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Systematic Review and Meta-Analysis
Orthognathic Surgery

Upper airway dimensions in patients undergoing orthognathic surgery: a systematic review and meta-analysis

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Abstract. The objective of this systematic review was to evaluate the effect of different types of orthognathic surgery on the dimensions of the upper airways assessed using three-dimensional images. An electronic search was performed in Cochrane Library, Medline, Scopus, VHL, Web of Science, and the System for Information on Grey Literature in Europe, ending January 2015. Inclusion criteria encompassed clinical studies in humans, patient age >15 years, patients submitted to maxillary or mandibular advancement or setback surgery, isolated or in combination, and presentation of airway measures, specifically volume and/or minimum cross-sectional area (CSA), obtained from computed tomography or magnetic resonance imaging. Additional searches were conducted on the references of included articles and in the NLM catalogue. An assessment of the risk of bias was performed. A total of 1180 studies were retrieved, of which 28 met the eligibility criteria; one was later excluded as it presented a high risk of bias. A meta-analysis was performed. There is moderate evidence to conclude that the upper airway minimum CSA increases significantly (124.13 mm^2) after maxillomandibular advancement (MMA); the total volume increases significantly after MMA (7416.10 mm^3) and decreases significantly after maxillary advancement + mandibular setback (−1552.90 mm^3) and isolated mandibular setback (−1894.65 mm^3).

Key words: upper airways; orthognathic surgery; imaging; three-dimensional.

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The upper airways are of increasing interest to the different medical professionals working in the head and neck region, primarily due to the associations between craniofacial development and morphology, the upper airway configuration, and respiratory disorders.[1–3]

Although orthognathic surgeries are performed to correct bone discrepancies, they inevitably affect the relationship between the soft and skeletal tissues. Maxillary and/or mandibular surgical replacement can cause different changes in the area and volume of the oral and nasal cavities, depending on the magnitude and direction of correction,[1,4] and subsequently may influence the quality of sleep of treated patients in the long term, when associated with risk factors.

According to Mattos et al.,[5] the airway anteroposterior length may be altered in the following ways: a decrease in the region of the soft palate and base of the tongue after isolated mandibular setback (MdS) surgery; an increase in the posterior nasal spine region and decrease in the soft palate, tongue, and vallecula regions after combined surgery of maxillary advancement with mandibular setback (MxA + MdS); and an increase in the soft palate region after maxillomandibular advancement (MMA) surgery. However, these results were based on cephalometric analyses.

Although cephalometry has been the recommended method for the analysis of craniofacial development for many years, the representation of the airways and other three-dimensional (3D) structures in two dimensions has its limitations.[2,6,7] It is known that computed tomography (CT) and magnetic resonance imaging (MRI)[6] allow linear, cross-sectional area (CSA), and volumetric assessment of the upper airways,[8,9] providing the otherwise unavailable useful quantitative and qualitative information. Both of these methods have been studied extensively and are considered reliable for reproducible assessment of the upper airways when based on well-defined parameters.[6,9–12]

No systematic reviews comparing changes in the airways resulting from different orthognathic surgeries exclusively using 3D examination have yet been reported in the literature. The systematic review by Mattos et al.[5] compared different types of orthognathic surgery and their effects on the upper airway dimensions; however, the meta-analysis used data from two-dimensional images only, as the four articles using CT were not comparable. Fernández-Ferrer et al.[13] assessed 3D images (CT) to investigate the results of one type of surgery (mandibular setback) only, and no meta-analysis was performed. It should also be noted that more than five new studies[14–19] have been published since the completion of the literature search of these two previous reviews.[5,13] Recently, an increase in this type of surgical assessment has been observed due to the introduction of these methods in the routine practice of surgeons and dentists, and also because of an increase in research in the field of OSAS (obstructive sleep apnoea syndrome). A search conducted on the Scopus database indicated an increasing number of publications on the subject, particularly since 2008.

The aim of this study was to assemble, through a systematic review, scientific evidence related to the effects of different types of orthognathic surgery on the minimum CSA and volume of the upper airway as assessed using CT or MRI.

Materials and methods

This review was based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.[20,21] The review protocol for this study was registered in the PROSPERO database as CRD42014013323 (http://www.crd.york.ac.uk/PROSPERO).

The inclusion criteria were as follows: prospective or retrospective clinical studies in humans; patient age >15 years; patients submitted to surgeries of maxillary or mandibular advancement or setback, isolated or combined; measurements of the upper airways, including volume and/or the minimum CSA, from the whole upper airway, retropalatal and/or retrolingual regions (pre- and post-surgical, or the difference between these times, with the standard deviation, *P*-value, or any other variability measures) obtained from CT or MRI. The exclusion criteria were the following: case reports, case series, review articles, editorials, reviews, and books; articles on reliability and/or comparison of methods or programmes of assessment; articles presenting only the axial area of specific levels; studies concerning patients who had craniofacial anomalies, lip and/or cleft palate, or patients who were systemically compromised; and studies concerning individuals who underwent orthognathic surgery involving transverse corrections or distraction osteogenesis.

Eligible studies that answered the PICO question (Table 1) were identified by an electronic search conducted in the following databases: Cochrane Library, Medline (via PubMed), Scopus, VHL (Virtual Health Library–Lilacs and BBO), Web of Science, and the System for Information on Grey Literature in Europe (OpenGrey). The end-point of the search period was January 9, 2015. Specific search strategies were developed for each database with the guidance of a librarian (DMTPF); the PubMed strategy is presented in Table 2. Details of the searches for all databases are provided in a supplementary file (Supplementary Material, Table S1). A complementary search was performed of journals referenced in the National Library of Medicine (NLM) catalogue (via PubMed) containing the entries of journals referenced in the NCBI database using the term 'oral and maxillofacial surg*'. The journals with their title in English that were once indexed in PubMed but are no longer indexed were selected for this additional search. A manual search of the reference lists of studies included in this systematic review was also performed.

Supplementary Table S1 related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ijom.2015.10.018.

Specific search strategy for each database.

After the exclusion of duplicate articles, two reviewers (IOC and COL) independently examined the list of titles and abstracts according to the eligibility criteria. The article was reviewed in full if the

Table 1. PICO question.

P – Population	Patients submitted to orthognathic surgery
I – Intervention	Surgical correction involving the anteroposterior aspects of the maxilla and/or mandible
C – Comparison	Between the different types of orthognathic surgery
O – Outcome	Dimensional changes of the upper airway (minimum cross-sectional area and volume) measured using CT or MRI images
Question	What are the effects of orthognathic surgery for anteroposterior correction of the maxilla and/or mandible on the dimensions of the upper airways assessed using 3D images?

CT, computed tomography; MRI, magnetic resonance imaging; 3D, three-dimensional.

Table 2. Specific search strategy for the PubMed database.

((((((((((((((((((((((((Orthognathic Surgery[MeSH Terms]) OR ''Orthognathic Surgery''[Title/Abstract]) OR Orthognathic Surgical Procedures[MeSH Terms]) OR ''Orthognathic Surgical Procedures''[Title/Abstract]) OR Surgery, Oral[MeSH Terms]) OR Maxillofacial Abnormalities[MeSH Terms]) OR Maxillofacial Abnormalities[Title/Abstract]) OR Maxillofacial Development[MeSH Terms]) OR Mandibular Advancement[MeSH Terms]) OR Orthodontics[MeSH Terms]) OR Mandible[MeSH Terms]) OR Maxilla[MeSH Terms]) OR ''jaw surgery''[Title/Abstract]) OR ''bimaxillary surgery''[Title/Abstract]) OR ''maxillo mandibular advancement''[Title/Abstract]) OR ''surgical orthodontic treatment''[Title/Abstract])))) OR (((Advancement[Title/Abstract] OR setback[Title/Abstract] OR surger*[Title/Abstract]) AND (Mandibular[Title/Abstract] OR Maxillary[Title/Abstract]))))) AND ((((((((((((((((pharynx[MeSH Terms]) OR pharyn*[Title/Abstract]) OR nasopharynx[MeSH Terms]) OR nasopharyn*[Title/Abstract]) OR hypopharynx[MeSH Terms]) OR hypopharyn*[Title/Abstract]) OR oropharynx[MeSH Terms]) OR oropharyn*[Title/Abstract]) OR airway obstruction[MeSH Terms]) OR ''airway obstruction''[Title/Abstract])OR sleep apnea syndromes[MeSH Terms]) OR ''Sleep Disordered Breathing''[Title/Abstract]) OR laryngopharyn*[Title/Abstract]) OR ''posterior airway space''[Title/Abstract]) OR ''air space''[Title/Abstract]) OR ''upper airway''[Title/Abstract]) OR ''oral airway''[Title/Abstract]) OR ''nasal airway''[Title/Abstract]))) AND ((((((((((((((((((((((Tomography, X-Ray Computed[MeSH Terms]) OR ''Cone-Beam Computed Tomography''[Title/Abstract]) OR CBCT[Title/Abstract]) OR Multidetector Computed Tomography[MeSH Terms]) OR ''Multidetector Computed Tomography''[Title/Abstract]) OR Imaging, Three-Dimensional[MeSH Terms]) OR ''Three-Dimensional Image''[Title/Abstract]) OR ''3-D Imaging''[Title/Abstract]) OR Magnetic Resonance Imaging[MeSH Terms]) OR ''Magnetic Resonance''[Title/Abstract]) OR ''Tomography MR''[Title/Abstract]) OR ''Tomography NMR''[Title/Abstract]) OR ''minimum axial area''[Title/Abstract]) OR volume[Title/Abstract]) OR area[Title/Abstract]) OR linear[Title/Abstract]) OR ''airway cross section''[Title/Abstract]) OR ''CBCT Scans''[Title/Abstract]) OR ''CBCT Scan''[Title/Abstract]) OR ''CAT Scans''[Title/Abstract]) OR ''CAT Scan''[Title/Abstract]) OR ''Cone Beam CT''[Title/Abstract]) OR ''NMR Imaging''[Title/Abstract]) OR ''MRI Scan''[Title/Abstract]) OR Invivo[Title/Abstract]) OR Dolphin[Title/Abstract]))))

title and abstract did not provide sufficient information. Disagreements between the two reviewers were resolved by seeking a third reviewer's (CTM) opinion in a consensus meeting. The authors of some studies were contacted by e-mail or social media to check the eligibility criteria and to provide missing data or information on sample overlap, including patient age.[15,22–33] In cases where the articles did not present the minimum age of the patients and the authors did not respond to attempts at contact, these were included only if they mentioned that the patients were adults and/or presented the average age (x) and standard deviation (σ), and $[x - 2\ (\sigma)] > 15$ years.

After checking the full text of the articles for eligibility, two reviewers (IOC and COL) analyzed the studies for risk of bias based on the quality assessment method reported by Mattos et al.[5] Some adjustments were made (the items corresponding to the control group and blinding assessment were removed and the sample size calculation was scored) and the selected papers were evaluated in six categories, as described in Table 3. Each article was classified as presenting a low risk of bias (score $\geq$4.5), moderate risk of bias (score >2 and <4.5), or high risk of bias (score $\leq$2). High-risk studies were excluded from the review. Any disagreement during this step was resolved by consulting a third reviewer (AAC).

The data from the selected articles were extracted and presented in a table. A meta-analysis was performed using Comprehensive Meta-Analysis software (version 3.2.00089; Biostat, Inc., Englewood, NJ, USA) with a fixed-effects model. The correlation coefficient for comparison was estimated from the studies that presented pre- and post-surgical means for the volume and minimum CSA and the post-surgical minus pre-surgical mean difference with the standard deviation.[16,25,29,34,35] In the case of two or more options, the longest follow-up period was considered. Heterogeneity was tested using the *Q*-value, I^2 index, and Tau^2, and a sensitivity analysis was performed in the case of high heterogeneity.

Studies were compared (with 'type of surgery' as a subgroup) for changes in the following measurements: total volume, retropalatal volume, retrolingual volume, minimum CSA, retropalatal minimum CSA, and retrolingual minimum CSA. A comparison of total volume change between MdS and MxA + MdS was performed using data collected from

Table 3. Risk of bias assessment modified from Mattos et al.[5]

Component	Risk of bias	Points	Definition
1. Eligibility criteria for participants described	Low	1.0	Inclusion and/or exclusion criteria described
	Moderate	0.5	No description of criteria, but selection done at least by age and type of surgery
	High	0	No description of criteria for selection
2. Statistical analysis performed	Low	1.0	Statistical analysis described fully, including sample size calculation, and adequate
	Moderate	0.5	Statistical analysis not described fully or inadequate
	High	0	No statistical analysis applied
3. Reliability of measures tested	Low	1.0	Measures repeated and statistical tests applied
	Moderate	0.5	Measures repeated and inadequate or no statistical tests applied
	High	0	Measures not repeated
4. Drop-outs reported	Low	1.0	Drop-outs reported with an explanation
	Moderate	0.5	Drop-outs reported with no explanation
	High	0	No description of drop-outs
5. Follow-up period reported	Low	1.0	Follow-up period reported
	High	0	No description of the follow-up period or unclear follow-up period
6. Potential bias and trial limitations addressed	Low	1.0	Description of potential bias and trial limitations acknowledging them
	High	0	No description of potential bias or trial limitations

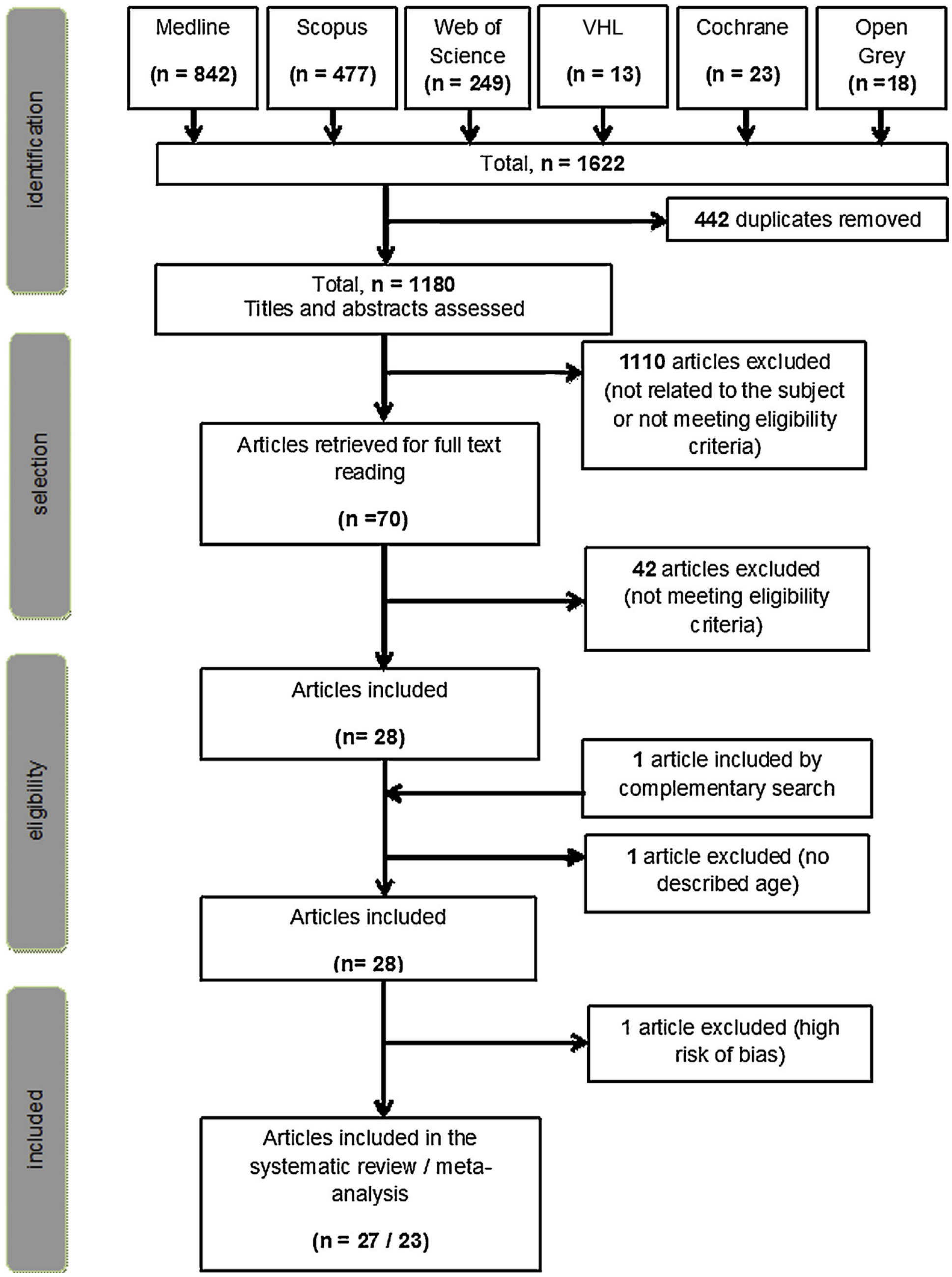


Fig. 1. Flow diagram of the study selection process (PRISMA).

studies that examined these two groups (subtracting the changes in the MdS group from the changes in the MxA + MdS group).

Results

A flow diagram of the study selection process is shown in Fig. 1. An additional search was performed in the following journals identified from the NLM catalogue: *Journal of the Korean Association of Oral and Maxillofacial Surgeons*, *Journal of Maxillofacial and Oral Surgery*, and *Atlas of the Oral and Maxillofacial Surgery Clinics of North America*; one article was found.[36] One article was excluded as we were unable to contact the authors.[24] The total number of articles included was 28.[14–19,23,25–45]

The risk of bias assessment is shown in Table 4. Only eight studies were classified as having a low risk of bias,[15,19,27,29,32–34,41] and the majority of the rest had a moderate risk of bias. One study had a high risk of bias and was excluded.[39] The least scored items and the main cause of high risk of bias in the articles was blinding, followed by report of drop-outs. Although most studies presented adequate statistical analysis, only Brunetto et al.[15] performed a sample size calculation.

Information regarding the study, patients, surgery, follow-up, measurements, and results are given in Table 5. The age of the patients varied between 16 and 62 years. The most frequent surgical procedure evaluated by the studies was MxA + MdS, while MxA + MdS versus MdS were the surgeries most commonly compared in the same study.[19,34,42] Only

Table 4. Results of the methodological quality (risk of bias) assessment.

Study	Eligibility criteria for participants described	Statistical analysis performed	Reliability of measures tested	Drop-outs reported	Follow-up period reported	Potential bias and trial limitations addressed	Total points	Risk of bias[a]
Abramson et al.,[43] 2011	1	0.5	0	1	0	1	3.5	Moderate
Bianchi et al.,[14] 2014	1	0.5	0	0	1	1	3.5	Moderate
Brunetto et al.,[15] 2014	1	1	1	0	1	1	5.0	Low
de Souza Carvalho et al.,[37] 2012	1	0.5	0	0	1	0	2.5	Moderate
Faria et al.,[38] 2013	1	0.5	0	0	1	0	2.5	Moderate
Gokce et al.,[16] 2014	1	0.5	1	0	1	0	3.5	Moderate
Gordina et al.,[39] 2013	1	0	0	0	1	0	2.0	High
Hernández-Alfaro et al.,[23] 2011	0.5	0.5	0	0	1	1	3.0	Moderate
Hong et al.,[34] 2011	1	0.5	1	0	1	1	4.5	Low
Hsieh et al.,[40] 2014	1	0.5	1	0	1	0	3.5	Moderate
Jakobsone et al.,[41] 2010	1	0.5	1	1	1	1	5.5	Low
Kim et al.,[25] 2010	1	0.5	0	0	1	0	2.5	Moderate
Kim et al.,[31] 2013	1	0.5	1	0	1	0	3.5	Moderate
Kim et al.,[32] 2014	1	0.5	1	0	1	1	4.5	Low
Kim et al.,[17] 2014	1	0.5	0	0	1	0	2.5	Moderate
Kochel et al.,[26] 2013	1	0.5	1	0	1	0	3.5	Moderate
Kwon,[36] 2012	1	0.5	0	0	1	1	3.5	Moderate
Lee et al.,[27] 2009	1	0.5	1	0	1	1	4.5	Low
Li et al.,[45] 2014	1	0.5	1	0	1	0	3.5	Moderate
Panou et al.,[29] 2013	1	0.5	1	0	1	1	4.5	Low
Park et al.,[28] 2010	1	0.5	0.5	0	1	1	4.0	Moderate
Park et al.,[42] 2012	1	0.5	1	0	1	0	3.5	Moderate
Raffaini and Pisani,[30] 2013	1	0.5	0	0	1	1	3.5	Moderate
Schendel et al.,[18] 2014	1	0.5	0	0	1	1	3.5	Moderate
Uesugi et al.,[19] 2014	1	0.5	1	1	1	0	4.5	Low
Wang et al.,[35] 2012	1	0.5	0	0	1	0	2.5	Moderate
Wang et al.,[44] 2012	1	0.5	0	0	1	0	2.5	Moderate
Zinser et al.,[33] 2013	1	0.5	1	0	1	1	4.5	Low

[a] Low risk of bias: score ≥4.5; moderate: score >2 and <4.5; high: score ≤2.

one study assessed the upper airways using MRI.[38]

Two authors of different papers, Min-Ah Kim and Wang Hongwei, apparently used the same group of patients or overlapping samples in two different articles each.[31,32,35,44] It was attempted to confirm this information by contacting the authors, but they could not be contacted. Therefore, the data collected from these four articles were also collated. However, the meta-analysis only included one article from each author to avoid duplication or bias in the analysis.[31,35]

In the meta-analysis, the correlation coefficient used to compare changes in the total/partial volume and minimum CSA of the airways was 0.786 and 0.622, respectively. The unit of measurement used was the cubic millimetre (mm^3) for volume and the square millimetre (mm^2) for area. The data were transformed or inferred by the researchers in cases where a different unit was used, and the authors were contacted when necessary. Means and standard deviations were calculated for studies that did not report them.[14,18,23,30,37]

In the MMA surgery comparison, there was a significant increase in total volume (mean 7416.10 mm^3) and in minimum CSA (mean 124.13 mm^2), as seen in Fig. 2. A sensitivity analysis was performed for the total volume change comparisons. The heterogeneity decreased significantly (I^2 from 98% to 0%) on exclusion of the study by Zinser et al.,[33] which included the nasal cavity in the volumetric calculation, and those by Abramson et al.[43] and de Souza Carvalho et al.,[37] which reported genioplasty concomitant with MMA, from this comparison. Therefore, these studies were excluded from the meta-analysis but were retained in the review. A sensitivity analysis was also performed for the minimum CSA changes comparison. The decrease in heterogeneity was considerable (I^2 from 84% to 43%) when the studies by Brunetto et al.[15] and Zinser et al.[33] were excluded from this meta-analysis comparison, because of the different anatomical limits used (fourth cervical vertebra as the lower limit and nasal cavity as the upper limit, respectively).

In the MdS and MxA + MdS comparisons, there was a significant decrease in total volume for MdS (mean −1894.65 mm^3) and MxA + MdS (mean −1552.90 mm^3). When studies that compared the total volume of MdS vs. MxA + MdS were analyzed, heterogeneity among studies was lower and the difference was not significant (Fig. 3).

With respect to regional volume changes, the retropalatal region showed a significant increase for MMA (mean 727.44 mm^3) and significant decrease for MdS (mean −3158.90 mm^3) and MxA + MdS (mean −4566.87 mm^3). In the retrolingual region, there was a significant increase for MMA (mean 2530.05 mm^3), a significant decrease for MdS (mean −2461.60 mm^3), and a significant increase for MxA + MdS (mean 1430.40 mm^3).

With respect to regional minimum CSA changes for the retropalatal region, there was a significant increase for MMA (118.63 mm^2) and MdS (23.03 mm^2). In the retrolingual region, there was a significant increase for MMA (94.84 mm^2).

Table 5. Data from the studies included.

Author, year	Type of study[a]	Patients		Intervention		Measurements		Outcomes		Statistical significance
		No. and sex	Age range, years (mean)	Type of surgery	Follow-up (mean)	Area (CSA)	Volume	Area	Volume	
Abramson et al.,[43] 2011	R	9M	21–55 (38.9)	MMA + GTA	Not reported	Mean, minimum, RP, RL	Total	Increased	Increased	Pre vs. Post: increase in volume ($P = 0.02$), CSA mean ($P = 0.01$), minimum ($P = 0.01$), RP ($P < 0.01$), RL ($P = 0.04$)
Bianchi et al.,[14] 2014	R	10M	16–59 (45)	MMA	6 months	–	Total	–	Increased	Mean volume increased ($P = 0.005$) Inverse relationship between Pre volume and the percentage increase Post ($P = 0.001$)
Brunetto et al.,[15] 2014	R	18M 24F (G1: 22; G2: 20)	18–30 (G1: 23.02; G2: 24.77)	G1: MxA + MdS G2: MMA	5–8 months	Minimum	S, I, total	G1: decreased G2: increased	G1: increased, except I G2: increased	Difference in the volume (S) percentage variation in the groups ($P \leq 0.001$)
de Souza Carvalho et al.,[37] 2012	R	11M 9F	19–57	MMA (genioplasty or anticlockwise rotation)[b]	At least 6 months	–	Total	–	Increased	Pre vs. Post immediate ($P < 0.001$) Difference among Pre and late Post ($P < 0.001$) Difference among Post immediate and late Post ($P = 0.022$)
Faria et al.,[38] 2013	P	15M 5F	26–60	MMA	6 months	–	RP, RL	–	Increased	Pre vs. Post volume in RP ($P < 0.01$) and RL ($P = 0.01$) regions
Gokce et al.,[16] 2014	R	25M	19–35 (21.6)	MxA + MdS	At least 1 year	NP, RP, OP, HP	S, Mid, I, total	Increased: NP and RP Decreased: OP and HP	Increased: S and T Decreased: Mid and I	Pre vs. Post CSA in all measurements ($P < 0.05$): increase in NP and RP, decrease in OP and HP Pre vs. Post volume: increase in S ($P < 0.001$), and T ($P < 0.005$); decrease in Mid and I ($P < 0.05$) between Pre and Post
Hernández-Alfaro et al.,[23] 2011	R	22F 8M (10 per group)	18–36 (32)	G1: MMA G2: MxA G3: MdA	(133.5 days)	–	Total	–	Increased	Increase in all groups ($P < 0.05$)
Hong et al.,[34] 2011	R	14M 7F (G1: 12; G2: 9)	18–30 (G1: 23.20; G2: 22)	G1: MdS G2: MxA + MdS	2 months	Level of: PNS, SP, EP	Total	G1: decreased G2: decreased, except CSA–PNS	Decreased	Pre vs. Post CSA: decrease in SP and EP in G1; decrease of the volume in both groups ($P < 0.05$)
Hsieh et al.,[40] 2014	P	12M 4F	22–48 (33)	MMA modified	At least 6 months (12 months)	10 levels Minimum: VP, OP, HP	VP, OP, HP, total	Increased	Increased	Increase in CSA from 1 to 9 level ($P < 0.01$) Increase in the volume and minimum CSA (VP, OP, HP) ($P < 0.01$)
Jakobsone et al.,[41] 2010	P	8M 6F	17.4–24.9 (20.3)	MxA + MdS	6 months	RP, OP, HP	NaP, OP, HP, total	Increased: RP and HP Decreased: CSA–OP	Increased: OP, HP and total Decreased: RP	Pre vs. Post: increase in the volume in OP and HP
Kim et al.,[25] 2010	R	12M 8F	(21.53)	MdS	2.3 months 12 months	–	NP, OP, HP, total	–	Decreased	Pre vs. Post: decrease at 2.3 months in total and OP ($P < 0.001$), NP and HP ($P < 0.01$); at 12 months in total and OP ($P < 0.001$), NP ($P < 0.05$), and HP ($P < 0.01$)
Kim et al.,[31] 2013	R	14M 11F	17.2–48.1 (30.04)	MxA + MdS (with clockwise rotation and genioplasty[b])	2–4 months 5–8 months	–	NP, OP, HP, total	–	Decreased	Pre vs. Post: volume decrease (both follow-ups) in T, NP, and HP ($P < 0.001$)
Kim et al.,[32] 2014	R	14M 11F	17.2–48.1 (30.04)	MxA + MdS (with clockwise rotation and genioplasty[b])	5–8 months	–	NP, OP, HP, sub-pharyngeal, total	–	Decreased Increased: HP	Pre vs. Post: decrease NP and OP ($P < 0.05$)
Kim et al.,[17] 2014	R	26M 34F (G1:30 G2: 30)	18–32 (23)	G1: maxillary impaction + MdS G2: MxS + impaction + MdS	At least 6 months	Minimum: RP	RP	G1: increased G2: decreased	G1: increased G2: decreased	Increase: G1 of the volume ($P < 0.01$) and minimum CSA ($P < 0.05$) Decrease: G2 of the volume and minimum CSA ($P < 0.01$)
Kochel et al.,[26] 2013	R	75F 27M	17.08–55 (31.8)	MdA	5 weeks	Minimum, PNS, SP, EP	S, Mid, I, total	Increased	Increased	Pre vs. Post: increase in all volume and area measurements ($P < 0.001$)
Kwon,[36] 2012	R	8M 10F	17–43 (28.7)	MxS + MdS	6 months	Minimum: OP, LP	NP, OP, LP, total	Decreased	Decreased: total and OP Increased: NP	Pre vs. Post: decrease in volume total and NP; minimum CSA–OP ($P < 0.05$)
Lee et al.,[27] 2009	R	4M 8F	Min 19 (M 23.5; F 21.4)	MxA + MdS (genioplasty[b])	1 year	–	Total	–	Decreased	Pre vs. Post: decrease in volume ($P < 0.001$)
Li et al.,[45] 2014	R	29F	18–35 (23.6)	MxA + MdS	6 months	Level of: PNS, SP, EP	NP, OP, total	Increased: CSA PNS Decreased: CSA SP and EP	Increased: NP Decreased: OP and total	Pre vs. Post: decrease in volume total and OP ($P < 0.05$), CSA SP ($P < 0.05$)

Table 5 (*Continued*)

Author, year	Type of study[a]	Patients		Intervention		Measurements		Outcomes		Statistical significance
		No. and sex	Age range, years (mean)	Type of surgery	Follow-up (mean)	Area (CSA)	Volume	Area	Volume	
Panou et al.,[29] 2013	R	6M 11F	17–34 (22.59)	MxA + MdS (maxillary impaction[b])	10–22 weeks	Minimum	S, I, total	Increased	Increased: S Decreased: I and total	Pre vs. Post: decrease in volume total and I (males) ($P = 0.028$)
Park et al.,[28] 2010	R	5M 7F	(25.5)	MdS	6 months	PNS, CV2, CV3	NP, OP, pharynx (total)	Decreased	Decreased	No significance changes in volume and CSA
Park et al.,[42] 2012	R	23M 13F (G1: 20; G2: 16)	19–29 (22.97)	G1: MdS G2: MxA + MdS	4.6 months (4.6 moths) 1.4 years (16.6 months)	PNS–Vomer (PNS–V), CV1, CV2, CV3, CV4	NP, OP, HP, total	G1: decreased, except PNS–V G2: decreased, except PNS–V and CV1	G1: decreased G2: decreased, except NP (1.4 years)	Comparison among Pre and 2 times follow-up G1: CSA CV1, CV2, and volume HP ($P < 0.05$); CSA CV3, CV4, volume OP, and total ($P < 0.01$); G2: CSA CV1 ($P < 0.01$); CSA CV4 and volume OP ($P < 0.05$)
Raffaini and Pisani,[30] 2013	R	10F	17–35 (22)	MMA (with anti-clockwise rotation)	6–12 months	Minimum	VP, OP, HP, total	Increased	Increased	Increase in minimum CSA and volume ($P < 0.05$)
Schendel et al.,[18] 2014	R	8M 2F	35–62 (mean 46.4)	MMA (genioplasty and/or septoplasty)[b]	At least 3 months	Minimum: RP, RL	RP, RL	Increased, except in one patient	Increased, except in one patient	Increased: volume upper airways
Uesugi et al.,[19] 2014	P	21M 19F (G1: 22; G2: 18)	16–54 (23)	G1: MdS G2: MxA + MdS	At least 6 months (9 months)	Average: nasal, palatal, OP, tongue	NP, OP, total	G1: decreased, except CSA nasal G2: decreased, except CSA nasal and palatal	Decreased, except NP	Decrease: G1 of the volume total and OP; of the CSA average, OP, and tongue ($P < 0.01$)
Wang et al.,[35] 2012	R	9M 11F	18–21	MdS	6 months	Minimum: PP, GP, HP	PP, GP, HP, total	Decreased	Decreased	Pre vs. Post: decrease in CSA PP, HP and volume HP, total ($P < 0.05$); in CSA GP and volume PP, GP ($P < 0.01$)
Wang et al.,[44] 2012	R	9M 11F	18–24	MdS	6 months	Minimum: PP, GP, HP	PP, GL, HP, total	Decreased	Decreased	Pre vs. Post: decrease in CSA PP, HP and volume HP, total ($P < 0.05$); in CSA GP and volume PP, GP ($P < 0.01$)
Zinser et al.,[33] 2013	R	10M 7F	25–63 (38.64)	MMA modified + anti-clockwise rotation (genioplasty and/or septoplasty)[b]	3–6 months	NP, OP, HP, minimum, maximum, average	Nasal, NP, OP, HP, total	Increased	Increased	Pre vs. Post: increase in all volume and CSA measurements ($P < 0.005$, except volume NP where $P < 0.003$), except CSA NP

CSA, cross-sectional area; CV, cervical vertebra; EP, epiglottis; F, female; G, group; GP, glossopharyngeal; GTA, genial tubercle advancement; HP, hypopharyngeal; I, inferior; LP, laryngopharyngeal; M, male; Mid, middle; MdA, mandibular advancement; MdS, mandibular setback; MMA, maxillomandibular advancement; MxA, maxillary advancement; NaP, nasopalatal; NP, nasopharyngeal; OP, oropharyngeal; PNS, posterior nasal spine; Post, postoperative; PP, palatopharyngeal; Pre, preoperative; RL, retrolingual; RP, retropalatal; S, superior; SP, soft palate; T, total; VP, velopharyngeal;

[a] Study type: R, retrospective; P, prospective.

[b] With or without.

Discussion

Three-dimensional analysis of the upper airways is a well-known, reliable, and reproducible method used by dental professionals.[2,7,8,38,46] In a previous systematic review on the same subject, the authors suggested the need for more studies using this method to assess the effects of orthognathic surgery on the airways.[5] Therefore, the present systematic review considered only studies that used CT or MRI for airway evaluation. CT, particularly cone beam CT (CBCT), presents a lower cost for the patient, can be used in various positions (sitting and lying), and allows for a more detailed study of pre- and post-surgical cases.[8,47,48] MRI provides high quality images of the airways that allow the accurate measurement of area and volume without exposing the patient to radiation. However, it is relatively expensive and has lower accessibility than CT.[11,12,38,49]

Randomized clinical trials (RCTs) represent the ideal study type for a systematic review. However, when assessing the effects of orthognathic surgery, there are ethical aspects that limit the development of this type of study design. The surgical procedure cannot be randomized since the patients must have the best treatment option available for their case, and in most instances surgeries are not interchangeable. Blinding is also not feasible for patients and professionals due to the nature of the procedures, and is therefore restricted to evaluators or the statistician. Thus, in this review, non-randomized clinical studies were selected. Most were retrospective studies ($n = 23$) – only four were prospective.[19,38,40,41] In the review by Mattos et al.,[5] the methodological quality assessment performed was based on the Consolidated Standards of Reporting Trials (CONSORT), and these standards were also used in the present review. However, as blinding assessment and control groups were presented in very few studies in the previous review, these parameters were not considered in the present analysis. Fernández-Ferrer et al.[13] also used the CONSORT guidelines, whereas Alsufyani et al.[46] evaluated the risk of bias based on the following criteria: selection, detection or measurement, analysis or interpretation, and performance. The risk of bias attributed to each article in the present review must then be considered in the context of studies that are viable for orthognathic surgery. As such, papers included and classified as presenting a low risk of bias in this review provide less scientific evidence than RCTs because

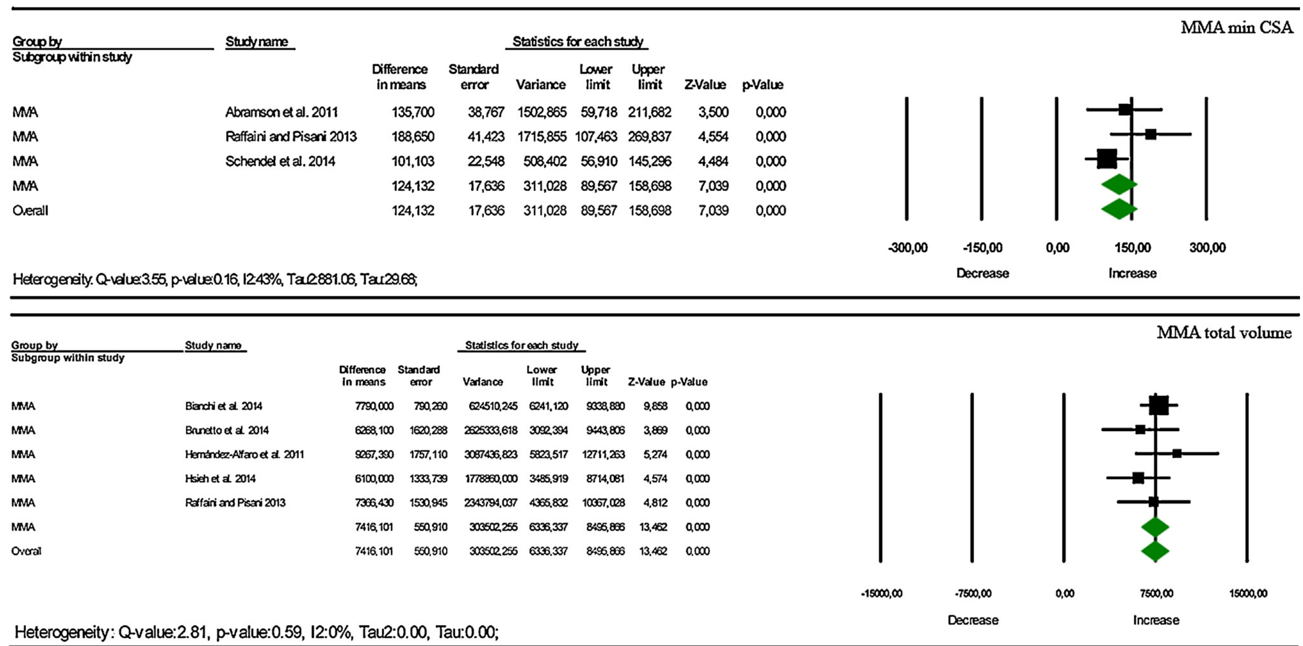


Fig. 2. Comparison of the minimum cross-sectional area (CSA) and total volume changes in maxillomandibular advancement (MMA).

randomization and blinding were not scored. This could be considered a limitation of this review. However, every effort was made to obtain the best available evidence on the subject.

Dental professionals should be aware that airway dimensions may be affected by skeletal patterns.[8,50,51] Therefore, when surgery is considered, it is advisable that potential airway dimensional changes be studied for each patient. According to Schendel et al.,[52] who studied growth and development in a 3D analysis, the size and length of the airway increase up until 20 years of age at which time it stabilizes. Their results showed a major increase (approximately 3210 mm^3) in the average airway volume from the age group of 12 to 14 years to the age group of 15 to 17 years, which was the major difference observed between two subsequent groups from 6 to 60 years. This was the reason why age above 15 years was selected as an inclusion criterion in the present review.

In relation to the sex of patients, two studies included only women in their sampling[43,45] and two others included only men.[14,16] There are studies in the literature that have reported differences between the sexes when analyzing the upper airways.[29,53] However, Degerliyurt et al.[54] divided the patients according to sex and surgical procedure and reported no statistically significant differences between the sexes ($P < 0.05$). As there is no consensus, all studies were considered together in this review. However, if this proves to be a limitation, new studies should consider sex in their analyses.

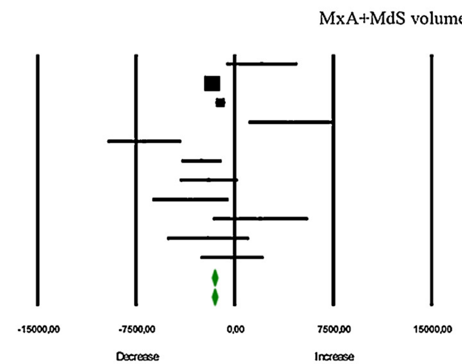
According to Lenza et al.,[8] professionals should consider linear, area, and volumetric measurements to perform a complete analysis of the airways. Alsufyani et al.[46] reported that total volume and minimum CSA measurements were the most common airway parameters evaluated. This is probably due to the relevance of the total volume, which represents the amount of air that can occupy the airways, as well as the minimum CSA, which represents the region of greatest constriction and is the smallest area of fair passage. According to Schendel et al.,[18] there is an association between the minimum area of the airways and the occurrence of obstructive sleep apnoea, as the lower the minimum area is, the greater the predisposition to apnoea. Therefore, this systematic review considered the minimum axial area and volume, and the volumetric measurement was the most frequently observed in the articles included.[14–19,23,25–38,40–45]

There is no evidence to confirm that changes in upper airway dimensions after orthognathic surgery predispose the individual to obstructive sleep apnoea.[13] Although pre- and even post-surgery airway dimensions may differ in patients with and without sleep disordered breathing, the present comparison of the studies focused on changes in the airway dimensions, instead of on initial and final specific values, and they are more likely to be comparable. Indeed, the low heterogeneity in the comparison of studies including patients with and without sleep disordered breathing (I^2 = 0% and 43%; Fig. 2) confirmed the possibility of this analysis.

In the assessment of surgeries that included mandibular advancement, for MMA surgery, which is indicated for the treatment of severe cases of obstructive sleep apnoea,[55] the effect size (treatment effect) indicated by the meta-analysis when considering the upper airways was a significant increase in the total volume and in the volume of the retropalatal and retrolingual regions. Alsufyani et al.[46] showed similar results with respect to the increase in total volume. The treatment effect in minimum CSA was a significant increase in the upper airways as a whole and in the retropalatal and retrolingual regions. These results are compatible with those of Caples et al.[56] and Holty et al.,[55] who reported this surgical procedure as being effective due to the considerable decrease in the apnoea–hypopnoea index observed post-surgically.

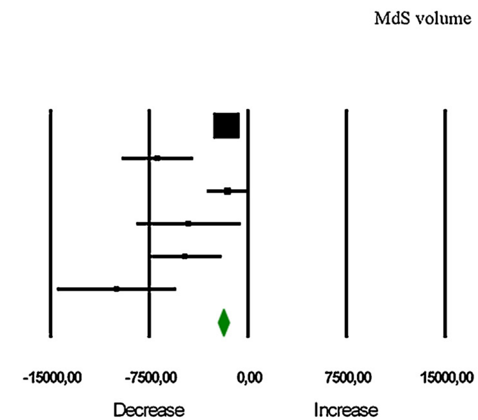
In the assessment of surgeries that included mandibular setback, the treatment effect of MxA + MdS surgery was a significant decrease in volume. However, when assessed by regions, a significant decrease was observed in the retropalatal region while a significant increase was seen in the retrolingual region. This appears contradictory and is exactly the opposite of what one would expect. Brunetto et al.[15] suggested that surgeries where both jaws move in the same direction tend to have

Group by Subgroup within study	Study name	Difference in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
MxA+MdS	Brunetto et al. 2014	2062,910	1377,300	1896954,943	-636,548	4762,368	1,498	0,134
MxA+MdS	Gokce et al. 2014	-1712,000	113,200	12814,240	-1933,868	-1490,132	-15,124	0,000
MxA+MdS	Hong et al. 2011	-1085,750	197,697	39083,972	-1473,228	-698,272	-5,492	0,000
MxA+MdS	Jakobsone et al. 2010	4270,000	1640,984	2692828,571	1053,730	7486,270	2,602	0,009
MxA+MdS	Kim et al. 2013	-6883,480	1431,754	2049919,517	-9689,666	-4077,294	-4,808	0,000
MxA+MdS	Lee et al. 2009	-2522,860	782,806	612785,447	-4057,132	-988,588	-3,223	0,001
MxA+MdS	Li et al. 2014	-1970,000	1120,982	1256599,724	-4167,084	227,084	-1,757	0,079
MxA+MdS	Panou et al. 2013 men	-3375,530	1479,765	2189705,435	-6275,817	-475,243	-2,281	0,023
MxA+MdS	Panou et al. 2013 women	1955,570	1844,586	3402497,895	-1659,752	5570,892	1,060	0,289
MxA+MdS	Park et al. 2012	-2031,080	1588,866	2524495,024	-5145,200	1083,040	-1,278	0,201
MxA+MdS	Uesugi et al. 2014	-200,000	1226,096	1503311,111	-2603,104	2203,104	-0,163	0,870
MxA+MdS		-1552,907	95,673	9153,314	-1740,423	-1365,392	-16,231	0,000
Overall		-1552,907	95,673	9153,314	-1740,423	-1365,392	-16,231	0,000



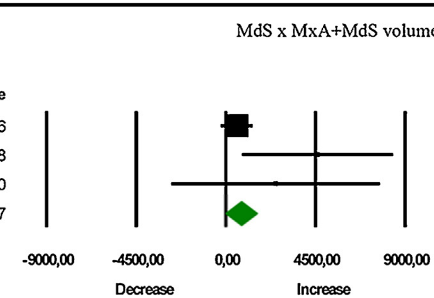
Heterogeneity: Mxa+MdS - Q-value:49,02, p-value:0.00, I2:79%, Tau2:822001.76, Tau:906,64;

Study name	Difference in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Hong et al. 2011	-1625,170	218,585	47779,320	-2053,588	-1196,752	-7,435	0,000
Kim et al. 2010	-6899,090	1385,231	1918864,080	-9614,092	-4184,088	-4,980	0,000
Park et al. 2010	-1540,000	814,598	663570,267	-3136,583	56,583	-1,891	0,059
Park et al. 2012	-4529,630	2022,099	4088884,770	-8492,871	-566,389	-2,240	0,025
Uesugi et al. 2014	-4800,000	1434,799	2058647,273	-7612,154	-1987,846	-3,345	0,001
Wang et al. 2012	-9991,000	2314,778	5358195,200	-14527,881	-5454,119	-4,316	0,000
	-1894,659	204,659	41885,432	-2295,783	-1493,534	-9,258	0,000



Heterogeneity: MdS - Q-value:32.79, p-value:0.00, I2:84%, Tau2:5140667, Tau:2267.30;

Study name	Subgroup within study	Difference in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Hong et al. 2011	MdS x MxA+MdS	539,420	408,019	166479,801	-260,283	1339,123	1,322	0,186
Uesugi et al. 2014	MdS x MxA+MdS	4600,000	1936,738	3750952,259	804,064	8395,936	2,375	0,018
Park et al. 2012 (1,4 years)	MdS x MxA+MdS	2498,550	2673,185	7145917,340	-2740,796	7737,896	0,935	0,350
		750,967	394,875	155926,605	-22,975	1524,908	1,902	0,057



Heterogeneity. Q-value:4.64, p-value:0.09, I2:56%, Tau2:3422107.95, Tau:1849.89

Fig. 3. Comparison of the total volume changes in maxillary advancement + mandibular setback (MxA + MdS), MdS, and MdS vs. MxA + MdS.

more predictable outcomes. Additionally, they mentioned that when the base of the tongue moves backwards, the soft palate can be pushed in the same direction, thus decreasing the retropalatal volume. The study by Kim and Park[24] (not included in this review) utilized a different format, wherein patients were divided into extraction and non-extraction groups. In the extraction group, the total volume decreased, similar to the findings of the present meta-analysis, but it remained practically stable in the non-extraction group. None of the studies included in the present review showed this division or gave any information regarding extraction. This may be an interesting topic for future studies to check, particularly in borderline cases. In the isolated MdS surgery, the treatment effect for volume was a significant decrease in total volume and regional volume (retropalatal and retrolingual). Fernández-Ferrer et al.[13] also observed a significant decrease in total volume.

Both MxA + MdS and MdS surgeries may be indicated in mandibular prognathism and/or maxillary deficiency and are, therefore, the two types of orthognathic surgery most frequently compared in the same study. In this meta-analysis, in the comparison between MxA + MdS and MdS, although the volume of the upper airways decreased less in combined surgery than in the mandibular setback alone, the treatment effect was not significant. The evidence found from this comparison could guide clinical decisions, particularly in difficult cases where the surgeon can opt for either surgery, when airways are concerned. Uesugi et al.[19] reported no differences in the apnoea–hypopnoea index between the two groups, which further emphasizes this consideration. However, the authors stressed that it is important to assess each case individually, taking into consideration obesity and the amount of mandibular setback.[19]

According to the results of the present analysis, the consequences of orthognathic surgery represent more a benefit in airway dimensions (volume in cases of maxilla and/or mandibular advancement) than an impairment (in cases of mandibular setback). This can be inferred from the magnitude of the volume increase in MMA (approximately 7000 mm^3) compared to the decrease in MdA + MdS and MdS (between 1500 and 2000 mm^3).

Fewer studies have evaluated area alterations compared to volume, and the minimum CSA could not be compared between all of these studies as some of the authors had calculated this measurement in different regions of the airways and did not consider the upper airway in its entirety. For the study by Schendel et al.,[18] it was possible to calculate the mean and standard deviation of the minimum CSA as the authors had provided pre- and post-surgical values for each patient for the retropalatal and retrolingual regions. Nonetheless, future studies should focus on presenting the minimum CSA for the whole upper airway and not only for specific regions, as this information is extremely relevant and is not necessarily inferred from the regional mean.

One of the limitations of this review is the high heterogeneity observed in some comparisons in the meta-analysis. This was probably due to methodological differences, including those due to variations in surgeries combined with anteroposterior surgeries, such as genioplasty, septoplasty, and impaction, which are not always mentioned by the authors. However, the most evident difference was regarding the anatomical limits used to assess the airways, which varied greatly among studies. The upper limits described were the hard palate, soft palate, the upper point of the pharynx, the posterior nasal spine, and the first cervical vertebra. The lower limits were the hyoid, epiglottis, the third and fourth cervical vertebrae, vallecula, vocal cords, and larynx. These limits were either parallel to the Frankfort plane or inclined. The name, number, and boundaries of the regions also varied. There is no specific standard that is used by all researchers to evaluate the upper airway. Previous systematic reviews have mentioned this limitation,[2,13] and Guijarro-Martinez and Swennen[57] have proposed clinical 3D anatomical limits for the upper airway subregions. Nonetheless, standardization is still necessary. There also remains a need for studies assessing the long-term stability of post-surgical changes in airway dimensions.

There is moderate evidence to infer that the upper airway minimum CSA increases significantly after MMA, while the total volume increases significantly after MMA and decreases significantly after MxA + MdS and isolated MdS, based on 3D images.

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Competing interests

There are no competing interests.

Ethical approval

Ethical approval was not necessary for this systematic review.

Patient consent

Not required.

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