Advances in Oral and Maxillofacial Surgery 22 (2026) 100633

Contents lists available at ScienceDirect

Advances in Oral and Maxillofacial Surgery

journal homepage: www.sciencedirect.com/journal/advances-in-oral-and-maxillofacial-surgery

Three-dimensional assessment of upper airway changes following orthognathic surgery and skeletally anchored orthodontics: A systematic review

Gianna Dipalma [a,b,c,2], Grazia Marinelli [a,2], Sharon Di Serio [a], Maral Di Giulio Cesare [a], Marialuisa Longo [a], Francesco Inchingolo [a,*], Andrea Palermo [d], Angelo Michele Inchingolo [a,b,1], Alessio Danilo Inchingolo [a,1]

[a] Interdisciplinary Department of Medicine, University of Bari "Aldo Moro", 70124, Bari, Italy
[b] Department of Biomedical, Surgical and Dental Sciences, Milan University, 20122, Milan, Italy
[c] Link Camp University, Italy
[d] University of Salento, Department of Experimental Medicine, Lecce, 73100, Italy

ARTICLE INFO

Keywords:
Airway space
Surgery
Orthodontics
Skeletally anchored

ABSTRACT

This systematic review critically evaluates the effects of orthognathic surgery and skeletally anchored orthodontic treatments on upper airway morphology in patients with obstructive sleep apnoea syndrome (OSAS), with particular emphasis on biomechanical mechanisms and methodological limitations. A structured search of PubMed, Scopus, and Web of Science identified 13 human studies published between 2010 and 2025 that met predefined inclusion criteria. Maxillomandibular advancement consistently produced the most stable and clinically relevant airway improvements, primarily through coordinated skeletal repositioning and soft tissue tensioning rather than volumetric enlargement alone. Mandibular setback demonstrated a dose-dependent reduction of lower pharyngeal dimensions, while transverse maxillary expansion mainly affected the nasal cavity with limited impact on the collapsible pharyngeal airway. Considerable heterogeneity in imaging protocols, segmentation methods, and outcome measures limits direct comparison among studies and weakens correlations between anatomical and functional outcomes. Overall, the evidence supports a shift from a purely volumetric interpretation of airway change toward a biomechanical and functional framework emphasizing airway geometry, stability, and neuromuscular adaptation. Standardized three-dimensional imaging integrated with polysomnographic outcomes is required to better define the role of craniofacial interventions in OSAS management.

1. Introduction

The upper airway is a complex three-dimensional structure whose patency depends on the interaction between craniofacial skeletal morphology and surrounding soft tissues, including the tongue, soft palate, pharyngeal walls, and hyoid apparatus [1–3]. Variations in sagittal, vertical, and transverse skeletal relationships can significantly influence airway geometry and resistance, with potential consequences for respiratory function and the development of obstructive sleep apnoea syndrome (OSAS). Among airway segments, the oropharynx is particularly vulnerable to collapse because it lacks rigid skeletal support (Fig. 1).

Craniofacial skeletal discrepancies, especially skeletal Class III malocclusion and hyperdivergent growth patterns, have been associated

* Corresponding author.
E-mail addresses: gianna.dipalma@uniba.it, gianna.dipalma@unimi.it, g.dipalma@unilink.it (G. Dipalma), graziamarinelli@live.it (G. Marinelli), sharon.diserio@uniba.it (S. Di Serio), maral.digiuliocesare@uniba.it (M.D.G. Cesare), marialuisa.longo@uniba.it (M. Longo), francesco.inchingolo@uniba.it (F. Inchingolo), andreapalermo@unisalento.it (A. Palermo), angelomichele.inchingolo@uniba.it, angelo.inchingolo@unimi.it (A.M. Inchingolo), alessiodanilo.inchingolo@uniba.it (A.D. Inchingolo).
[1] These authors contributed equally to this work as co-last.
[2] These authors contributed equally to this work as co-first.

https://doi.org/10.1016/j.adoms.2026.100633
Received 11 February 2026; Accepted 13 February 2026
Available online 16 February 2026

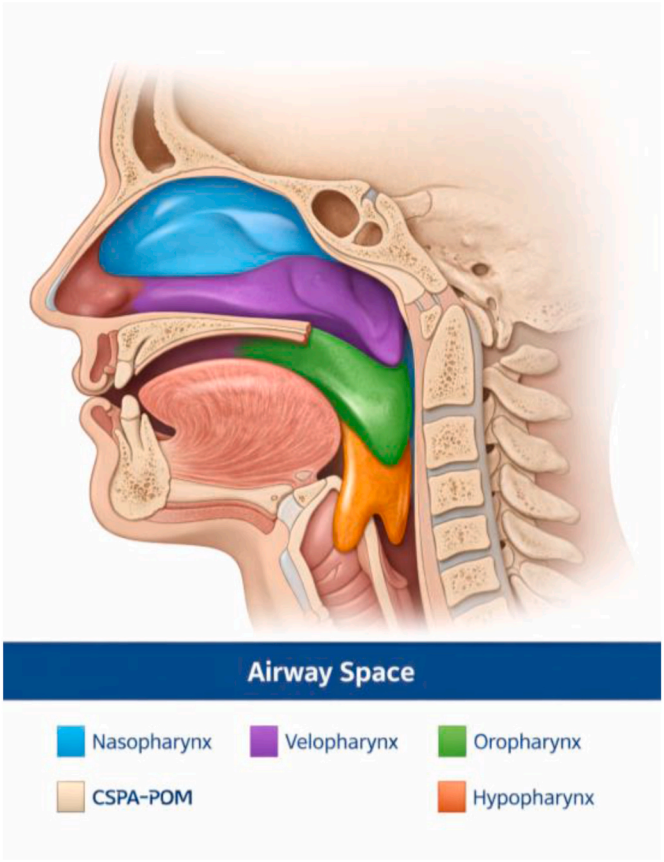

Fig. 1. Airway space.

with reduced upper airway dimensions, predominantly at the oro- and hypopharyngeal levels [4–7]. These anatomical features may predispose patients to compromised respiratory function and increase susceptibility to postoperative airway narrowing following orthognathic surgery. While orthognathic procedures are the gold standard for correcting dentofacial deformities, their impact on the airway remains a critical consideration during treatment planning [8–12].

Mandibular setback surgery, commonly performed to correct Class III malocclusion, has been consistently associated with postoperative airway reduction, particularly in the lower pharynx. Although not all patients develop clinically significant respiratory impairment, those with pre-existing airway constriction may be at increased risk of snoring or OSAS [13–18]. Consequently, airway assessment has become an integral component of preoperative evaluation. An additional variable frequently encountered in Class III patients is mandibular deviation [19, 20]. Mandibular asymmetry has been shown to independently influence airway morphology, producing asymmetric narrowing and reduced airway volume. Surgical correction of mandibular deviation may theoretically improve airway symmetry and partially offset the negative effects of mandibular setback [21–24]. However, the relative contribution of these opposing factors remains poorly defined, particularly in hyperdivergent patients who already exhibit reduced airway dimensions. Beyond sagittal repositioning, transverse maxillary expansion and orthodontic interventions using skeletal anchorage have been proposed as adjunctive strategies to improve airway dimensions [25–29]. However, their true impact on clinically relevant airway segments remains controversial [30–32]. This systematic review aims to synthesize current evidence on the effects of orthognathic surgery and skeletally anchored orthodontics on upper airway morphology, focusing on biomechanical mechanisms, imaging methodology, and clinical relevance in OSAS management [33–37].

2. Materials and methods

2.1. Protocol and registration

The current systematic review was conducted following the PRISMA guidelines (Preferred Reporting Items for SR and Meta-Analyses) and International Prospective Register of SR Registry procedures (PROSPERO: 1286053) (Fig. 2).

2.2. Search process

The following databases were combed from January 2010 to July 2025: PubMed, Web of Science (WoS), and Scopus. The search strategy was developed by combining terms relevant to the study's purpose. In the advanced search strings used in the databases, the following keywords were applied using Boolean operators to combine terms pertinent to this study's purpose (Table 1).

2.3. Inclusion and exclusion criteria

The reviewers worked in groups to assess all relevant studies that evaluated studies considering eligible if they met the following criteria:

- Open-access and written in English;
- Published within the last five years;
- Full-text articles available for review;
- Designed as randomized controlled trials (RCTs);
- Conducted on human participants;
- Investigated patients with pathological or clinical conditions relevant to the research topic.

Studies that fulfilled at least one of the following criteria were excluded:

Studies were excluded if they met one or more of the following conditions:

- Preprints or unpublished manuscripts;
- Systematic reviews, meta-analyses, case reports, or case series;
- Letters to the editor, conference abstracts, or commentaries;
- Studies involving animal models;
- In vitro or laboratory-based experiments.

2.4. PICO question

The PICO format is a framework used in qualitative research to structure clinical research questions. In this study, the PICO addressed the following question: “In patients with skeletal dentofacial deformities or OSA (P), do orthognathic surgical and complex orthodontic interventions (I), compared to pre-treatment baseline or alternative therapeutic protocols (C), induce significant morphological and volumetric expansion of the upper airway space assessed via three-dimensional imaging (O)?"

2.4.1. P – population (P)

Growing and adult patients presenting with skeletal malocclusions (specifically Class III, transverse maxillary deficiency, or anterior open bite) or diagnosed with OSA.

2.4.2. I – Intervention(I)

Surgical and orthopedic/orthodontic treatments affecting skeletal bases, including:Maxillomandibular Advancement (MMA); Surgically Assisted Rapid Palatal Expansion (SARPE) or Miniscrew-Assisted Rapid Palatal Expansion (MARPE/MISMARPE); Maxillary protraction with skeletal anchorage; Genioplasty; Molar intrusion with Temporary Anchorage Devices (TADs).)

2.4.3. Comparison (C)

Primary: Pre-treatment airway dimensions (T0 vs T1/T2). *Secondary*: Comparison between specific surgical techniques (e.g., with vs. without pterygomaxillary disjunction; Hybrid vs. Conventional Hyrax).

2.4.4. Outcome (O)

Quantitative changes in the Upper Airway Space (UAS), specifically: total and segmental volume (nasopharynx, oropharynx, hypopharynx); Minimum Cross-Sectional Area (MinCSA); Linear dimensions and morphology; *Secondary Outcome:* Reliability and accuracy of 3D imaging methods (CBCT/MRI) and automated segmentation.

2.5. Data processing

Five independent reviewers (M.L., S.d.S., M.d.G.C., M.L. and F.I.) assessed the methodological quality and risk of bias of the included studies using the Cochrane Risk of Bias 2 (RoB 2) tool. The tool evaluates key domains such as selection, measurement validity, confounding, and data analysis. Discrepancies in scoring were resolved through discussion and consensus, with support from additional reviewers (A.D.I., A.P., G. M., A.M.I., and G.D.) when needed. The reviewers screened all retrieved records based on predefined inclusion and exclusion criteria. After screening, a total of 805 articles were imported into Zotero (version 6.0.36) for organization and full-text analysis.

3. Results

3.1. Selected studies and their characteristics

The systematic search process, conducted according to PRISMA guidelines, identified a total of 218 records from three major databases: PubMed (n = 85), Scopus (n = 83), and Web of Science (n = 50). After the removal of 2 duplicates, 216 articles were screened by title and abstract. Following the application of the predefined inclusion and exclusion criteria, 150 full-text articles were assessed for eligibility. Of these, 137 were excluded for the following reasons: systematic reviews or meta-analyses (n = 37), in vitro studies (n = 30), animal studies (n = 5), case reports (n = 15), and off-topic articles (n = 50). Ultimately, 13 RCTs met all inclusion criteria and were included in the final synthesis (Table 2).

Table 1
Indicators for database searches.

Article-screening strategy	Keywords: "upper airway" orthodontics Boolean Indicators: OR and AND Timespan: January 2010 to December 2025 Electronic databases: PubMed; Scopus; WOS.

3.2. Quality and risk of bias assessment for the included article

The methodological quality and risk of bias of the thirteen included RCT were assessed using the Cochrane Risk of Bias 2 (RoB 2) tool (Table 3). This tool is specifically designed to evaluate potential bias in randomized clinical trials. Each study was independently reviewed by four reviewers (M.L., M.D.G.C., S.D.S., and A.P.), and any discrepancies in the assessments were resolved through discussion and consensus, with additional researchers (G.M., F.I., G.D., A.D.I., and A.M.I.) involved when necessary to ensure consistency and accuracy.

The RoB 2 tool evaluates five key domains: (1) bias arising from the randomization process, (2) bias due to deviations from intended

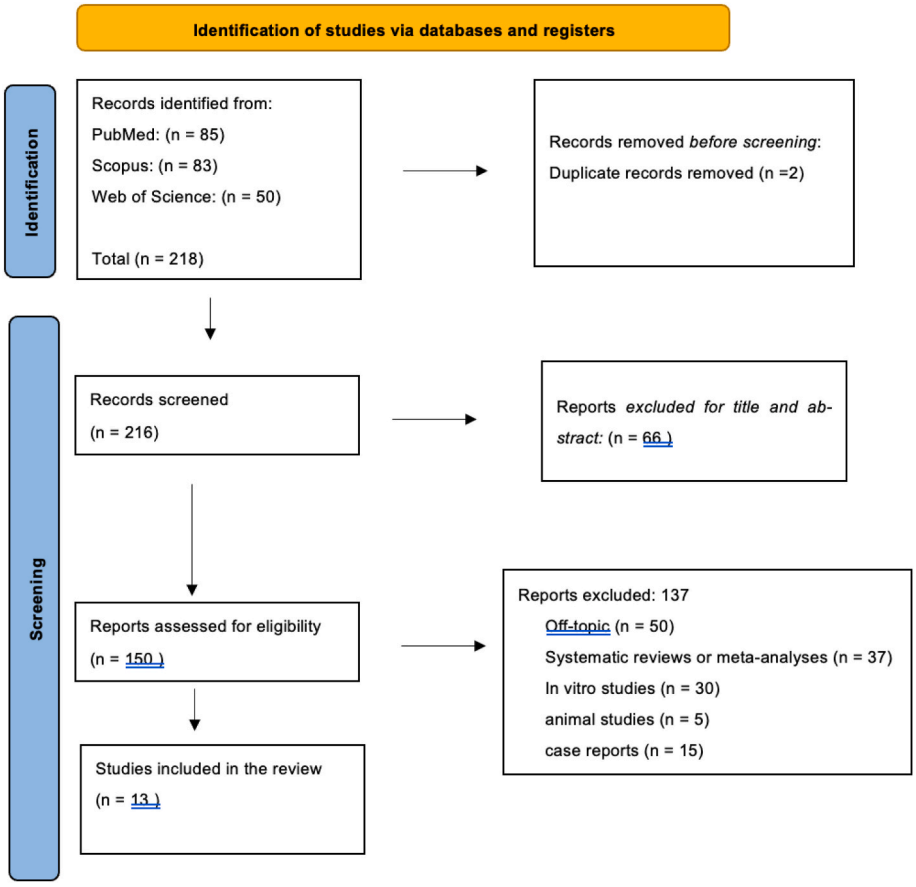

Fig. 2. PRISMA flow diagram illustrates the study selection process, including the number of records identified, screened, assessed for eligibility, and included in the final systematic review.

Table 2
Summary of the studies selected and included in the systematic review, indicating authors, publication year, study design, sample characteristics, interventions, and main outcomes.

Authors	Study Type	Sample Used	Study Objective	Materials and Methods	Conclusions
Yuh-Jia Hsieh et al. (2014)	Prospective clinical cohort study	16 adult patients with moderate–severe OSA	To assess how maxillomandibular advancement (MMA) changes upper airway size and related structures, and how these changes relate to OSA improvement.	Pre- and ≥6-month post-operative polysomnography and 3D CT. Volumetric airway analysis (velopharynx, oropharynx, hypopharynx), minimum CSA, airway length; evaluation of skeletal and soft-tissue movements (soft palate, tongue, hyoid).	MMA significantly increases upper airway volume, reduces airway length, and moves soft palate, tongue, and hyoid anteriorly. OSA improvement is associated with maxillary advancement and anterior movement of soft palate and hyoid.
Stephen A. Schendel et al. (2014)	Prospective clinical cohort study	10 adult patients with moderate–severe OSA (8 men, 2 women; mean age ≈46 years; mean BMI ≈28)	To analyze three-dimensional volumetric, morphologic, cross-sectional, and dimensional changes of the upper airway following maxillomandibular advancement (MMA) and their relationship with OSA improvement.	Pre- and postoperative CBCT and polysomnography. Airway segmented from posterior nasal spine to hyoid and divided into retropalatal and retroglossal regions. Measurements: airway volume, minimum cross-sectional area (CSA), anteroposterior and transverse diameters, airway height. Analysis performed with 3dMD Vultus software.	MMA produced a significant increase in total airway volume (≈2.5-fold), particularly in the retropalatal region, with enlargement predominantly in the transverse dimension and reduction of airway collapsibility.
E. D. Ubaldo et al. (2015)	Retrospective cohort study with long-term follow-up	43 patients with OSA treated with orthodontics and surgical jaw advancement (BSSO and/or MMA); 29 patients for cephalometric analysis; 33 patients for long-term survey (mean follow-up ≈6 years).	To evaluate skeletal and posterior airway changes after orthognathic surgery and to determine whether greater mandibular advancement correlates with long-term improvement in OSA	Lateral cephalograms at four time points (pre-treatment, pre-surgery, post-surgery, end of treatment). Posterior airway space (PAS), maxillary and mandibular advancement measured. Polysomnography (AHI), Epworth Sleepiness Scale (ESS), and patient questionnaires used for long-term outcomes. Linear regression tested correlation between advancement magnitude and OSA improvement.	Surgical advancement significantly increased PAS and improved both objective (AHI) and subjective outcomes. However, no linear relationship was found between the amount of mandibular advancement and long-term OSA improvement. Successful outcomes were achieved even with advancements <10 mm.
R. M. Bastos et al. (2024)	Comparative cohort study	37 adults with transverse maxillary deficiency: 21 MISMARPE, 16 SARPE	To compare the effects of MISMARPE versus SARPE on the nasal cavity and upper airway in adults.	Pre- (T0) and post-activation (T1) CBCT; linear and volumetric measurements of dental, alveolar, nasal cavity, and oropharyngeal regions; Dolphin Imaging; generalized estimating equations with Bonferroni correction.	Both techniques increased transverse dimensions; MISMARPE produced greater expansion at the nasal floor and midpalatal suture with similar screw activation. Volumetric airway changes were modest.
G. Jakobsone et al. (2010)	Prospective clinical trial	10 Class III patients evaluated pre-surgery and 6 months post-surgery	To assess area and volumetric upper-airway changes after bimaxillary surgery and to compare CT-based measures with lateral cephalometrics.	Pre/post CT (3D segmentation of naso-, oro-, hypopharynx) and lateral cephalograms; CSA and regional volumes; Wilcoxon tests; Spearman correlation.	No decrease in PAS after surgery; oropharyngeal and hypopharyngeal volumes increased significantly, while total volume increase was not always significant.
V. Bedoucha et al. (2015)	Retrospective comparative study	47 hyperdivergent, non-obese adolescents with mouth breathing: 23 treated with early functional genioplasty + orthodontics; 24 orthodontic controls	To evaluate whether early functional genioplasty during growth improves oro- and nasopharyngeal dimensions compared with orthodontics alone.	Cephalometric analysis; inter-group comparison of changes in oro-/nasopharyngeal measurements and skeletal variables using ANCOVA to adjust for confounders.	Early genioplasty produced significantly greater increases in velopharyngeal and linguopharyngeal spaces and reduced vertical divergence, supporting a beneficial "recalibration" of the upper airway in growing patients with mouth breathing.
G. Chu et al. (2023)	A retrospective, cross-sectional methodological study	201 adult orthodontic patients (CBCT-derived 2D airway images); training set n = 161, validation set n = 40	To develop and validate AI models capable of automatically segmenting the upper airway and localising the minimum cross-sectional area (CSAmin) using 2D radiographic images.	CBCT scans converted into 2D midsagittal airway images. Four CNN models (UNet18, UNet36, DeepLab50, DeepLab101) trained for automatic segmentation of nasopharynx, retropalatal and retroglossal regions. CSAmin localisation validated against manual 3D CBCT reconstructions. Performance evaluated with precision, recall, IoU, Dice coefficient, height error, and processing time.	AI models achieved high accuracy (>90%) in airway segmentation and reliable CSAmin localisation (κ = 0.944), with processing times <1 s versus >25 min manually. The study demonstrates the feasibility of fully automated, fast, and accurate airway assessment from 2D images, supporting future AI-assisted screening for airway obstruction.

(*continued on next page*)

Table 2 (*continued*)

Authors	Study Type	Sample Used	Study Objective	Materials and Methods	Conclusions
P. Liu et al. (2019)	Retrospective Case Series	20 young adults with maxillary transverse deficiency (11 males, 9 females; mean age 25.1 ± 6.3 years)	To evaluate changes in maxillary transverse width and upper airway dimensions following SARPE combined with surgically facilitated orthodontic therapy (SFOT).	Tooth-borne palatal expander placed on premolars and first molars. SARPE combined with corticotomies and alveolar osteotomies (SFOT). CBCT performed before treatment and after 3 months of retention. Measurements of maxillary width, molar inclination, airway volume, minimum cross-sectional area (MCA), and anteroposterior and transverse diameters using Dolphin 3D software. Paired t-tests for statistical analysis.	SARPE combined with SFOT significantly expands maxillary width and upper airway dimensions, specifically increasing volume and the minimum cross-sectional area (MCA). While this technique offers potential respiratory benefits for young adults with maxillary deficiency, long-term stability remains to be confirmed.
Y.-J. Chen et al. (2018)	Prospective clinical cohort study (pre–post)	12 non-obese adult patients (19–44 years) with acquired anterior open bite	To evaluate morphological changes of the upper airway after nonsurgical orthodontic closure of anterior open bite using TADs, and to compare 2D cephalometric and 3D MRI measurements.	Patients underwent TAD-assisted posterior intrusion to induce counterclockwise mandibular rotation, with airway changes evaluated via pre- and post-treatment cephalograms and 3D MRI. The study analyzed the retropalatal and retroglossal regions, assessing linear dimensions, volumes, cross-sectional areas, airway morphology, and tongue position, while correlating 2D and 3D measurements	TAD-assisted open bite closure significantly enlarges retroglossal airway volume and improves morphology via counterclockwise mandibular rotation and anterior tongue repositioning. Additionally, the weak correlation between 2D and 3D measurements highlights the superiority and necessity of 3D imaging for reliable airway assessment
J. R. de Medeiros et al. (2017)	Prospective randomized clinical trial	28 adult patients with transverse maxillary deficiency (final analysis: 13 in SARME with PD, 12 in SARME without PD; mean age ≈26.9–27.5 years.	To determine whether adding PD to surgically assisted rapid maxillary expansion (SARPE) results in greater increases in upper airway volume and minimum oropharyngeal cross-sectional area.	Patients underwent SARPE with or without PD. CBCT scans were obtained at three time points: preoperative (T1), immediately after expansion (T2), and after 6 months of retention (T3). Using Dolphin Imaging 3D, volumetric measurements of the nasal cavity, maxillary sinuses, nasopharynx, oropharynx, and the minimum oropharyngeal cross-sectional area (OMCSA) were calculated. Repeated-measures ANOVA with Bonferroni correction was applied.	SARPE with PD resulted in significant short- and mid-term increases in nasopharyngeal volume and minimum oropharyngeal cross-sectional area, whereas SARPE without PD did not show significant airway changes. The findings suggest that PD enhances posterior maxillary expansion and produces more consistent airway enlargement, although some relapse was observed over time.
F. Miranda et al. (2022)	RCT	40 growing patients with skeletal Class III (final analysis: 20 in Hybrid Hyrax [HH], 15 in Conventional Hyrax [CH]); mean age ≈10.8–11.5 years	To compare upper airway shape and volume changes after miniscrew-anchored maxillary protraction using a hybrid hyrax versus a conventional hyrax expander.	CBCT at baseline (T1) and after ≈12 months of treatment (T2). Semi-automatic airway segmentation (ITK-SNAP), 3D shape analysis (SPHARM-PDM/SlicerSALT), and volumetric assessment (Dolphin 3D). Outcomes: oropharyngeal volume and minimum axial area; intergroup comparisons with Mann–Whitney U; ITT analysis.	Both protocols produced similar increases in oropharyngeal volume and in the most constricted area, with transverse and anteroposterior enlargement. No significant differences were found between hybrid and conventional hyrax anchorage. Miniscrew-anchored maxillary protraction may benefit airway dimensions in growing Class III patients.
D. L. Mei et al. (2024)	Retrospective comparative cohort study (pre–post surgery)	Patients with skeletal Class III high-angle malocclusion: • Baseline comparison: 15 with mandibular deviation vs 15 without deviation • Surgical cohort: 16 with deviation vs 13 without deviation (orthodontic-orthognathic treatment)	To determine how mandibular deviation affects upper airway morphology and whether correction of deviation modifies postoperative airway changes after orthognathic surgery.	CBCT before and one year after surgery. 3D reconstruction (MIMICS); segmentation into naso-, oro-, and laryngopharynx. Measurements: regional heights, cross-sectional areas, sagittal/transverse diameter ratios, and volumes. Intergroup t-tests and Pearson correlations with mandibular setback.	Patients with mandibular deviation presented narrower initial airways but experienced less post-surgical constriction, as correcting the deviation partially mitigated the setback-induced narrowing. Consequently, preoperative airway assessment is critical for surgical planning.
I.A. Halim et al. (2024)	Retrospective, cross-sectional methodological (reliability) study	36 healthy adult males (30 military personnel, 6 laypeople; 21–29 years), no airway pathology or prior airway surgery	Primary: to evaluate the reliability of CBCT for measuring upper airway volume using a standardized protocol. Secondary: to compare airway volumes between physically fit military personnel and laypeople.	Standardized CBCT acquisition; 3D analysis in SimPlant®. Airway divided into superior, middle, and inferior sections; volumes measured twice (days 0 and 14). Reliability assessed with intraclass correlation coefficients (ICC) and	CBCT with a standardized protocol shows **excellent intrarater reliability** for total and sectional airway volumes (ICC ≈0.99). No significant differences in airway volume were found between military personnel and laypeople. CBCT is a reliable tool for pre-/post-

(*continued on next page*)

Table 2 (*continued*)

Authors	Study Type	Sample Used	Study Objective	Materials and Methods	Conclusions
				Bland–Altman plots; group comparison with Tukey's test.	treatment airway assessment in orthodontics.

Table 3
A tabular summary of the risk of bias assessment for 15 studies, evaluated across the seven domains of RoB 2.

Author (Year)	Study (Abbreviated) Title	D1 (Randomiz)	D2 (Deviations)	D3 (Missing Data)	D4 (Measurement)	D5 (Reporting)	Overall
Medeiros et al. (2017)	*Does pterygomaxillary disjunction influence upper airway volume?*	◍	◍	◍	◍	◍	◍
Miranda et al. (2022)	*Upper airway changes in Class III using miniscrew-anchored protraction*	◍	○	○	◍	◍	○
Bastos et al. (2024)	*Effects of MISMARPE on nasal cavity and upper airway*	◍	○	◍	◍	○	◍
Chen et al. (2018)	*Airway increase after open bite closure with TADs*	◍	○	◍	◍	○	◍
Hsieh et al. (2014)	*Changes in calibre of upper airway after MMA*	◍	○	◍	◍	○	◍
Liu et al. (2019)	*Changes in maxillary width and upper airway after SARPE*	◍	○	◍	○	○	◍
Schendel et al. (2014)	*3D upper-airway changes with MMA for OSA treatment*	◍	○	◍	◍	○	◍
Ubaldo et al. (2015)	*Cephalometric analysis and long-term outcomes of orthognathic surgery*	◍	○	●	○	○	◍
Mei et al. (2025)	*Upper airway changes after orthognathic surgery in Class III*	◍	○	◍	◍	○	◍
Halim et al. (2025)	*Reliability of CBCT images for upper airway volume*	◍	○	◍	◍	◍	○
Chu et al. (2023)	*Deep Learning Models for Automatic Upper Airway Segmentation*	○	◍	◍	◍	◍	○
Bedoucha et al. (2015)	*Impact of genioplasty during puberty on the upper airways*	◍	○	◍	○	○	◍
Jakobsone et al. (2010)	*Two- and three-dimensional evaluation of the upper airway after bimaxillary correction*	◍	○	◍	◍	○	◍

Legend:

- ◍ **Low Risk**
- ○ **Some Concerns** (Moderate Risk)
- ● **High Risk** (Note: Common in non-randomized/retrospective studies due to selection bias).

Domains (Cochrane RoB 2):

- **D1:** Randomization process.
- **D2:** Deviations from the intended interventions.
- **D3:** Missing outcome data.
- **D4:** Measurement of the outcome.
- **D5:** Selection of the reported result.

interventions, (3) bias due to missing outcome data, (4) bias in the measurement of the outcome, and (5) bias in the selection of the reported result. Each domain was judged as "low risk," "some concerns," or "high risk," leading to an overall judgment of the study's risk of bias.

The qualitative analysis of the selected literature, although highlighting a prevalence of studies classified as having a high risk of bias due to their predominantly retrospective nature, offers a body of evidence with remarkable clinical and instrumental reliability. It is crucial to interpret the "high risk" classification not as an indication of data inaccuracy, but rather as an intrinsic limitation of the observational design characterizing much of the research in the surgical and orthodontic fields—as evidenced by the works of **Bastos et al. (2024)** and **Schendel et al. (2014)**—where the complexity of the procedures often renders prospective randomization unfeasible. However, the robustness of the results is underscored by the methodological consistency observed in the outcome measurement domain, where subjective error has been drastically reduced. Studies such as those by **Chen et al. (2018)** and **Hsieh et al. (2014)** demonstrate how the systematic employment of advanced three-dimensional imaging technologies, such as magnetic resonance imaging (MRI) and CBCT, enables the acquisition of objective and reproducible volumetric data, thereby overcoming the limitations of traditional cephalometry.

This technical precision is further validated by recent methodological research, such as that by **Chu et al. (2023)**, which confirms the high reliability of automated anatomical segmentation. Furthermore, the external validity of the observations is reinforced by the convergence of the results: the conclusions drawn from retrospective studies are fully consistent with those of the only included low-risk randomized clinical trial, conducted by **Medeiros et al. (2017)**. The fact that such diverse study designs, applied in different contexts—as also highlighted by **Liu et al. (2019)**—reach the same conclusions regarding the increase in airway spaces, grants this body of literature sufficient solidity to guide clinical decision-making, confirming the efficacy of the examined therapies beyond individual methodological limitations.

4. Discussion

The evidence synthesized in this systematic review demonstrates that surgical and orthopaedic modification of craniofacial structures exerts a profound yet mechanistically multifactorial influence on upper airway morphology and function in the context of obstructive sleep apnoea syndrome (OSAS), while simultaneously revealing substantial methodological heterogeneity that complicates definitive causal interpretation. Among the most influential contributions, the three-dimensional imaging studies by Hsieh et al. (2014), and Schendel et al. (2014), provide robust anatomical evidence that maxillomandibular advancement (MMA) induces substantial enlargement of the upper airway at multiple levels, including the velopharynx, oropharynx, and hypopharynx [38,39]. However, both studies converge on the conclusion that the therapeutic efficacy of MMA cannot be fully explained by airway volume enlargement alone. Hsieh et al. (2014) demonstrated that postoperative reductions in the apnoea–hypopnoea index (AHI) correlated more strongly with coordinated anterior displacement of the maxilla, soft palate, tongue, and hyoid bone than with the absolute magnitude of volumetric airway gain, thereby emphasizing the importance of neuromuscular tensioning and spatial reconfiguration of collapsible structures. This finding supports a conceptual shift from a purely volumetric paradigm toward a biomechanical framework in which airway stability and resistance to collapse are central determinants of OSAS improvement. Schendel et al. (2014) reinforce this interpretation by describing a postoperative transformation of airway geometry from a funnel-shaped, collapse-prone morphology to a more cylindrical and tube-like configuration, with a particularly pronounced transverse expansion in the retropalatal region. Their observation that the retropalatal airway represented the primary site of preoperative obstruction and the most responsive segment following MMA aligns with prevailing models of OSAS pathophysiology and provides an anatomical explanation for the high clinical success rates reported with MMA in moderate-to-severe disease. Importantly, both Hsieh et al. (2014) and Schendel et al. (2014) highlight a dissociation between volumetric change and functional outcome, suggesting that airway shape, segmental mechanics, and the redistribution of soft tissue forces may be more clinically relevant than gross size metrics. The long-term cohort study by Ubaldo et al. (2015), further strengthens this interpretation by demonstrating durable subjective and functional improvement over a mean follow-up exceeding six years, despite mandibular advancement values that were frequently below the traditionally advocated 10 mm threshold [40]. The lack of a statistically significant association between advancement magnitude and long-term AHI or Epworth Sleepiness Scale (ESS) scores in Ubaldo et al. (2015) directly challenges rigid dose–response assumptions and underscores the importance of individualized surgical planning that balances airway benefit with facial aesthetics and surgical morbidity. Clinically, this finding suggests that once a critical biomechanical threshold is achieved, further skeletal advancement may yield diminishing functional returns, particularly if neuromuscular adaptation and airway shape remodeling have already been optimized. From a methodological standpoint, however, the reliance on two-dimensional cephalometry in Ubaldo et al. (2015) limits insight into transverse and volumetric airway changes, which are emphasized as critical in the three-dimensional analyses by Schendel et al. (2014) and Hsieh et al. (2014), thereby illustrating how imaging modality selection can influence mechanistic interpretation. Concerns regarding the adequacy of two-dimensional airway assessment are also evident in the work of Jakobsone et al. (2010), who demonstrated poor correlation between lateral cephalometric and CT-derived airway measurements both before and after surgery [41]. Their findings that bimaxillary correction did not reduce PAS and, in fact, produced significant increases in oropharyngeal and hypopharyngeal volumes challenge long-standing assumptions that mandibular setback necessarily compromises airway patency, particularly when balanced by maxillary advancement. Moreover, Jakobsone et al. (2010) highlighted a dissociation between volumetric airway change and minimal cross-sectional area, suggesting that airway remodeling may occur predominantly in the anteroposterior dimension while maintaining an elliptical transverse morphology that limits detectable changes in axial slices. This observation is directly relevant to OSAS research, as it underscores why studies relying on single-slice or linear measurements may underestimate or misinterpret clinically meaningful airway adaptations. The importance of sagittal mandibular positioning in influencing lower pharyngeal airway morphology is further elucidated by Chen et al. (2018), which, although not an OSAS surgical study, provides a valuable biomechanical analogue by isolating mandibular counterclockwise rotation achieved orthodontically [42]. Using three-dimensional MRI, Chen et al. (2018) demonstrated significant enlargement of the retroglossal airway following mandibular autorotation, with comparatively limited changes at the retropalatal level. This preferential retroglossal response reinforces the central role of mandibular advancement—whether surgical or orthodontic in stabilizing the lower pharyngeal airway and supports the mechanistic observations of Hsieh et al. (2014) regarding the importance of tongue and hyoid repositioning. The poor correlation between two-dimensional cephalometric and three-dimensional MRI airway measurements reported by Chen et al. (2018) further emphasizes the methodological limitations inherent in two-dimensional approaches and strengthens the argument for volumetric and shape-based analyses in OSAS- related research. The contribution of transverse maxillary expansion to airway modification is addressed by several studies included in this review, collectively indicating that such procedures predominantly affect the uppermost segments of the airway and function primarily as adjunctive interventions. Bastos et al. (2024), demonstrated that both MISMARPE and conventional SARPE produced significant increases in nasal cavity dimensions, with MISMARPE achieving greater skeletal expansion at the

nasal floor and midpalatal suture despite avoiding PD [43]. However, neither technique resulted in significant changes in oropharyngeal volume, reinforcing the concept that transverse expansion primarily improves nasal airflow rather than addressing collapsible lower pharyngeal segments. Liu et al. (2019), reported increases in airway volume and minimum cross-sectional area driven predominantly by transverse widening, while anteroposterior dimensions remained unchanged, further supporting the notion that palatal expansion modifies lateral boundaries and tongue space rather than sagittal airway patency [44]. De Medeiros et al. (2017), refined this understanding by demonstrating that PD enhanced nasopharyngeal volume and minimum oropharyngeal cross-sectional area in the short term, whereas SARME without disjunction produced no significant airway changes [45]. Nonetheless, the absence of significant differences in total airway volume and evidence of partial relapse at mid-term follow-up suggest that even optimized transverse expansion protocols may provide limited and potentially unstable airway benefits. Collectively, these studies indicate that transverse maxillary expansion may reduce upstream resistance and improve nasal breathing but is unlikely to yield clinically sufficient resolution of moderate-to-severe OSAS in the absence of sagittal skeletal advancement. A critical and previously missing component of this discussion is provided by Miranda et al. (2022), which offers high-level evidence on airway remodeling associated with sagittal maxillary advancement during growth [46]. Although conducted in a pediatric Class III population without OSAS, this RCT is highly informative from a mechanistic standpoint, as it isolates the effects of sagittal maxillary protraction combined with transverse expansion on upper airway morphology. Miranda et al. (2022) demonstrated significant anteroposterior and transverse enlargement of the oropharyngeal airway, including increases in oropharyngeal volume and minimum axial area, with no significant differences between hybrid (skeletal anchorage) and conventional hyrax expanders. Importantly, their advanced three-dimensional shape analysis revealed region-specific surface displacements rather than uniform volumetric expansion, indicating that airway improvement occurred through complex geometric remodeling. The absence of a correlation between the magnitude of skeletal advancement (as measured by SNA and Wits appraisal) and airway changes closely parallels the findings of Ubaldo et al. (2015) and Hsieh et al. (2014), reinforcing the concept that airway response does not scale linearly with skeletal displacement. Although Miranda et al. (2022) did not assess polysomnographic outcomes and evaluated a growing population, their findings provide compelling evidence that sagittal maxillary advancement alone can exert a meaningful influence on oropharyngeal airway morphology, supporting the broader inference that sagittal skeletal repositioning whether maxillary, mandibular, or bimaxillary is a key driver of clinically relevant airway remodeling. The relevance of mandibular setback and asymmetry to airway risk is addressed most directly by Mei et al. (2025), who demonstrated that mandibular deviation is associated with smaller preoperative oropharyngeal and hypopharyngeal airway dimensions, identifying asymmetry as an independent risk factor for airway narrowing [47]. Postoperatively, both deviation and non-deviation groups exhibited reductions in lower airway volume consistent with the known effects of mandibular setback; however, the reduction was less pronounced in the deviation group, suggesting a partial compensatory effect of deviation correction. Crucially, Mei et al. (2025) identified a strong negative correlation between setback magnitude and airway volume change in both groups, reinforcing the dose-dependent airway risk of mandibular setback and underscoring the importance of baseline airway assessment in surgical planning. These findings, when considered alongside Jakobsone et al. (2010), support surgical strategies that favor bimaxillary advancement or reduced setback in patients at elevated risk for OSAS. Neuromuscular mechanisms contributing to airway stability are further illuminated by Bedoucha et al. (2015), which demonstrated that early functional genioplasty increased velopharyngeal and linguopharyngeal dimensions without significant hyoid displacement, suggesting that anterior repositioning and tensioning of the genioglossus and suprahyoid musculature can enhance airway patency [48]. While conducted in a pediatric and non-OSAS cohort, this study provides mechanistic plausibility for the adjunctive use of genioplasty or genioglossus-related procedures within multilevel OSAS surgery, complementing the soft tissue repositioning effects observed by Hsieh et al. (2014). Methodological heterogeneity remains a pervasive limitation across the reviewed studies, complicating synthesis and interpretation. Variability in imaging modality, patient positioning, segmentation protocols, and outcome measures contributes to inconsistent reporting of airway changes and weakens correlations with functional outcomes. Halim et al. (2025), address this issue by demonstrating excellent intrarater reliability of CBCT-derived airway volume measurements when strict standardization is applied, thereby suggesting that some of the variability observed in the literature may reflect methodological noise rather than true biological differences [49]. However, Halim et al. (2025) also highlight a fundamental limitation: reliable volumetric measurement does not equate to functional relevance, as airway volume alone failed to distinguish between physically fit military personnel and laypeople. This reinforces the necessity of integrating anatomical metrics with polysomnographic outcomes. Chu et al. (2023), contribute a complementary methodological advance by demonstrating that artificial intelligence can accurately and efficiently localize minimum cross-sectional area (CSAmin), a parameter more directly linked to airway collapsibility than total volume. While promising, the clinical utility of AI-derived metrics remains contingent on validation in OSAS populations and on demonstrating robust associations with functional endpoints such as AHI and oxygen desaturation [50]. In summary, the collective findings of this review support a paradigm shift from a simplistic volumetric interpretation of airway change to a mechanism-based framework emphasizing airway stability, shape remodeling, and coordinated skeletal–soft tissue displacement as the principal mediators of OSAS improvement. Maxillomandibular advancement, as characterized by Hsieh et al. (2014) and Schendel et al. (2014), remains the most consistently effective surgical intervention for achieving substantial and multi-level airway remodeling, while long-term data from Ubaldo et al. (2015) suggest that durable benefit can be achieved without extreme advancement magnitudes. Sagittal maxillary advancement during growth, as demonstrated by Miranda et al. (2022), reinforces the centrality of sagittal skeletal repositioning in airway remodeling and provides mechanistic continuity with adult MMA findings. Transverse expansion techniques, as reported by Bastos et al. (2024), Liu et al. (2019), and de Medeiros et al. (2017), offer adjunctive nasal-level benefits but limited impact on collapsible lower airway segments, while mandibular setback carries a dose-dependent airway risk that is modulated by baseline morphology and asymmetry, as shown by Mei et al. (2025). Adjunctive neuromuscular interventions such as genioplasty may contribute to airway stabilization but require OSAS-specific validation, as suggested by Bedoucha et al. (2015). Finally, methodological advances in imaging reliability and automation, highlighted by Halim et al. (2025) and Chu et al. (2023), underscore the need for standardized, integrated anatomical and functional assessment in future research. Together, these studies advocate for patient-specific, mechanism-driven surgical strategies that prioritize airway stability and functional outcome over maximal anatomical enlargement, thereby refining the role of maxillofacial surgery in the comprehensive management of OSAS.

5. Conclusion

The available evidence indicates that effective airway improvement in OSAS depends on coordinated skeletal repositioning, soft tissue adaptation, and neuromuscular tensioning rather than airway volume increase alone. Maxillomandibular advancement remains the most predictable intervention, while transverse expansion serves a supportive role. Mandibular setback requires careful preoperative airway evaluation due to its dose-dependent risk. Future research should integrate

standardized three-dimensional imaging with polysomnographic and patient-reported outcomes to refine mechanism-driven, individualized treatment strategies.

Informed consent statement

This study is a systematic review of previously published data and did not involve direct participation of human subjects. Therefore, ethical approval was not required. All studies included in this review were conducted in accordance with established ethical standards and reported that written informed consent for treatment was obtained from all adult participants and from the parents or legal guardians of minor participants, in compliance with the principles of the Declaration of Helsinki.

Abbreviation

Abbreviations: The following abbreviations are used in this manuscript.

Abbreviation	Definition
AHI	Apnoea–Hypopnoea Index
AI	Artificial Intelligence
BMI	Body Mass Index
CBCT	Cone-Beam Computed Tomography
CI	Confidence Interval
CNN	Convolutional Neural Network
CSA	Cross-Sectional Area
CSAmin	Minimum Cross-Sectional Area
CT	Computed Tomography
ESS	Epworth Sleepiness Scale
ICC	Intraclass Correlation Coefficient
MMA	Maxillomandibular Advancement
MRI	Magnetic Resonance Imaging
MISMARPE	Miniscrew-Assisted Rapid Palatal Expansion
OSAS	Obstructive Slee Apnoea Syndrome
PAS	Posterior Airway Space
PD	Pterygomaxillary Disjunction
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RCT	Randomized Controlled Trial
SARPE	Surgically Assisted Rapid Palatal Expansion
SFOT	Surgically Facilitated Orthodontic Therapy
TADs	Temporary Anchorage Devices
UNet	U-shaped Convolutional Neural Network

Author contributions

Conceptualization, M.L., A.M.I., S.D.S., M.D.G.C., F.I., A.D.I., G.M., and G.D; methodology, G.D., A.M.I., M.L., M.D.G.C., S.D.S., and A.P.; software, S.D.S., F.I., G.D., G.M., M.D.G.C., M.L. and A.M.I.; validation, G.D., M.L., A.P., A.D.I., A.M.I., F.I., and S.D.S.; formal analysis, S.D.S., I. T., A.M.I., G.M., G.D., A.D.I., and M.D.G.C.; resources, M.L., G.D., A.M.I., F.I., and A.D.I.; data curation, G.D., M.L., A.M.I., S.D.S., F.I., and G.M.; writing—original draft preparation, M.L., G.M., A.M.I., G.D., M.D.G.C., and F.I.; writing—review and editing, G.D., A.P., S.D.S., A.M.I., F.I. and A.D.I.; visualization, M.L., G.D., A.D.I., A.M.I., F.I., and M.D.G.C.; supervision, G.M, M.L.S.D.S., A.M.I., F.I., and G.D.; project administration, G.D., M.L., A.D.I., A.M.I., F.I., G.M., and M.D.G.C. All authors have read and agreed to the published version of the manuscript.

Funding

This research received no external funding.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.adoms.2026.100633.

References

[1] Farronato G, Giannini L, Galbiati G, Maspero C. A 5-Year longitudinal study of survival rate and periodontal parameter changes at sites of dilacerated maxillary central incisors. Prog Orthod 2014;15:3. https://doi.org/10.1186/2196-1042-15-3.
[2] Sammartino G, Marenzi G, Tammaro L, Bolognese A, Calignano A, Costantino U, Califano L, Mastrangelo F, Tetè S, Vittoria V. Anti-inflammatory drug incorporation into polymeric nano-hybrids for local controlled release. Int J Immunopathol Pharmacol 2005;18:55–62.
[3] Inchingolo AM, Patano A, Di Pede C, Inchingolo AD, Palmieri G, de Ruvo E, Campanelli M, Buongiorno S, Carpentiere V, Piras F, et al. Autologous tooth graft: innovative biomaterial for bone regeneration. Tooth transformer® and the role of microbiota in regenerative dentistry. A systematic review. J Funct Biomater 2023; 14:132. https://doi.org/10.3390/jfb14030132.
[4] Inchingolo AD, Malcangi G, Inchingolo AM, Piras F, Settanni V, Garofoli G, Palmieri G, Ceci S, Patano A, De Leonardis N, et al. Benefits and implications of resveratrol supplementation on microbiota modulations: a systematic review of the literature. Int J Mol Sci 2022;23:4027. https://doi.org/10.3390/ijms23074027.
[5] Inchingolo AD, Di Cosola M, Inchingolo AM, Greco Lucchina A, Malcangi G, Pettini F, Scarano A, Bordea IR, Hazballa D, Lorusso F, et al. Correlation between occlusal trauma and oral microbiota: a microbiological investigation. J Biol Regul Homeost Agents 2021;35:295–302. https://doi.org/10.23812/21-2supp1-29.
[6] Dipalma G, Inchingolo AD, Calò F, Lagioia R, Bassi P, de Ruvo E, Inchingolo F, Palermo A, Marinelli G, Inchingolo AM. Eighty-four-month clinical outcomes of autologous dentin graft using tooth transformer® and concentrated growth factors in maxillary atrophy: a retrospective study of 31 patients. J Funct Biomater 2025; 16:357. https://doi.org/10.3390/jfb16100357.
[7] Inchingolo AM, Dipalma G, Bassi P, Lagioia R, Cavino M, Colonna V, de Ruvo E, Inchingolo F, Giudice G, Palermo A, et al. Evaluation of surgical protocols for speech improvement in children with cleft palate: a systematic review and case series. Bioengineering (Basel) 2025;12:877. https://doi.org/10.3390/bioengineering12080877.
[8] Xiang Y, Mao H, Tong S-C, Liu C, Yan R, Zhao L, Zhu L, Bao C. A facile and versatile approach to construct photoactivated peptide hydrogels by regulating electrostatic repulsion. ACS Nano 2023;17:5536–47. https://doi.org/10.1021/acsnano.2c10896.
[9] Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. J Chiropract Med 2016;15:155–63. https://doi.org/10.1016/j.jcm.2016.02.012.
[10] Melsen B. A histological study of the influence of sutural morphology and skeletal maturation on rapid palatal expansion in children. Trans Eur Orthod Soc 1972: 499–507.
[11] AASM scoring manual - american academy of sleep medicine. American Academy of Sleep Medicine – Association for Sleep Clinicians and Researchers.
[12] Eskander A, de Almeida JR, Irish JC. Acute upper airway obstruction. N Engl J Med 2019;381:1940–9. https://doi.org/10.1056/NEJMra1811697.
[13] Ko S-H, Hur KY, Rhee SY, Kim N-H, Moon MK, Park S-O, Lee B-W, Kim HJ, Choi KM, Kim JH, et al. Antihyperglycemic agent therapy for adult patients with type 2 diabetes mellitus 2017: a position statement of the Korean diabetes association. Korean J Intern Med 2017;32:947–58. https://doi.org/10.3904/kjim.2017.298.
[14] Broadbent BH, Golden WH, Brown RG. Bolton standards of dentofacial development growth. In: Proceedings of the plastic and reconstructive surgery, 59; January 1977. p. 115.
[15] Van Holsbeke CS, Verhulst SL, Vos WG, De Backer JW, Vinchurkar SC, Verdonck PR, van Doorn JWD, Nadjmi N, De Backer WA. Change in upper airway geometry between upright and supine position during tidal nasal breathing. J Aerosol Med Pulm Drug Deliv 2014;27:51–7. https://doi.org/10.1089/jamp.2012.1010.
[16] Aloufi F, Preston CB, Zawawi KH. Changes in the upper and lower pharyngeal airway spaces associated with rapid maxillary expansion. ISRN Dent 2012;2012: 290964. https://doi.org/10.5402/2012/290964.
[17] Feng X, Li G, Qu Z, Liu L, Näsström K, Shi X-Q. Comparative analysis of upper airway volume with lateral cephalograms and cone-beam computed tomography. Am J Orthod Dentofacial Orthop 2015;147:197–204. https://doi.org/10.1016/j.ajodo.2014.10.025.
[18] Ertugrul B. Changes in upper airway anatomy following orthodontic treatment for malocclusion: a comparative retrospective study in 96 patients. Med Sci Monit 2023;29. https://doi.org/10.12659/MSM.941749. e941749-1.
[19] Ludlow JB, Ivanovic M. Comparative dosimetry of dental CBCT devices and 64-Slice CT for oral and maxillofacial radiology. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2008;106:106–14. https://doi.org/10.1016/j.tripleo.2008.03.018.
[20] Sears CR, Miller AJ, Chang MK, Huang JC, Lee JS. Comparison of pharyngeal airway changes on plain radiography and cone-beam computed tomography after orthognathic surgery. J Oral Maxillofac Surg 2011;69:e385–94. https://doi.org/10.1016/j.joms.2011.03.015.
[21] Obelenis Ryan DP, Bianchi J, Ignácio J, Wolford LM, Gonçalves JR. Cone-beam computed tomography airway measurements: can we trust them? Am J Orthod

Dentofacial Orthop 2019;156:53–60. https://doi.org/10.1016/j.ajodo.2018.07.024.
[22] Lorenzoni DC, Bolognese AM, Garib DG, Guedes FR, Sant'anna EF. Cone-beam computed tomography and radiographs in dentistry: aspects related to radiation dose. Int J Dent 2012;2012:813768. https://doi.org/10.1155/2012/813768.
[23] Brevi BC, Toma L, Pau M, Sesenna E. Counterclockwise rotation of the occlusal plane in the treatment of obstructive sleep apnea syndrome. J Oral Maxillofac Surg 2011;69:917–23. https://doi.org/10.1016/j.joms.2010.06.189.
[24] Manlove AE, Romeo G, Venugopalan SR. Craniofacial growth: current theories and influence on management. Oral Maxillofac Surg Clin North Am 2020;32:167–75. https://doi.org/10.1016/j.coms.2020.01.007.
[25] Schwab RJ, Gefter WB, Hoffman EA, Gupta KB, Pack AI. Dynamic upper airway imaging during awake respiration in normal subjects and patients with sleep disordered breathing. Am Rev Respir Dis 1993;148:1385–400. https://doi.org/10.1164/ajrccm/148.5.1385.
[26] Ronchi P, Novelli G, Colombo L, Valsecchi S, Oldani A, Zucconi M, Paddeu A. Effectiveness of Maxillo-Mandibular advancement in obstructive sleep apnea patients with and without skeletal anomalies. Int J Oral Maxillofac Surg 2010;39:541–7. https://doi.org/10.1016/j.ijom.2010.03.006.
[27] Zhao Z, Zheng L, Huang X, Li C, Liu J, Hu Y. Effects of mouth breathing on facial skeletal development in children: a systematic review and meta-analysis. BMC Oral Health 2021;21:108. https://doi.org/10.1186/s12903-021-01458-7.
[28] Vroegop AVMT, Vanderveken OM, Van de Heyning PH, Braem MJ. Effects of vertical opening on pharyngeal dimensions in patients with obstructive sleep apnoea. Sleep Med 2012;13:314–6. https://doi.org/10.1016/j.sleep.2011.08.005.
[29] Effetto Della posizione mandibolare sulla forma tridimensionale dell'orofaringe in posizione seduta. | Studioso Di Semantica Available online: https://www.semanticscholar.org/paper/Effect-of-mandibular-position-on-three-dimensional-Furuya-Tamada/7fdf62743b1d38080fb23d33c2360de0ddf46723 (accessed on 13 January 2026).
[30] Bobak CA, Barr PJ, O'Malley AJ. Estimation of an inter-rater intra-class correlation coefficient that overcomes common assumption violations in the assessment of health measurement scales. BMC Med Res Methodol 2018;18:93. https://doi.org/10.1186/s12874-018-0550-6.
[31] Villa MP, Rizzoli A, Miano S, Malagola C. Efficacy of rapid maxillary expansion in children with obstructive sleep apnea syndrome: 36 months of Follow-Up. Sleep Breath 2011;15:179–84. https://doi.org/10.1007/s11325-011-0505-1.
[32] Ogawa T, Enciso R, Shintaku WH, Clark GT. Evaluation of cross-section airway configuration of obstructive sleep apnea. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2007;103:102–8. https://doi.org/10.1016/j.tripleo.2006.06.008.
[33] Kalaskar R, Balasubramanian S, Kalaskar A. Evaluation of the average nasal and nasopharyngeal volume in 10-13-Year-Old children: a preliminary CBCT study. Int J Clin Pediatr Dent 2021;14:187–91. https://doi.org/10.5005/jp-journals-10005-1917.
[34] Van Holsbeke C, Vos W, Van Hoorenbeeck K, Boudewyns A, Salgado R, Verdonck PR, Ramet J, De Backer J, De Backer W, Verhulst SL. Functional respiratory imaging as a tool to assess upper airway patency in children with obstructive sleep apnea. Sleep Med 2013;14:433–9. https://doi.org/10.1016/j.sleep.2012.12.005.
[35] Winnberg A, Pancherz H, Westesson PL. Head posture and Hyo-Mandibular function in man. A synchronized electromyographic and videofluorographic study of the open-close-clench cycle. Am J Orthod Dentofacial Orthop 1988;94:393–404. https://doi.org/10.1016/0889-5406(88)90128-x.
[36] Yan D, Ma Y, Wang H, Jia W, Niu X, Wang H, Zou W, Wang L. High ionic conductivity conjugated artificial solid electrolyte interphase enabling stable lithium metal batteries. Green Chem 2025;27:7564–74. https://doi.org/10.1039/D5GC01282A.
[37] Rosenbluth KH, Kwiat DA, Harrison MR, Kezirian EJ. Hyoid bone advancement for improving airway patency: cadaver study of a magnet-based system. Otolaryngol Head Neck Surg 2012;146:491–6. https://doi.org/10.1177/0194599811429522.
[38] Hsieh Y-J, Liao Y-F, Chen N-H, Chen Y-R. Changes in the calibre of the upper airway and the surrounding structures after maxillomandibular advancement for obstructive sleep apnoea. Br J Oral Maxillofac Surg 2014;52:445–51. https://doi.org/10.1016/j.bjoms.2014.02.006.
[39] Schendel SA, Broujerdi JA, Jacobson RL. Three-dimensional upper-airway changes with maxillomandibular advancement for obstructive sleep apnea treatment. Am J Orthod Dentofacial Orthop 2014;146:385–93. https://doi.org/10.1016/j.ajodo.2014.01.026.
[40] Ubaldo ED, Greenlee GM, Moore J, Sommers E, Bollen A-M. Cephalometric analysis and long-term outcomes of orthognathic surgical treatment for obstructive sleep apnoea. Int J Oral Maxillofac Surg 2015;44:752–9. https://doi.org/10.1016/j.ijom.2015.01.022.
[41] Jakobsone G, Neimane L, Krumina G. Two- and three-dimensional evaluation of the upper airway after bimaxillary correction of class III malocclusion. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2010;110:234–42. https://doi.org/10.1016/j.tripleo.2010.03.026.
[42] Chen Y-J, Chen H-H, Hsu L-F, Wang S-H, Chen Y-J, Lai EH-H, Chang JZ-C, Yao C-CJ. Airway increase after open bite closure with temporary Anchorage devices for intrusion of the upper posteriors: evidence from 2D cephalometric measurements and 3D magnetic resonance imaging. J Oral Rehabil 2018;45:939–47. https://doi.org/10.1111/joor.12712.
[43] Bastos RM, Junior OLH, Piccoli V, Rosa BM da, Oliveira RB de, Menezes LM. de Effects of Minimally Invasive Surgical and Miniscrew-Assisted Rapid Palatal Expansion (MISMARPE) on the Nasal Cavity and Upper Airway: a Comparative Cohort Study. Int J Oral Maxillofac Surg 2024;53:821–8. https://doi.org/10.1016/j.ijom.2024.03.012.
[44] Liu P, Jiao D, Wang X, Liu J, Martin D, Guo J. Changes in maxillary width and upper airway spaces in young adults after surgically assisted rapid palatal expansion with surgically facilitated orthodontic therapy. Oral Surg Oral Med Oral Pathol Oral Radiol 2019;127:381–6. https://doi.org/10.1016/j.oooo.2018.11.005.
[45] Does pterygomaxillary disjunction in surgically assisted rapid maxillary expansion influence upper airway volume? A prospective study using dolphin imaging 3D. Int J Oral Maxillofac Surg 2017;46:1094–101. https://doi.org/10.1016/j.ijom.2017.04.010.
[46] Miranda F, Garib D, Pugliese F, da Cunha Bastos JC, Janson G, Palomo JM. Upper airway changes in class III patients using miniscrew-anchored maxillary protraction with hybrid and hyrax expanders: a randomized controlled trial. Clin Oral Invest 2022;26:183–95. https://doi.org/10.1007/s00784-021-03989-3.
[47] Mei D-L, Liu L-N, Han L-C. Upper airway changes after orthognathic surgery in patients with skeletal class III high-angle malocclusion and mandibular deviation. Clin Oral Invest 2025;29:73. https://doi.org/10.1007/s00784-024-06105-3.
[48] Bedoucha V, Boutin F, Frapier L. Impact of genioplasty during puberty on the upper airways. Int Orthod 2015;13:421–35. https://doi.org/10.1016/j.ortho.2015.09.005.
[49] Halim IA, Zeinalddin M, Halim H, Rahmantya KF, Maskoen AM, Wandawa G, Mardiati E. Preliminary study: evaluating the reliability of cone-beam computed tomography images for upper airway volume in orthodontics. APOS-Trends Orthod 2025;15:218–24. https://doi.org/10.25259/APOS_216_2024.
[50] Chu G, Zhang R, He Y, Ng CH, Gu M, Leung YY, He H, Yang Y. Deep learning models for automatic upper airway segmentation and minimum cross-sectional area localisation in two-dimensional images. Bioengineering (Basel) 2023;10:915. https://doi.org/10.3390/bioengineering10080915.