Received: 18 March 2024 | Revised: 7 June 2024 | Accepted: 24 June 2024

DOI: 10.1111/joor.13797

REVIEW

JOURNAL OF ORAL REHABILITATION WILEY

Association between orthodontic treatment and upper airway changes in children assessed with cone-beam computed tomography (CBCT): A systematic review

Yousef Abdalla[1] | Liselotte Sonnesen[2]

[1]Department of Orthodontics, School of Dentistry, James Cook University, Cairns, Queensland, Australia

[2]Section for Orthodontics, Department of Odontology, Faculty of Health and Medical Sciences, University of Copenhagen, Copenhagen, Denmark

Correspondence
Liselotte Sonnesen, Section for Orthodontics, Department of Odontology, Faculty of Health and Medical Sciences, University of Copenhagen, 20 Nørre Alle, DK-2200 Copenhagen N, Denmark.
Email: alson@sund.ku.dk

Abstract

Background: Some orthodontic devices used in children share similar design principles to appliances used to treat obstructive sleep apnoea in adults. As well as treating malocclusion, orthodontic appliances used in children may therefore also have effects on the upper airway.

Objective: A review of the literature to assess the effects of orthodontic treatment on the upper airway dimensions in children assessed on CBCT.

Materials and Methods: Following registration of the protocol (PROSPERO CRD42023439056), a systematic electronic search of published studies was performed using several databases (PubMed; Scopus, Web of Science and Science Direct) in accordance with the PRISMA guidelines. Inclusion criteria were as follows: age under 18 years, orthodontic treatment with any appliance, a control group who received no treatment or a non-active alternative treatment and airway measurement using CBCT. RoB-2 and ROBINS-I tools were used to assess risk of bias and quality of the evidence.

Results: In total, 341 studies were identified following the initial search. Title and abstract screening resulted in 45 studies for further full-text analysis. On completion of the screening process, a total of 23 studies met the inclusion criteria. Study interventions included functional appliances (10 studies), rapid maxillary expansion (RME) (9 studies), reverse-pull headgear (1 study) and 4 premolar dental extractions (3 studies). The included studies had moderate to high risk of bias, and the quality of evidence was low.

Conclusion: The scientific evidence shows that functional appliances are associated with significant improvements in both upper airway volume and constriction when used in children however, the effects on the nasal cavity are limited. RME was associated with a significant increase in nasal cavity and nasopharyngeal dimensions, but not the upper pharyngeal airway. Neither reverse-pull headgear nor dental extractions were associated with any change in airway dimensions; however, the evidence is limited. Functional appliances may reduce the severity of obstructive sleep apnoea (OSA) in children.

KEYWORDS
adolescent, airway, CBCT, children, orthodontics, review

1 | BACKGROUND

Mandibular retrognathia and maxillary constriction are risk factors for reduced upper airway dimensions in children.[1,2] Consequently, dentofacial changes achieved with orthodontic treatment have the potential to also influence the dimensions of the upper airway.[3] Rapid maxillary expansion (RME) corrects arch width discrepancies by expanding the maxilla in the transverse dimension.[4] Likewise, functional appliances (FA) correct increased overjet while also improving mandibular retrognathia.[4] Furthermore, mandibular advancement devices (MAD) share the same design principals as FA and have been shown to increase upper airway patency in patients with obstructive sleep apnoea (OSA).[5,6]

It is not possible to accurately assess the upper airway using standard 2-dimensional (2D) orthodontic imaging, as the upper airway is a complex 3-dimensional (3D) structure.[7] Furthermore, most 3D imaging methods such as magnetic resonance imaging (MRI) and medical computed tomography (CT) have not routinely been used in orthodontics due to accessibility, high costs and higher radiation doses.[8]

Cone-beam computed tomography (CBCT) is a contemporary 3D imaging technique which can be used for orthodontic diagnosis and treatment planning and offers distinct advantages over MRI and CT, such as a lower radiation dose, lower cost, easier access and shorter acquisition time.[9] Furthermore, CBCT has the ability to accurately differentiate between the airway and soft tissues with high resolution, which allows for more accurate imaging of the upper airway when compared to traditional 2D orthodontic imaging.[10]

Therefore, the aim of this study was to systematically review the literature to determine the 3D airway effects of orthodontic treatment in children, when assessed with CBCT imaging, and using a comparable matched control group. A review utilising these parameters has not been previously reported.

2 | METHODS

This systematic review was carried out by two assessors (YA and LS) and is reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statements.[11]

2.1 | Registration of protocol

The protocol was registered in the PROSPERO database (CRD42023439056). There were no significant deviations from the protocol.

2.2 | Inclusion and exclusion criteria

Inclusion and exclusion criteria were established with the PICO method (Population, Intervention, Controls and Outcome).

Population: Children or adolescents (<18 years age).

Intervention: Orthodontic treatment with any orthodontic appliance.

Controls: Longitudinal non-treatment or alternative non-active treatment control group.

Outcome: Effects on airway constriction and/or airway volume assessed with CBCT.

Research articles not published in English, as well as review articles, systematic reviews, editorials, letters and commentary were excluded.

2.3 | Data sources

Following registration of the protocol, a retrospective search of four databases (PubMed, Scopus, Web of Science and Science Direct) was carried out in February 2024, with no date limit set.

2.4 | Search strategies and screening

All MeSH terms, keywords and terms related to orthodontics; airway; CBCT; and children or adolescents were used and combined with Boolean operators 'AND' and 'OR' (Table 1). Once duplicates were removed, the studies collected from the database search were initially screened using titles and abstracts based on the inclusion and exclusion criteria. Studies meeting the criteria were then subject to a second stage of full-text screening to confirm the articles' suitability for inclusion. Furthermore, reference lists of included studies were manually searched to identify any additional studies for inclusion. The systematic search of the literature was carried out by the authors.

2.5 | Data extraction and synthesis

The data extracted from each study included the date of publication, first author, journal name, type of publication, study objectives, sample size, intervention details and outcomes.

2.6 | Quality assessment

The quality assessment was carried out according to the Cochrane Handbook of Systematic Reviews[12] Randomised controlled

TABLE 1 Search strategy.

PubMed	Orthodont* AND airway AND (cone beam computed tomography OR cone beam CT OR cone-beam CT OR CBCT OR 3D volumetric computed tomography OR volume computed tomography OR 3D OR 3-D OR three dimensions OR three-dimensional OR three-dimension) AND (child* OR adolescent)	281
Scopus	TITLE-ABS-KEY (child* OR adolescent) AND TITLE-ABS-KEY (airway) AND TITLE-ABS-KEY ((cone AND beam AND computed AND tomography) OR (cone AND beam AND ct) OR (cone-beam AND ct) OR (cbct) OR (3d AND volumetric AND computed AND tomography) OR (three-dimensional)) AND TITLE-ABS-KEY (orthodont*) AND NOT DOCTYPE (re)	131
Web of Science	(((ALL=(airway)) AND ALL=((Cone beam computed tomography) AND (CBCT) AND (cone-beam CT) AND (cone beam CT) AND (CBCT))) AND ALL=(orthodont*)) AND ALL=(child* OR adolescent)	10
Science Direct	Orthodontics AND airway AND (CBCT OR (cone beam CT) OR (cone beam computed tomography)) AND (child OR adolescent)	146

trials were assessed using the Risk of Bias 2 (RoB-2) tool.[13] Non-randomised studies were assessed using the Risk of Bias in Non-randomised Studies of Interventions (ROBINS-I) tool.[14]

3 | RESULTS

A total of 355 studies were identified following the initial search and once duplicates were removed. Abstract screening resulted in 42 studies for further full-text analysis. On completion of the screening process, the search yielded 23 included studies (Figure 1). Nineteen studies were excluded at the full-text screening stage due to a lack of a suitable control group. Without a control group, the effects of growth cannot be excluded as a significant confounding variable rendering these studies as having a severe risk of bias.

3.1 | Study characteristics

Twenty-three studies met the inclusion criteria. No studies were published prior to 2010. Descriptive data for the studies and the main findings are summarised in Table 2. Study interventions included FA (10 studies),[15–24] RME (9 studies),[25–33] Reverse-pull headgear (facemask therapy) (1 study)[34] and 4 premolar dental extractions (3 studies).[35–37] Only 4 studies had sample sizes over 60 patients,[21–23,25] with most studies having sample sizes of 30 or fewer patients.[14–20,27–31,34,35] There was heterogeneity among the included studies in definition of airway boundaries, methods of airway measurement, airway demarcation and orthodontic appliance designs. Consequently, meta-analysis was not possible.

3.2 | Risk of bias assessment

The risk of bias assessment for the RoB-2 (randomised) and Robins-I (non-randomised) studies is shown in Figures 2 and 3, respectively. Six studies were of high risk of bias due to methodological limitations. The only randomised controlled trial[25] had a high risk of bias due to a lack of reported allocation concealment. Furthermore, although blinding of treatment providers and patients was not feasible, there was no blinding during outcome assessment.

Of the non-randomised studies, five[17,20,28,30,33] were of high risk of bias as they did not control for the time interval between scans, meaning growth was a significant confounding variable. The remaining studies were of moderate risk of bias. All except two studies[24,35] did not control for body mass index (BMI). As BMI is not routinely recorded as part of standard orthodontic records, retrospective studies would not be expected to have access to this data.

3.3 | Results for functional appliances

The studies used various functional appliance designs (5 herbst,[15,19,21–23] 2 twinblock,[18,20,24] 1 MARA appliance,[17] 1 monoblock and twinblock[16]). All studies demonstrated a significant increase upper airway volume when compared to controls,[15–24] and all studies except one[19] found a significant improvement in airway minimum cross-sectional area (MCA). Two of the studies[15,16] did not report MCA changes.

One study[22] found a reduced sagittal jaw discrepancy, a forward mandibular rotation and an anterior repositioning of the hyoid bone were skeletal changes significantly associated with airway changes in FA treatment. A further study[23] found morphological deviations of the upper spine (MDUS) were significantly associated with a reduced effect on the upper airway volume and MCA when compared to patients without MDUS. However, patients with MDUS still showed a significant increase in upper airway dimensions when compared to controls treated without FA.

One study[24] was conducted on children diagnosed with OSA and found, as well as a significant increase in airway dimensions, FA treatment was also associated with a significant reduction in OSA symptoms measured using the Apnoea Hypopnea Index (AHI).

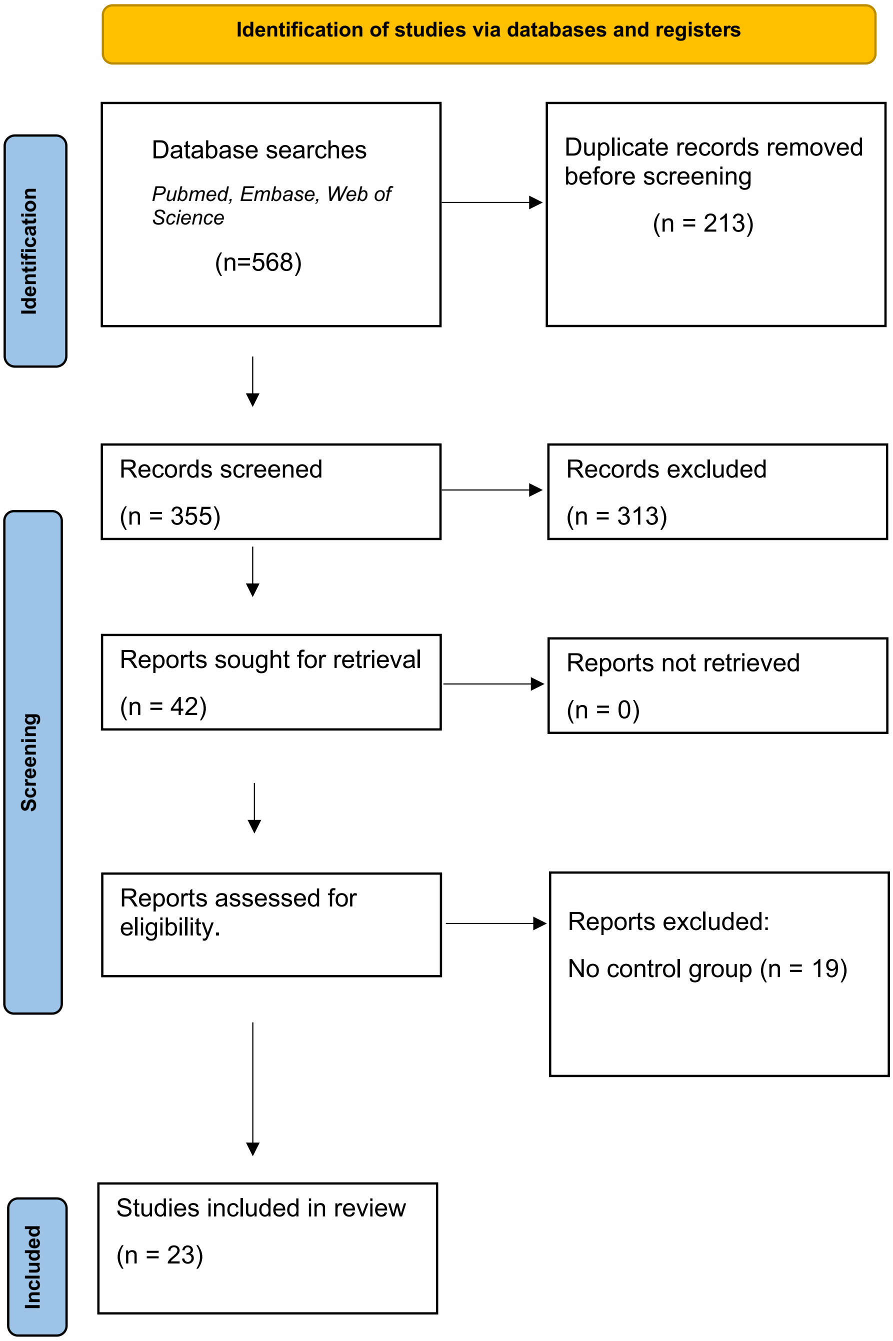

FIGURE 1 Flow diagram of the study selection process.[11]

3.4 | Results for rapid maxillary expansion

The findings of most studies were that RME had no significant effects on the upper airway volume when compared to controls.[25–27,29,30,32,33] Two studies[28,31] which segmented the upper airway into different zones found significant increases in the volume of the nasopharynx but not the oropharynx, when compared to controls. Furthermore, one study[30] found no significant increase in upper airway volume or MCA. However, when the retropalatal area was studied in isolation, a significant difference in the MCA was found.

Three studies[26,27,31] investigated the nasal cavity and upper airway separately. There were significant improvements in volume and constriction of the nasal cavity compared with controls. In contrast, there were no significant improvements in upper airway dimensions.

3.5 | Results for reverse-pull headgear

One study[34] found there were no significant effects on the upper airway when reverse-pull headgear (facemask) was used.

TABLE 2 Summary of characteristics of included studies and main findings.

Study	Year	Intervention	Study design	Inclusion criteria	Sample size	Age	Control group	Outcome measure	Measurement method	Summary of findings for airway volume and MCA
Functional appliance										
Oliviera et al.[15]	2020	Herbst appliance	Retrospective	Class II division 1 malocclusion (ANB >4°)	15; 9F	Mean age 13.8 years	10M; 8F Class II division 1 malocclusion (ANB >4°) No treatment	Changes in airway volume	Automatic 3D measurement using software with manual threshold adjustment	Significantly greater increase in airway volume in Herbst group compared with control group in oropharynx only. No difference in nasopharynx and nasal cavity
Isidor et al.[16]	2018	Monobloc activator or twin block followed by fixed appliances	Retrospective	Overjet ≥6 mm	8M; 12F	Mean age 11.4 years	4M; 14F Class I malocclusion <6 mm overjet Treated with fixed appliances only	Changes in airway volume	Software generated 3D volume measurement using manual threshold	Significantly greater increase in airway volume in Herbst group compared with control group in oropharynx and total airway only. No significant differences in changes to velopharynx and lower nasopharynx
Rizk et al.[17]	2016	MARA appliance followed by fixed appliances	Retrospective	Skeletal class II (ANB ≥4.5°)	7M; 13F	Mean age 11.7 years	73 untreated skeletal class II (ANB ≥4.5°) matched for CVMS	Changes in airway volume and MCA	Software generated 3D volume and MCA measurement using same standard pre-defined threshold for all scans	Significantly greater increase in airway volume and MCA in MARA group compared with control group
Elfeky and Fayed[18]	2015	Twin block	Prospective	Skeletal class II (ANB >4°) Class II molar relationship	27F with 9 patient dropouts	Females age 10–12 years	26F untreated Same inclusion criteria as intervention group 8 patient dropouts	Changes in airway volume and MCA	Software generated 3D volume and MCA measurement using same standard pre-defined threshold for all scans	Significantly greater increase in airway volume and MCA in the twin block group compared with control group

(Continues)

TABLE 2 (Continued)

Study	Year	Intervention	Study design	Inclusion criteria	Sample size	Age	Control group	Outcome measure	Measurement method	Summary of findings for airway volume and MCA
Iwasaki et al.[19]	2014	Herbst appliance followed by fixed appliances	Retrospective	Class II division 1 malocclusion (ANB ≥5°) Age 9–14 years Cranio-cervical angle between 90°–105°	11M; 13F	Mean age 11.6 years pre-treatment and 15.4 years post-treatment	Class I malocclusion Class 1 skeletal (2 ≤ ANB ≤4) Matched for age, gender, FMA Treated with fixed appliances only	Changes in airway volume and MCA	Manual 3D measurement of airway volume between upper and lower anatomical boundaries. Cross-sectional area measured at 4 distinct anatomical points	Pre-treatment airway volume was significantly smaller in the Herbst group compared with control group There was a significant difference in the changes to airway volume but not MCA between the two groups after treatment
Li et al.[20]	2014	Twin block	Retrospective	Overjet >7 mm Class II malocclusion (ANB > 4°) Mandibular retrognathia (SNB <75°)	13M; 17F	Mean age 11.6 years	13M; 17F Same inclusion criteria as intervention group Matched for age and gender Only pre-treatment scans used	Changes in airway volume and MCA	Software generated 3D volume and MCA measurement using automatic threshold	Significantly greater increase in airway volume in treatment group compared with pre-treatment control group (oropharynx and hypopharynx only). No significant differences in changes to nasopharynx. Significant difference in MCA in all airway sub-sections between treatment group and pre-treatment control group scans
Abdalla et al.[21]	2020	Herbst Appliance followed by fixed appliances	Retrospective	Age 8–15 Full unit class II molar relationship ANB >5°	36M; 37F	Mean age 12.0 years	36M; 37F pair-matched for age, skeletal age, gender, mandibular inclination, time interval between pre- and post-treatment scans	Changes in airway volume and MCA	Software generated 3D volume and MCA measurement using operator-adjusted threshold	Significantly greater increase in airway volume and MCA in treatment group when compared to the control group

TABLE 2 (Continued)

Study	Year	Intervention	Study design	Inclusion criteria	Sample size	Age	Control group	Outcome measure	Measurement method	Summary of findings for airway volume and MCA
Abdalla et al.[22]	2021	Herbst Appliance followed by fixed appliances	Retrospective	Age 8–15 Full unit class II molar relationship ANB >5°	36M; 37F	Mean age 12.0 years	36M; 37F pair-matched for age, skeletal age, gender, mandibular inclination, time interval between pre- and post-treatment scans	Association between skeletal and airway changes in volume and MCA	Software generated 3D volume and MCA measurement using operator-adjusted threshold	Changes in the sagittal jaw relationship; sagittal position of the hyoid bone; and mandibular rotation were all significantly associated with airway changes
Abdalla et al.[23]	2022	Herbst Appliance followed by fixed appliances	Retrospective	Age 8–15 Full unit class II molar relationship ANB >5° Two treatment groups: one with morphological deviations of the upper spine (MDUS) and one without MDUS	21 patients with MDUS; 42 patients without MDUS	Mean age 12.0 years	21 matched with MDUS group and 42 matched to no MDUS group. Pair-matched for age, skeletal age, gender, mandibular inclination, time interval between pre- and post-treatment scans	Changes in airway volume and MCA and association with MDUS	Software generated 3D volume and MCA measurement using operator-adjusted threshold	Significantly greater increase in airway volume and MCA in treatment both treatment groups when compared to the control group. Significantly reduced changes in airway volume and MCA in the MDUS group compared with the control group
Zreaqat et al.[24]		Twin block		Diagnosis of obstructive sleep apnoea (OSA) with Apnoea Hypopnea Index (AHI) >1 Skeletal class II (SNA 79°–84°; SNB ≤76°) Overjet 6–10 mm	29M; 18F		29M;18F without OSA (AHI <1) matched for gender, age and body mass index (BMI)	Changes in AHI, airway volume, length and MCA	Software generated 3D volume and MCA measurement using operator-adjusted threshold	Significantly greater increase in airway volume (oropharynx only), length and MCA in treatment group when compared to the control group. Significant reduction in AHI in the treatment group
RME										
Kabalan et al.[25]	2015	Tooth-borne or bone-borne RME (Hyrax)	Prospective randomised trial.	11–17 years old Maxillary expansion clinically indicated		61 patients randomised into the 2 intervention and 1 control groups	Untreated control group had treatment delayed for 6 months	Changes in airway volume and MCA	Software generated 3D volume and MCA measurement	No significant difference in changes to pharyngeal airway volume and MCA between 2 groups

(Continues)

TABLE 2 (Continued)

Study	Year	Intervention	Study design	Inclusion criteria	Sample size	Age	Control group	Outcome measure	Measurement method	Summary of findings for airway volume and MCA
El and Palomo[26]	2013	RME (Hyrax)	Retrospective	Maxillary constriction Non-extraction treatment	20M; 15F	Mean age 14.0 years	20M; 15F Treated with fixed appliances only matched for age, gender and treatment duration	Changes in airway volume and MCA	Software generated 3D volume and MCA measurement.	No significant difference in changes to pharyngeal airway volume and MCA between 2 groups. Significant difference in change in nasal airway volume
Iwasaki et al.[27]	2013	RME (Hyrax)	Retrospective	Class II skeletal relationship Cranio-cervical angle between 90°–105°	13M; 15F	Mean age before RME 10.0 years	8M; 12F matched for age and gender	Changes in airway volume	Software generated 3D measurement using software with manual threshold adjustment	No significant difference in changes to oropharyngeal airway volume between 2 groups. Significant changes in nasal airway and retropalatal airway
Zhao et al.[28]	2010	RME (Hyrax)	Retrospective	Late mixed or early permanent dentition Unilateral or bilateral crossbite	6M; 18F	Mean age 12.8 years	6M; 18F matched for age and gender. Treated without RME	Changes in airway volume and MCA	Software generated 3D volume and MCA measurement with operator determined threshold	No significant difference in changes to airway volume and MCA between 2 groups
Abdalla et al.[29]	2018	RME (Hyrax)	Retrospective	Age 8–15 Class I molar relationship Minimum increase of 3 mm in inter-molar width	12M; 14F	Mean age 12.4 years	12M; 14F Pair-matched for age, skeletal age, gender, time interval between pre- and post-treatment scans	Changes in airway volume and MCA	Software generated 3D volume and MCA measurement using operator-adjusted threshold	No significant difference in changes to airway volume and MCA between 2 groups
Aljawad et al.[30]	2021	RME (Hyrax)	Retrospective	Age 10–16 CBCT scan after at least 4 months of retention	3M; 14F	Mean age 10.6 years	17 patients pair-matched and controlled for age, gender, CBCT interval and tongue posture	Changes in airway volume and MCA	Software generated 3D volume and MCA measurement	Significant greater increase in MCA in the treatment group (retropalatal area only). No significant difference in airway volume changes

TABLE 2 (Continued)

Study	Year	Intervention	Study design	Inclusion criteria	Sample size	Age	Control group	Outcome measure	Measurement method	Summary of findings for airway volume and MCA
DiCosimo et al.[31]	2021	RME (Hyrax)	Retrospective	Successful skeletal maxillary expansion	11M; 17F	Mean age 9.7 years	20 patients with mean age 10.4 years	Changes in airway volume and MCA (nasal)	Software generated 3D volume measurement. Manual measurement of nasal airway constriction	Significant greater increase in volume of the nasal cavity and nasopharynx only. No significant difference in volume of oropharynx. Significant increase in MCA of nasal cavity
Niu et al.[32]	2021	RME (Hyrax)	Retrospective	Age 10–16 Cervical maturation <CS4 Time interval between CBCT scans <36 months	39 patients	Mean age 10.4 years	29 age-matched untreated patients with class I malocclusion	Changes in volume and MCA	Software generated 3D measurement using software with manual threshold adjustment	Significantly greater increase in volume and MCA of nasal cavity only. No significant differences in dimensions of pharynx
Korayem[33]	2023	RME (Hyrax)	Retrospective	Age 8–15 Class I molar relationship Minimum increase of 3 mm in inter-molar width	52	Mean age not specified	52 patients aged 8–15 treated non-extraction with fixed appliances only for class I malocclusion	Changes in volume and MCA	Software generated 3D measurement using software generated threshold	No significant difference in changes to airway volume and MCA between 2 groups
Reverse-pull headgear										
Husson et al.[34]	2021	Bonded bite block and face mask	Prospective with a retrospective control group	Anterior crossbite Normal or horizontal vertical growth pattern ANB <0°	9M; 9F	Mean age 7.8 years	7M; 9F. Same inclusion criteria as intervention. Untreated patients	Changes in airway volume and MCA	Software generated 3D volume and MCA measurement with operator-adjusted threshold	No significant differences in changes to airway volume and MCA between the two groups
Dental extraction										
Valiathan et al.[35]	2010	Extraction of four premolars	Retrospective	No further inclusion criteria stated	10M; 10F	Mean age 13.8 years (M); 13.5 years (F)	10M; 10F pair-matched for age, gender, height, weight, BMI	Changes in airway volume and MCA	Software generated 3D volume and MCA measurement	No significant differences in changes to airway volume and MCA between the two groups

(Continues)

TABLE 2 (Continued)

Study	Year	Intervention	Study design	Inclusion criteria	Sample size	Age	Control group	Outcome measure	Measurement method	Summary of findings for airway volume and MCA
Stefanovic et al.[36]	2012	Extraction of four premolars	Retrospective	No further inclusion criteria stated	15M; 16F	Mean age 13.0 years	15M; 16F matched for age and gender	Changes in airway volume and MCA	Software generated 3D volume and MCA measurement with operator-adjusted threshold	No significant differences in changes to airway volume and MCA between the two groups
Mladenovic et al.[37]		Extraction of 4s premolars	Retrospective	Treatment using fixed orthodontic appliances	18M; 36F	Mean age 15.0 years	24M; 35F matched for age and amount of dental crowding	Changes in oral cavity volume	Software generated 3D volume measurement using a threshold determined by a computer algorithm	Significantly less increase in the oral cavity volume in the extraction group when compared to the control group

3.6 | Results for dental extractions

Two studies[35,36] compared pre- and post-treatment airway volume in patients who had fixed orthodontic appliance treatment with four premolar extractions to a control group also treated with fixed appliances but without extractions. Both studies found no significant differences in airway dimensions and volume between the extraction and non-extraction groups. Both patient groups were matched for molar relationship, age and gender. One study[35] also matched patients for ethnicity, pre-treatment airway volume, BMI and height.

A further study[37] compared the pre- and post-treatment volume of the oral cavity in patients who had treatment with fixed appliances and four premolar extractions compared to a control group who received the same treatment without extractions. The groups were matched for age and degree of dental crowding. This study found that there was a lesser increase in the oral cavity volume over time in the extraction group when compared to the non-extraction group. Furthermore, males demonstrated a greater increase in oral cavity volume when compared to females.

4 | DISCUSSION

This systematic review is the first of its kind to exclude studies that did not include a suitable matched control group, of which a significant number were identified in the literature search. The volume of the upper airway increases with growth in untreated children.[38] Consequently, growth is a significant confounding variable when intervention studies are conducted on the upper airway in children, which can only be accounted for by using an age-matched and untreated control group.[39]

4.1 | Functional appliances

All studies demonstrated a significant increase in upper airway volume when compared to controls,[15–24] and all studies except one[20] found a significant improvement in airway constriction. All the studies which found a positive effect on airway constriction used software to determine the slice of the airway with the least area (MCA method).[15–18,20–24]

The study[19] which found no significant difference in airway constriction used an alternative method involving linear antero-posterior (A-P) measurements at three standardised points along the airway. There are significant limitations in measuring airway constriction using a small number of linear measurements, compared with the MCA method that measures airway constriction in all CBCT slices between upper and lower boundaries. A cephalometric study[40] measuring five antero-posterior linear airway measurements found that not all points showed improvements in the airway constriction after FA. Consequently, the differences in the results of airway constriction could be due to methodological limitations of one of the studies.[19]

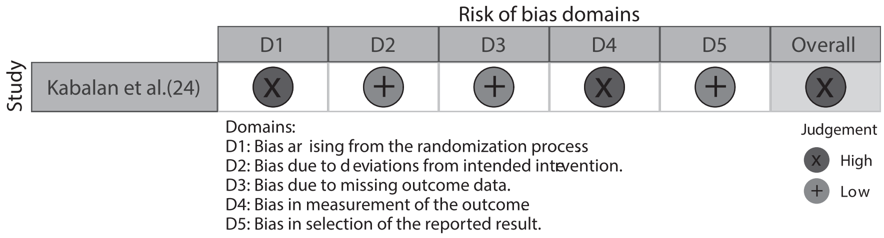

FIGURE 2 Quality assessment of randomised clinical trial using the RoB-2 tool[13] (created using 'robvis' package for R statistical software (v4.4; R Core Team 2024)).[50]

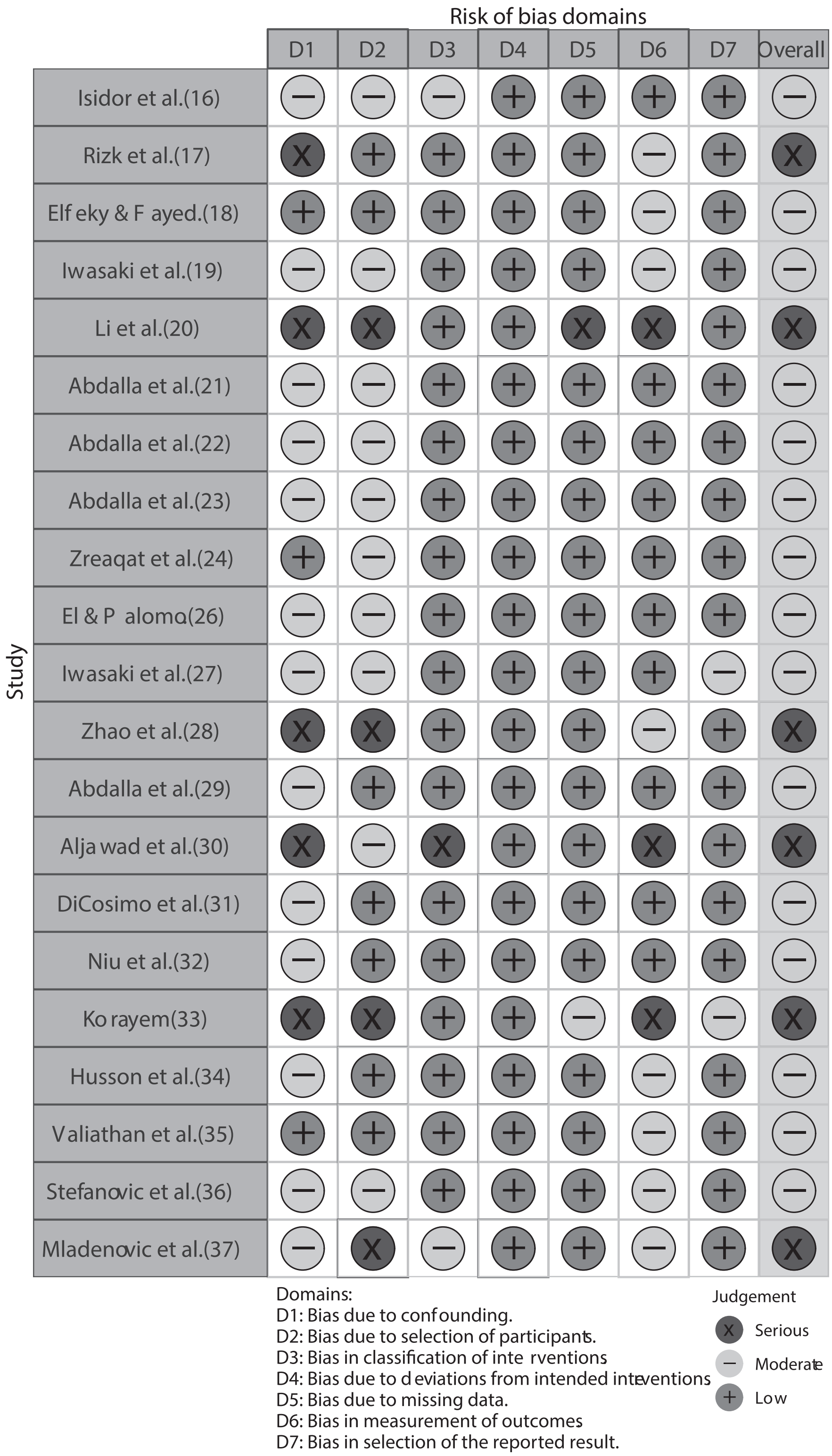

FIGURE 3 Quality assessment of non-randomised trials using the ROBINS-I tool[14] (created using 'robvis' package for R statistical software (v4.4; R Core Team 2024)).[50]

There was a 4-year mean time interval between pre- and post-treatment scans in the study[19] which found FA had no positive effect on airway constriction. This interval was considerably longer than all the other FA studies suggesting any change in airway constriction because of FA treatment may be transient. However, cephalometric studies with long-term follow-up[41] have shown dimensional changes in the upper airway following FA treatment were maintained and stable.

Three studies investigated the effects of FA on the nasal cavity and nasopharynx in isolation and reported no significant differences in airway changes between the FA and control groups.[15,16,20] This suggests that the airway effects of FA may be significant in the inferior part of the upper airway only.

One study[22] found that an anterior repositioning of the mandible, a forward rotation of the mandible and an anterior positioning of the hyoid bone were skeletal changes that were associated with a positive change in the airway after FA treatment. Previous studies have shown similar findings, with a more posterior positioning of pogonion and the hyoid bone being associated with increased symptoms of OSA.[42] This may be explained by a more posterior placed mandible forcing the tongue and soft palate back into the pharyngeal airway space.[42]

Although children with MDUS demonstrated an increase in airway dimensions when compared to controls, the change was significantly reduced when compared to children without MDUS. These findings are supported by a study of adults with OSA,[43] which found that OSA patients with MDUS may respond less favourably to treatment with MAD, when compared to adults without MDUS.

One FA study involved children with OSA and found a significant reduction in AHI scores when measured 30 days following the cessation of FA treatment. This is also consistent with the findings of a previous randomised controlled trial.[44] Unlike in adults, where a reduction in AHI requires a mandibular advancement appliance to be worn consistently,[5] these findings suggest that when FA are used in children AHI scores may remain reduced, even without the continuation of active appliance therapy. However, studies involving a greater follow up period would be required to determine whether these changes are sustained following FA treatment.

4.2 | Rapid maxillary expansion

The compensatory mechanism of head posture may explain why the majority of RME studies found no significant differences in airway dimensions, when compared to controls.[45] An extension of the head in relation to the upper cervical spine (increased craniocervical angle) occurs in response to airway constriction to ensure that an adequate airway volume is maintained.[45] Consequently, it is possible that RME increases the airway volume and airway constriction but the associated reduction in compensatory head posture results in no significant net gain in airway dimensions overall.[29]

RME studies isolating the nasal cavity from the rest of the upper airway found a significant improvement in airway dimensions when compared to controls.[26,27,31] In contrast to functional appliances, RME therefore appears to have a greater effect more superiorly in the upper airway at the level of the nasal cavity and nasopharynx.

4.3 | Reverse-pull headgear

One study[34] found no significant airway effects compared to untreated controls when reverse-pull headgear was used, although the sample size was relatively small (18 patients). However, these findings are supported by a systematic review, which found that surgical advancement of the maxilla in isolation did not have a positive effect on upper airway MCA.[46]

4.4 | Orthodontic extractions

Although the available evidence suggests that orthodontic extractions do not influence upper airway dimensions when compared to non-extraction controls, sample sizes of the two studies[35,36] were relatively small and further research with larger sample sizes would be beneficial to confirm these findings.

One study found orthodontic treatment with dental extractions may reduce the volume of the oral cavity when compared to a treatment involving a non-extraction treatment. However, the study also found that males demonstrated a greater increase in oral cavity volume when compared to females, and there were more males in the control group when compared to the extraction group. Consequently, this may have been a source of bias in the findings.

4.5 | Limitations of the existing literature

A significant limitation was the number of studies which did not include an adequate control group to allow for growth as a confounding variable. Furthermore, the pubertal growth spurt also needs to be accounted for with a control group, as the rate of airway growth increases during the pubertal growth spurt.[1] Chronological age is poorly correlated with the timing of the growth spurt; however, skeletal age is well correlated with the growth spurt.[1] The timing of the pubertal growth spurt is also influenced by gender.[47] In addition, an increased vertical jaw relationship is a risk factor for both a constricted upper airway[1] and a reduced skeletal response in relation to FA.[1] Only one RME,[28] and three FA studies[21–23] controlled for all these variables (age, skeletal age, gender and vertical jaw relationship).

Heterogeneity was found in the included studies in the anatomical definition and measurement of the upper airway; thus, pooling results was not possible. A validated method for delineating and measuring the upper airway has recently been proposed[48]; however, only four CBCT studies utilised a validated method.[21–23,28]

Furthermore, airway measurements may differ depending on the software used to measure volume and constriction.[49]

4.6 | Limitations of the review

The review was restricted to articles written in English only. It is possible that papers written in languages other than English may have further contributed to findings of this study.

5 | CONCLUSION

Although effective at achieving skeletal and dental expansion, RME is not associated with significant 3D changes in the upper airway. However, there may be significant isolated increases in the dimensions of the nasal cavity and nasopharyngeal airway. In contrast, FA are associated with a significant improvement in both upper pharyngeal airway volume and constriction when used in children however, the effects on the nasal cavity are limited. Reverse-pull headgear (facemask) as well as orthodontic extractions do not appear to have any significant effects on the airway; however, the evidence is limited. There is also limited evidence that FA may reduce the severity of OSA in children.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interests.

PEER REVIEW

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1111/joor.13797.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

ORCID

Yousef Abdalla https://orcid.org/0000-0003-3221-783X
Liselotte Sonnesen https://orcid.org/0000-0003-0320-8096

REFERENCES

1. Anandarajah S, Dudhia R, Sandham A, Sonnesen L. Risk factors for small pharyngeal airway dimensions in pre-orthodontic children: a three-dimensional study. *Angle Orthod*. 2017;87:138-146.
2. Hansen C, Markström A, Sonnesen L. Specific dento-craniofacial characteristics in non-syndromic children can predispose to sleep-disordered breathing. *Acta Paediatr*. 2022;111(3):473-477.
3. Hansen C, Markström A, Sonnesen L. Sleep-disordered breathing and malocclusion in children and adolescents-a systematic review. *J Oral Rehabil*. 2022;49(3):353-361.
4. Pancherz H. The Herbst appliance—its biologic effects and clinical use. *Am J Orthod*. 1985;87(1):1-20.
5. Knappe SW, Sonnesen L. Mandibular positioning techniques to improve sleep quality in patients with obstructive sleep apnea: current perspectives. *Nat Sci Sleep*. 2018;10:65-72.
6. Halfeld S, Sonnesen L. Daytime sleepiness and quality of life in obstructive sleep apnoea patients before and after long-term mandibular advancement device treatment. *Dent J*. 2022;10:226.
7. Lenza MG, Dalstra M, Melsen B, Cattaneo PM. An analysis of different approaches to the assessment of upper airway morphology: a CBCT study. *Orthod Craniofac Res*. 2010;13:96-105.
8. Doruk C, Sökücü O, Biçakçi AA, Yilmaz U, Taş F. Comparison of nasal volume changes during rapid maxillary expansion using acoustic rhinometry and computed tomography. *Eur J Orthod*. 2007;29:251-255.
9. Signorelli L, Patcas R, Peltomäki T, Schätzle M. Radiation dose of cone-beam computed tomography compared to conventional radiographs in orthodontics. *J Orofac Orthop*. 2016;77:9-15.
10. Weissheimer A, de Menezes LM, Sameshima GT, Enciso R, Pham J, Grauer D. Imaging software accuracy for 3-dimensional analysis of the upper airway. *Am J Orthod Dentofacial Orthop*. 2012;142:801-813.
11. Page MJ, Moher D, Bossuyt PM, et al. PRISMA 2020 explanation and elaboration: updated guidance and exemplars for reporting systematic reviews. *BMJ*. 2021;372:n160.
12. Higgins JPT, Thomas J, Chandler J, et al., eds. *Cochrane Handbook for Systematic Reviews of Interventions*. 2nd ed. John Wiley & Sons; 2019.
13. Sterne JA, Savović J, Page MJ, et al. RoB 2: a revised tool for assessing risk of bias in randomised trials. *BMJ*. 2019;366:I4898.
14. Sterne JA, Hernán MA, Reeves BC, et al. ROBINS-I: a tool for assessing risk of bias in non-randomised studies of interventions. *BMJ*. 2016;355:I4919.
15. Oliveira PM, Cheib-Vilefort PL, de Pársia GH, et al. Three-dimensional changes of the upper airway in patients with Class II malocclusion treated with the Herbst appliance: a cone-beam computed tomography study. *Am J Orthod Dentofacial Orthop*. 2020;157:205-211.
16. Isidor S, Di Carlo G, Cornelis MA, Isidor F, Cattaneo PM. Three-dimensional evaluation of changes in upper airway volume in growing skeletal Class II patients following mandibular advancement treatment with functional orthopedic appliances. *Angle Orthod*. 2018;88(5):552-559.
17. Rizk S, Kulbersh VP, Al-Qawasmi R. Changes in the oropharyngeal airway of Class II patients treated with the mandibular anterior repositioning appliance. *Angle Orthod*. 2016;86:955-961.
18. Elfeky H, Fayed MMS. Three-dimensional effects of twin block therapy on pharyngeal airway parameters in Class II malocclusion patients. *J World Fed Orthod*. 2015;4:114-119.
19. Iwasaki T, Takemoto Y, Inada E, et al. Three-dimensional cone-beam computed tomography analysis of enlargement of the pharyngeal airway by the Herbst appliance. *Am J Orthod Dentofacial Orthop*. 2014;146:776-785.
20. Li L, Liu H, Cheng H, et al. CBCT evaluation of the upper airway morphological changes in growing patients of class II division 1 malocclusion with mandibular retrusion using twin block appliance: a comparative research. *PLoS One*. 2014;9:e94378.
21. Abdalla Y, Brown L, Sonnesen L. Effects of a fixed functional appliance on the upper airway volume: a three-dimensional cone beam computed tomography study. *Am J Orthod Dentofacial Orthop*. 2020;158(1):40-49.
22. Abdalla Y, Kiliaridis S, Sonnesen L. Dentofacial changes following treatment with a fixed functional appliance and their three-dimensional effects on the upper airway. *Aust Orthod J*. 2021;37:284-293.
23. Abdalla Y, Kiliaridis S, Sonnesen L. Airway changes after fixed functional appliance treatment in children with and without morphologic deviations of the upper spine: a three-dimensional CBCT study. *Am J Orthod Dentofacial Orthop*. 2022;161:791-797.

24. Zreaqat M, Hassan R, Samsudin AR, Alforaidi S. Effects of twin-block appliance on upper airway parameters in OSA children with class II malocclusion and mandibular retrognathia: a CBCT study. *Eur J Pediatr*. 2023;182(12):5501-5510.
25. Kabalan O, Gordon J, Heo G, Lagravère MO. Nasal airway changes in bone-borne and tooth-borne rapid maxillary expansion treatments. *Int Orthod*. 2015;13:1-15.
26. El H, Palomo JM. Three-dimensional evaluation of upper airway following rapid maxillary expansion: a CBCT study. *Angle Orthod*. 2013;84:265-273.
27. Iwasaki T, Saitoh I, Takemoto Y, et al. Tongue posture improvement and pharyngeal airway enlargement as secondary effects of rapid maxillary expansion: a cone-beam computed tomography study. *Am J Orthod Dentofacial Orthop*. 2013;143:235-245.
28. Zhao Y, Nguyen M, Gohl E, Mah JK, Sameshima G, Enciso R. Oropharyngeal airway changes after rapid palatal expansion evaluated with cone-beam computed tomography. *Am J Orthod Dentofacial Orthop*. 2010;137:S71-S78.
29. Abdalla Y, Brown L, Sonnesen L. Effects of rapid maxillary expansion on upper airway volume: a three-dimensional cone-beam computed tomography study. *Angle Orthod*. 2019;89:917-923.
30. Aljawad H, Lee K-M, Lim H-J. Three-dimensional evaluation of upper airway changes following rapid maxillary expansion: a retrospective comparison with propensity score matched controls. *PLoS One*. 2021;16:e0261579.
31. DiCosimo C, Alsulaiman AA, Shah C, Motro M, Will LA, Parsi GK. Analysis of nasal airway symmetry and upper airway changes after rapid maxillary expansion. *Am J Orthod Dentofacial Orthop*. 2021;160:695-704.
32. Niu X, Motro M, Will LA, Cornelis MA, Cattaneo PM. Does rapid maxillary expansion enlarge the nasal cavity and pharyngeal airway? A three-dimensional assessment based on validated analyses. *Orthod Craniofac Res*. 2021;24:124-133.
33. Korayem MA. Effects of rapid maxillary expansion on upper airway volume in growing children: a three-dimensional cone-beam computed tomography study. *Cureus*. 2023;15(1):e34274.
34. Husson AH, Burhan AS, Hajeer MY, Nawaya FR. Three-dimensional oropharyngeal airway changes after facemask therapy using low-dose computed tomography: a clinical trial with a retrospectively collected control group. *Prog Orthod*. 2021;22:1-12.
35. Valiathan M, El H, Hans MG, Palomo MJ. Effects of extraction versus non-extraction treatment on oropharyngeal airway volume. *Angle Orthod*. 2010;80:1068-1074.
36. Stefanovic N, El H, Chenin DL, Glisic B, Palomo JM. Three-dimensional pharyngeal airway changes in orthodontic patients treated with and without extractions. *Orthod Craniofac Res*. 2013;16:87-96.
37. Mladenovic M, Freezer S, Dreyer C, Meade MJ. Influence of second premolar extractions on the volume of the oral cavity proper: a control comparative cone-beam computed tomography volumetric analysis study. *Angle Orthod*. 2024;94(1):31-38.
38. Abramson Z, Susarla S, Troulis M, Kaban L. Age-related changes of the upper airway assessed by 3-dimensional computed tomography. *J Craniofac Surg*. 2009;20:657-663.
39. Schendel SA, Jacobson R, Khalessi S. Airway growth and development: a computerized 3-dimensional analysis. *J Oral Maxillofac Surg*. 2012;70:2174-2183.
40. Ali B, Shaikh A, Fida M. Effect of Clark's twin-block appliance (CTB) and non-extraction fixed mechano-therapy on the pharyngeal dimensions of growing children. *Dent Press J Orthod*. 2015;20:82-88.
41. Han S, Choi YJ, Chung CJ, Kim JY, Kim K-H. Long-term pharyngeal airway changes after bionator treatment in adolescents with skeletal class II malocclusions. *Korean J Orthod*. 2014;44:13-19.
42. Petri N, Christensen IJ, Svanholt P, Sonnesen L, Wildschiødtz G, Berg S. Mandibular advancement device therapy for obstructive sleep apnea: a prospective study on predictors of treatment success. *Sleep Med*. 2019;54:187-194.
43. Sonnesen L, Petersson A, Berg S, Svanholt P. Pharyngeal airway dimensions and head posture in obstructive sleep apnea patients with and without morphological deviations in the upper cervical spine. *J Oral Maxillofac Res*. 2017;8(3):e4.
44. Idris G, Galland B, Robertson CJ, Gray A, Farella M. Mandibular advancement appliances for sleep-disordered breathing in children: a randomized crossover clinical trial. *J Dent*. 2018;71:9-17.
45. Solow B, Siersbæk-Nielsen S, Greve E. Airway adequacy, head posture, and craniofacial morphology. *Am J Orthod*. 1984;86:214-223.
46. Christovam IO, Lisboa CO, Ferreira D, Cury-Saramago AA, Mattos CT. Upper airway dimensions in patients undergoing orthognathic surgery: a systematic review and meta-analysis. *Int J Oral Maxillofac Surg*. 2016;45:460-471.
47. Hägg U, Taranger J. Maturation indicators and the pubertal growth spurt. *Am J Orthod*. 1982;82:299-309.
48. Anandarajah S, Abdalla Y, Dudhia R, Sonnesen L. Proposal of new upper airway margins in children assessed by CBCT. *Dentomaxillofacial Radiol*. 2015;44:20140438.
49. Capenakas SPG. *Oropharyngeal Dimensional Changes Following Maxillary Expansion with Two Different Appliances: a CBCT Study [Master's Thesis]*. University of Alberta; 2019.
50. McGuinness LA, Higgins JPT. Risk-of-bias VISualization (robvis): an R package and Shiny web app for visualizing risk-of-bias assessments. *Res Synth Methods*. 2020;12:1-7.

How to cite this article: Abdalla Y, Sonnesen L. Association between orthodontic treatment and upper airway changes in children assessed with cone-beam computed tomography (CBCT): A systematic review. *J Oral Rehabil*. 2024;00:1-14. doi:10.1111/joor.13797