification of individuals at risk for conditions like obstructive sleep apnea and upper airway resistance syndrome. Additionally, this study highlights the importance of including airway evaluation as a standard protocol of diagnosis, especially using advanced imaging tools like CBCT, which offer a more detailed view of airway dimensions. It also underscores the need for teamwork among oral and maxillofacial radiologists, orthodontists, oral and maxillofacial surgeons, and sleep specialists collaborate to develop personalized treatment plans. By considering airway space in craniofacial treatment planning, clinicians can optimize both functional outcomes and patient well-being, reducing the risk of airway-related complications in the long term.

Future Perspectives

Future studies should involve larger, multi-center samples for broader validation. Longitudinal research tracking airway changes from adolescence to adulthood can enhance understanding of growth patterns is warranted. Investigating correlations between airway dimensions and conditions like obstructive sleep apnea (OSA), as well as the impact of orthodontic and surgical treatments, will strengthen clinical relevance.

Advancements in AI-driven CBCT analysis can improve diagnostic accuracy and precision. Incorporating assessments of soft tissue function, breathing patterns, obesity, and metabolic conditions will provide a more comprehensive perspective. Cross-population comparisons can help establish normative airway values, while emerging investigations may offer superior imaging precision.Finally, deeper insights into age- and gender-related airway variations will support more customized treatment in maxillofacial regions.

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