REVIEW ARTICLE

Rapid Maxillary Expansion and Upper Airway Volume: Systematic Review and Meta-analysis on the Role of Rapid Maxillary Expansion in Mouth Breathing

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Abstract

Objective: Rapid maxillary expansion (RME) has been extensively used in orthodontic practice for over a century, and it is claimed to benefit upper airway morphology. However, its effect in actually alleviating mouth breathing has remained unexplored. This systematic review was planned with an objective to provide a comprehensive synthesis of the effects of RME on upper airway volume and most importantly, its role in alleviating mouth breathing.

Methods: A literature search of electronic databases were done for the time period of 2000–2018. Randomized controlled trials (RCTs) and non-RCTs conducted on 8–15-year-old children who received bonded or banded RME and upper airway measured using three-dimensional (3D) imaging were included.

Results: Twelve studies (two RCTs, nine nonrandomized clinical trials, and one non-RCT) were included in this systematic review, and nine studies were included for meta-analysis. Among the evaluated parameters, nasal cavity volume showed a significant increase which was maintained even after the retention phase, whereas nasopharyngeal and oropharyngeal volume did not report a significant change.

Conclusion: Based on this systematic review, it can be concluded that RME causes a significant increase in nasal cavity volume, but its effect on nasopharyngeal and oropharyngeal volume is not statistically significant in majority of studies. This increase in volume may not be considered as an equivalent for enhancement of airway and function unless proven so. In order to establish its significance in the improvement of breathing, it is necessary to conduct more well-designed RCTs with samples actually comprising mouth breathers.

Keywords: Mouth breathing, Palatal expansion technique, Systematic review, Upper airway.

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Introduction

Rationale

Respiration is a vital function of the body which under normal physiological conditions takes place through the nose.[1] When the nose is supplemented by the mouth, this mixed breathing pattern is referred to as mouth breathing. It is a deleterious oral habit with a prevalence of 10–15% among children. It results in a wide spectrum of both short- as well as long-term consequences affecting physical, psycho-behavioral, and cognitive development of the child. It is well-established that nasal airflow works as a continuous stimulus aiding the maxillary growth in the lateral direction and also lowering the position of the palate.[2] Therefore, mouth breathing hampers craniofacial development presenting as a transverse maxillary deficiency, high palatal vault, and lowered tongue posture.[3] Additionally, it is also known to affect the upper airway morphology due to the intimate anatomical association between these structures.

Rapid maxillary expansion occupies a distinct place in orthodontics and aims to correct transverse maxillary deficiencies and posterior crossbites, creates arch space for relieving crowding, and prevents impaction of maxillary canine.[4,5] Apart from maxilla, RME also influences other para maxillary structures and improves the upper airway morphology. The effect of RME extends up to the nasal cavity, hence causing lateral movement of the walls of the nasal cavity and also lowering the position of the palatal vault. This causes a resultant increase in the net width of nasal cavity, minimal cross-section area, volume of nasal cavity, decreased nasal resistance, and consequent improvement in the nasal airflow, which has been well-established in the literature.[6–8] However, the role of RME on the pharyngeal volume continues to remain a controversy.[9] Certain authors claim to obtain a resultant increase in nasopharyngeal and oropharyngeal volume owing to enlarged palatal space, lowered tongue posture, and mandibular position, whereas others report no change in the pharyngeal volumes.[10]

Various methods have been employed in the literature to evaluate the upper airway morphology, with each having its own strengths and limitations. These include lateral and posteroanterior cephalometry,

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rhinomanometry, acoustic rhinometry, computed tomography (CT), and cone beam computed tomography (CBCT). Hence keeping these limitations in mind, the use of 3D measurements, that is, CT and CBCT was done on a large scale for airway analysis and has shown high accuracy for the calculation of upper airway volume.[11–13]

Despite immense research undertaken till date to evaluate the consequence of RME on the volume of upper airway, its role in correcting mouth breathing still remains unclear.

Objectives

This systematic review was planned to provide a comprehensive synthesis of the effects of RME on upper airway volume and most importantly, its role in actually alleviating the mouth breathing habit, which is lacking in the literature.

Methods

Protocol and Registration

Prior to the commencement of this systematic review, it was registered on PROSPERO (ID-CRD42019122620). This review adheres to the PRISMA guidelines 2009.[14]

Eligibility Criteria

The eligibility criteria of the studies to be included were deduced with the objective of determining the influence of RME on upper airway and its effect in alleviating mouth breathing habits (Table 1). Only studies conducted among children belonging to 8–15 years age-group with transverse maxillary deficiency were included, since the effect of RME is more consistent in this age-group. Randomized and nonrandomized trials showing quantitative upper airway volumetric measurements using 3D imaging techniques (CT and CBCT) were included. Eligible studies reported both pretreatment both postexpansion volumetric changes.

Information Sources

Systematic searches were performed on PubMed, Cochrane Central Register of Controlled Trials (CENTRAL), and additionally on Google Scholar to include publications in the year 2000–2018. Only articles originally published in the English language were considered.

Search

The search strategy was developed and was independently performed by two authors. A predetermined search strategy was adopted for PubMed, for which the search limit was preset for time period January 2000 to December 2018. The keywords used for CENTRAL were Maxillary Expansion AND upper airway volume. Additional searches were carried out on Google Scholar using search terminologies RME and upper airway volume (Table 2).

Study Selection

Selection of studies and data collection were done by two authors independently, and in case of any discrepancy, the third author's opinion was considered. In the case where abstract was adhering to inclusion criteria and in cases where information obtained from abstract were not conclusive, full text was located. The selection criteria were diligently applied to the full-text articles.

Data Collection Process

Data collection was performed using a customized data extraction form.

Data Extraction Form

Contents

- Title of the study.
- Author's name.
- Year of publication.

Table 1: Eligibility criteria of the included studies

Category	*Inclusion criteria*	*Exclusion criteria*
Participant/ population characteristics	• Studies conducted in the period of 2000–2018 on children in age-group of 8–15 years with transverse maxillary deficiency (unilateral or bilateral crossbite) in need for expansion	• Patients with history of craniofacial deformities, cleft lip and/or palate • Patients with pharyngeal pathologies, nasal obstruction, history of adenoidectomy/tonsillectomy, obstructive sleep apnea, or snoring • Medically compromised patients.
Intervention	• Banded or bonded RME appliance	• Patients treated with SARME • Patients treated with miniscrew-assisted RME • Other concurrent orthodontic treatments that may influence the results • Expansion achieved with removable appliances
Comparison/ control group	• Same patients compared at baseline and after RME (immediately after active expansion or after retention period or both) • Patients who did not receive RME	• Patients treated with SARME
Outcome	• Studies showing quantitative upper airway volumetric measurements using3D imaging techniques: – CBCT – CT	• Studies providing only study model linear measurements • Studies assessing volumetric changes using two-dimensional imaging techniques: lateral and posteroanterior cephalometry • Studies using functional techniques for measurement: acoustic rhinometry and rhinomanometry
Study design	• RCTs • Nonrandomized clinical trials	• Case reports • Review articles • Conference abstracts • Interviews • Commentaries • Replies to editor/author

Table 2: Search strategy for PubMed and CENTRAL from 2000 to 2018

Sl. no.	*Category (based on)*	*Keywords*
PubMed search strategy (since 2000)		
1	Intervention	Maxillary expansion **OR** Expansion, maxillary **OR** Palatal expansion technique **OR** Maxillary disjunction **OR** Rapid maxillary expansion **OR** Rapid palatal expansion **OR** Palatal expansion **OR** Expansion, palatal **OR** Palatal disjunction **OR** Skeletal expansion
2	Outcome	Upper airway **OR** Upper airway volume **OR** Upper airway morphology **OR** Nasal cavity **OR** Nasal volume **OR** Nasal cavity volume **OR** Nasal dimension **OR** Nasal cavity dimension **OR** Nasal function **OR** Nasopharynx **OR** Nasopharynx cavity **OR** Nasopharynx volume **OR** Nasopharyngeal cavity **OR** Nasopharyngeal volume **OR** Oropharynx **OR** Oropharynx cavity **OR** Oropharynx volume **OR** Oropharyngeal cavity **OR** Oropharyngeal volume
3		**1 AND 2**
CENTRAL search strategy		
1	Intervention	Maxillary expansion
2	Outcome	Upper airway volume
3		**#1 AND #2**

- Institute and country of study.
- Study design.
- Ethical approval obtained.
- Informed consent obtained.
- Method of randomization used (if any).
- Control group (if any); details of comparator.
- Age of the included patients in study and control group.
- Details of inclusion and exclusion criteria in study group.
- Details of inclusion and exclusion criteria in control group.
- Type of intervention received by patients.
- Type of RME appliance fabricated.
- Activation protocol followed.
- Duration of RME.
- Retention period (if any).
- Type of retention appliance given.
- Points of volume measurements.
- Imaging technique used for volumetric assessment.
- Specifications of machine and image acquisition protocol.
- Standardization of image acquisition at all points if followed.
- Software used for volumetric assessment.
- Regions of upper airway evaluated.
- Anatomic landmarks used for evaluating nasal and pharyngeal area.
- Pre-RME volume obtained (T1).
- Post-RME volume obtained (T2) (if taken).
- Post-retention volume obtained (T3) (if taken).
- End point assessment of mouth breathing (if done then result of assessment).
- Method used to assess mouth breathing (if done).

Data Items

Information pertaining to the study namely the study design, descriptive analysis of population, that is, age and gender, selection criteria used for both study and control group, sample size, and method of randomization. The primary outcome was the upper airway volumetric changes assessed using 3D methods namely CT and CBCT. The upper airway included the nasal cavity, nasopharynx, and oropharynx. The details recorded were time point of measurement, image acquisition protocol, landmarks used for airway analysis, and the end point assessment of mouth breathing. Measurements were recorded for minimum two of the three time points: T1 (pre-RME), T2 (post-active expansion), and T3 (post-retention). The intervention studied was RME, whereas surgically assisted rapid maxillary expansion (SARME) and miniscrew-assisted RME were excluded. Details pertaining to the intervention, RME appliance, duration of RME, type of retention appliance, and duration of retention were recorded.

Risk of Bias in Individual Studies

Different tools were used to assess the risk of bias for RCTs and nonrandomized clinical trials.

The assessment of risk of bias was done using the approach recommended in Cochrane Reviews[15] using RevMan 5.4. Two-part tool was used to address six specific domains which were namely allocation concealment, sequence generation, blinding, selective outcome reporting, incomplete outcome data, and other bias. For each domain, there are specific one or more entries in "risk of bias" table. For each entry, the first part involves what was reported to have happened in the study. The second part involves assigning risk of bias for that particular entry, that is, low risk, high risk, or unclear risk.

For evaluating the risk of bias in nonrandomized trials, ROBINS-I tool was used.

Summary Measures

The primary objective of this systematic review was to assess the changes in upper airway volume before and after RME, and the secondary/additional objective was to evaluate if the resultant change in volume actually alleviates mouth breathing habits. The changes in the airway volume of various parts were described in different studies. Therefore, the outcomes were sorted out separately for all parts namely nasal cavity, nasopharynx, and oropharynx. The upper airway volume measured using 3D imaging techniques (CT and CBCT) was reported for a minimum of two time points: T1 (pre-RME), T2 (post-active expansion), and T3 (post-retention).

Synthesis of Results

The meta-analysis was performed using the SPSS version (v) 21.0 (IBM), MedCalc v 12.5.0.0 (Ostend, Belgium), Epi info v 7.1 (CDC, WHO), RevMan 5.4.1 (Cochrane), GraphPad Prism v 6.1, and a few resources available online for measuring heterogeneity and quality checks of individual articles, guidelines like PRISMA, CONSORT, MOOSE, and QUOROM. Cochrane's Q and I^2 statistics were used to assess the heterogeneity. Fixed-effect and random-effect meta-analyses were performed using Mantel-Haenszel and DerSimonian-Laird estimator of variance, respectively. The 95% confidence intervals (95% CI) and risk ratio were calculated as effect estimate.

Results

Study Selection

A total of 189 articles were obtained in the initial search strategy, including the articles obtained from Google Scholar. After removing the duplicates, 46 articles were assessed for their abstracts and full texts. After diligent application of selection criteria, finally 12 articles were included in the systematic review. Among the 12 studies included for systematic review, only nine studies qualified for meta-analysis (Flowchart 1). Studies conducted by Almuzian et al.,[16] Pangrazio-Kulbersh et al.,[17] and Bouserhal et al.[18] were excluded from the meta-analysis. The reasons for excluding these studies were: (A) study conducted by Almuzian et al.[16] compared two software and did not assess the required parameters; (B) Pangrazio-Kulbersh et al.[17] assessed the posterior airway as a whole and did not evaluate nasopharyngeal and oropharyngeal volume separately; (C) Bouserhal et al.[18] assessed the nasal cavity volume and reported very low values which made it difficult to perform a meta-analysis. Additionally, Izuka et al.[19] combined nasal cavity and nasopharynx into a single entity [nasal cavity and nasopharyngeal volume (VNN)], and calculated oropharyngeal volume separately. Hence, for meta-analysis, we included only oropharyngeal volume reported in this study.

Study Characteristics

In the 12 articles assessed, majority of the participants belonged to the age-group of 8–15 years. Out of the 12 trials included, two were RCTs,[17,20] nine were nonrandomized clinical trials (without control group),[16,18,19,21–26] and one was a non-RCT.[27] The most commonly adhered to inclusion criteria was the transverse maxillary deficiency, among which seven had mandatory requirement of posterior crossbite (unilateral or bilateral).[18,19–25] The level of skeletal maturation was assessed only in two studies using cervical vertebrae.[20,17] Two studies compulsorily included mouth breathers in inclusion criteria.[19,27]

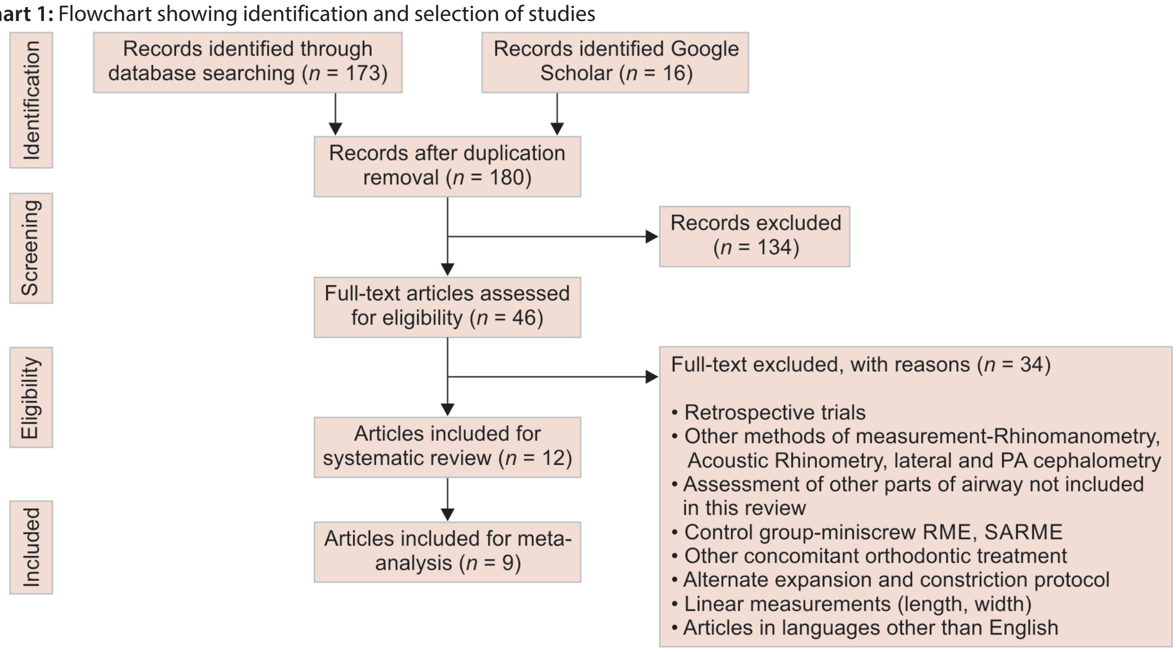
The expansion appliance used for RME included banded RME in four studies,[18,20,27,22] bonded RME in three studies,[23–25] both bonded and banded RME in one study,[17] and either bonded or banded RME in one study.[26] Two studies used the cast cap appliance[20,21] and one used modified Biederman appliance.[19] Most commonly used activation protocol was the quarter turn (0.25 mm) and two daily activations. However, activation protocol was not defined for three studies.[20,24,26] The commonly used method for retention was to keep the expander in place passively for the required period. The duration of retention varied in the included studies.

The regions of upper airway evaluated were nasal cavity, nasopharynx, and oropharynx. Among these studies, 10 evaluated the nasal cavity volume,[16,18,20–23,27] five evaluated the nasopharyngeal volume,[16,21,22,24] whereas oropharyngeal volume was evaluated in four studies.[19,22,24,27] But, one trial conducted by Izuka et al.[19] did not differentiate the nasal cavity and nasopharynx, and another trial conducted by Pangrazio-Kulbersh et al.[17] evaluated the posterior airway without differentiating the nasopharynx and oropharynx. The measurements were carried before expansion (T1) in all trials, and five trials evaluated immediately after expansion (T2)[16–19,21] and six evaluated after completion of retention period ranging from 3 to 8 months (T3).[20,22–25,27] Only the trial conducted by Palaisa et al.[26] evaluated the volume before expansion, after expansion, and even after retention period. The technique of measurement was 3D imaging with CBCT used in seven trials[16,17,19–22,24] and CT used in five trials.[18,23,25–27]

Risk of Bias within Studies

Both the RCTs showed poor methodological quality, that is, high risk of bias (Fig. 1). High risk of bias was owing to lack of blinding of participants and operators, which was due to the inherent nature of intervention. Unclear risk was seen in allocation concealment since both authors failed to report it clearly. Additionally, Guidice et al.[20] did not report clearly regarding blinding of observer, and Pangrazio-Kulbersh et al.[17] did not adequately report the technique of randomization used. The remaining parameters showed low risk of bias.

Flowchart 1: Flowchart showing identification and selection of studies



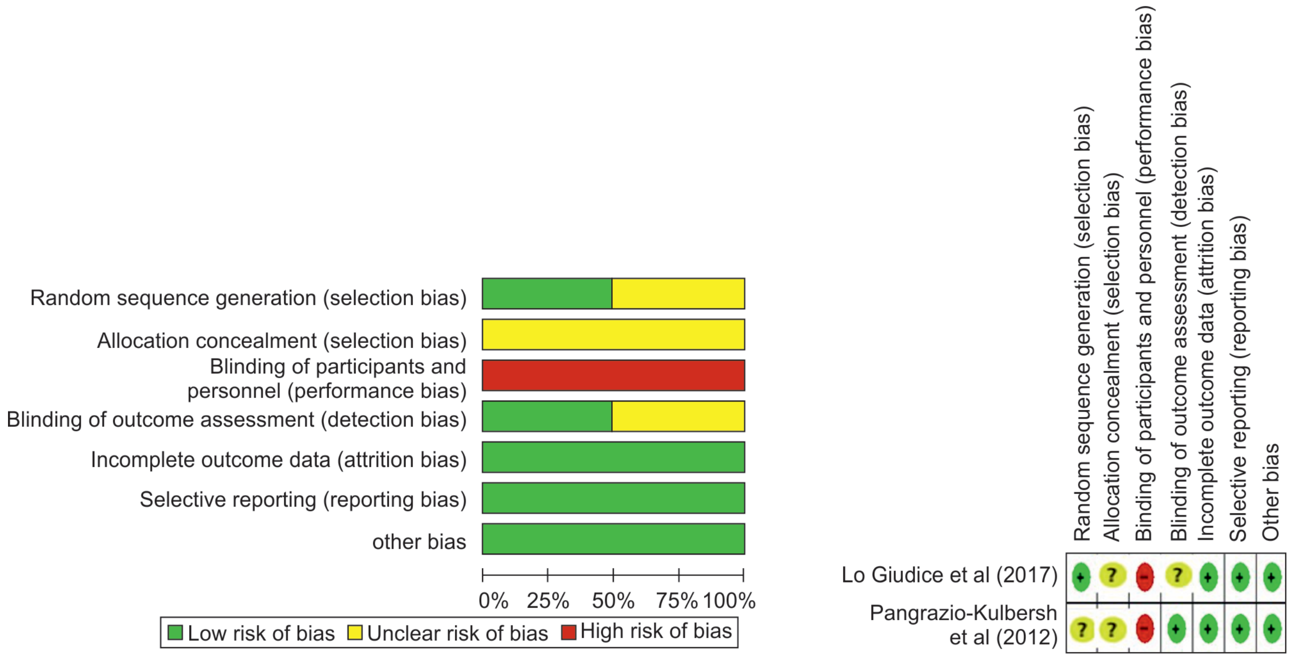


Fig. 1: Risk of bias assessment of RCTs

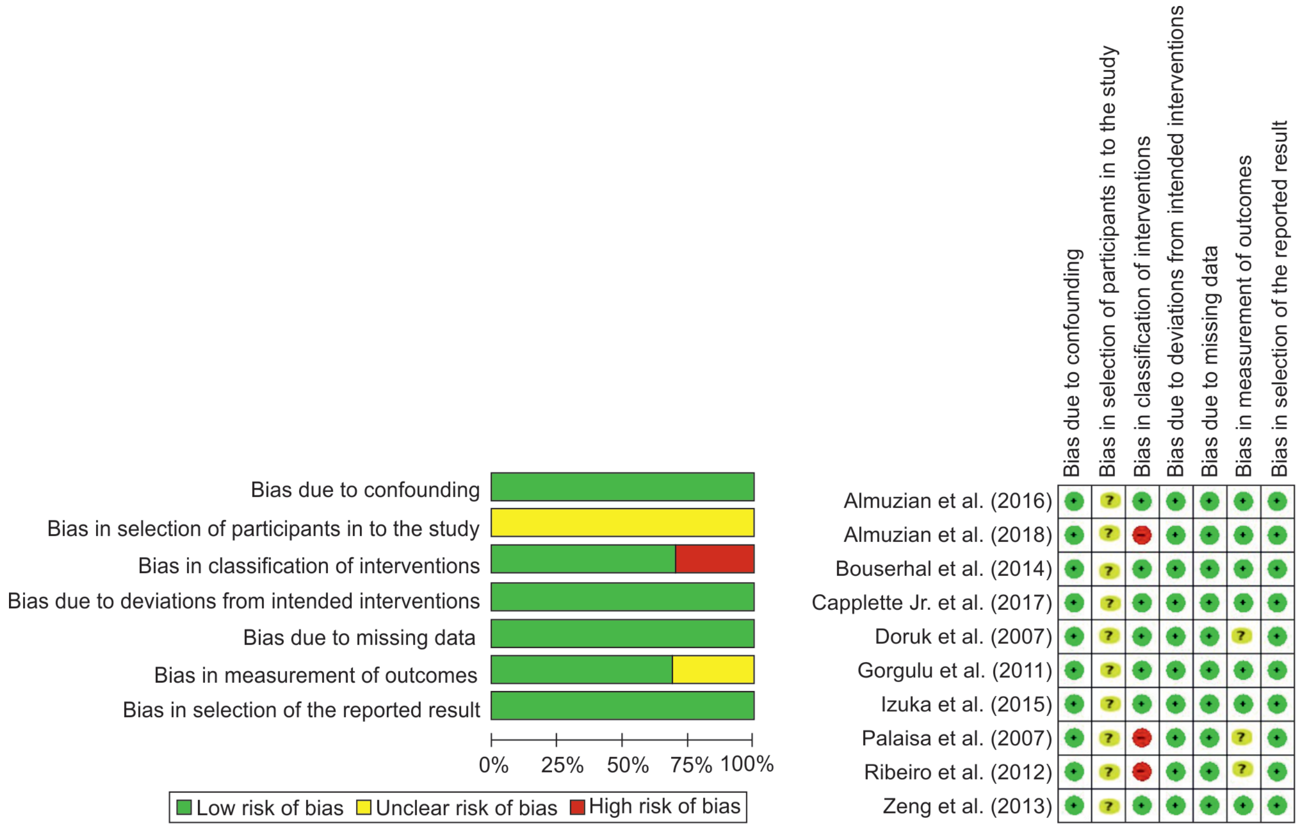


Fig. 2: Risk of bias assessment of nonrandomized clinical trials

In nonrandomized trials, majorly low risk of bias was observed (Fig. 2). The included studies failed to mention clearly regarding the method of selecting participants for the study, that is, sampling technique, etc. Three trials failed to elaborate on the expansion protocol hence categorized under high risk.[16,24,26] Furthermore, three trials did not clearly mention the blinding of assessor categorizing them into unclear risks.[24–26]

Results of Individual Studies

The complete description of 12 studies and upper airway volumetric measurements are included in Tables 3 and 4.

Synthesis of Results

The meta-analysis was performed separately for nasal cavity, nasopharyngeal, and oropharyngeal volume at two time points,

Table 3: Population, intervention, control, outcome, and study design of included studies

Sl. no.	*Study*	*Country*	*Population*	*Intervention*	*Control/comparator group*	*Retention period (if any)*	*Outcome (volume)*	*Study design*
1	Almuzian et al.[16] (2018)	UK	16 patients (eight boys, mean age: 12.4 years, range: 10.5–14.08 years; eight girls, mean age: 12.5 years, range: 10–16.25 years)	RME	None	–	• Lower nasal cavity • Upper nasopharynx	Nonrandomized clinical trial
2	Giudice et al.[20] (2017)	Italy	20 Caucasian children (10 boys; 10 girls) in age-group 8–13 years RME 10 (mean age: 10.4 years) SME 10 (mean age: 10.5 years)	RME	SME	7 months	Lower portion of nasal cavity	RCT
3	Cappellette et al.[27] (2017)	Brazil	38 mouth breathing patients Experimental group: 23 patients (11 female and 12 male) mean age: 9.6 years, range: 6.4–14.2 years Control group: 15 patients (nine male and six female) mean age: 10.5 years, range: 8.0–13.6 years	RME	Mouth breathers who did not receive RME	3 months	• Nasal cavity • Oropharynx	Non-RCT
4	Almuzian et al.[21] (2016)	UK	17 Caucasian patients (eight males, mean age: 12.4 years, range: 10.5–14.08 years; nine females, mean age: 12.8 years, range: 10–16.25 years)	RME	None	–	• Lower nasal cavity • Upper nasopharynx	Nonrandomized clinical trial
5	Izuka et al.[19] (2015)	Brazil	25 mouth breathers (14 females and 11 males; mean age: 10.5 years, range: 7.1–14.3 years)	RME	None	–	• Nasal cavity and nasopharynx • Oropharynx	Nonrandomized clinical trial
6	Zeng et al.[22] (2013)	China	16 children (10 males and six females; mean age: 12.73 ± 1.73 years, range: 10–15 years)	RME	None	3 months	• Lower nasal cavity • Nasopharynx • Oropharynx	Nonrandomized clinical trial
7	Bouserhal et al.[18] (2014)	Lebanon	30 patients (14 males, mean age: 9.5 ± 6 1.8 years; 16 females, mean age: 11.8 ± 6 1.7 years)	RME	None	6 months	• Nasal cavity	Nonrandomized clinical trial
8	Gorgulu et al.[23] (2011)	Turkey	15 patients (nine boys and six girls; mean age: 13.86 ± 1.4 years, range: 12–16 years)	RME	None	–	• Nasal cavity volume	Nonrandomized clinical trial
9	Pangrazio-Kulbersh et al.[17] (2012)	USA	23 patients Group I: banded expanders (13 patients; six males and six females; mean age: 12.6 ±1.8 years) Group II: bonded expanders (10 patients; five males and five females; mean age: 13.5 ± 2.1 years)	Banded RME	Bonded RME	6 months	• Posterior Airway	RCT
10	Ribeiro et al.[24] (2012)	Brazil	15 patients (eight females and seven males mean age: 7.5 years)	RME	No	4 months	• Nasopharynx • Oropharynx	Nonrandomized clinical trial
11	Doruk et al.[25] (2007)	Turkey	10 patients (six girls and four boys; age: 12–14 years)	RME	No	6 months	• Nasal cavity	Nonrandomized clinical trial
12	Palaisa et al.[26] (2007)	USA	19 patients (age range: 8–15 years)	RME	No	3 months	• Nasal cavity	Nonrandomized clinical trial

Table 4: Airway volumes measured at each time point of the included studies

Study	*Method for evaluating upper airway*	*Airway volumes at each time point*	*Outcome (statistical test values)*
Almuzian et al.[16] (2018)	CBCT	• **Lower nasal cavity volume** T1: 4695 ± 2108 mm^3 T2: 5517 ± 3371 mm^3 • **Upper nasopharyngeal volume** T1: 2761 ± 1409 mm^3 T2: 3079 ± 1391 mm^3	–
Giudice et al.[20] (2017)	CBCT	**Total nasal cavity volume** **RME** T1: 17.84 ± 4.21 cm^3 T3: 19.52 ± 4.14 cm^3 **SME** T1: 15.81 ± 3.31cm^3 T3: 17.06 ± 3.57 cm^3	– (feasibility study)
Cappellette et al.[27] (2017)	CT	**Nasal cavity volume** **RME** T1: 33418.7 ± 6107.6 mm^3 T3: 38450.6 ± 6329.1 mm^3 **Control** T1: 34426 ± 5059 mm^3 T3: 34488.7 ± 5088.9 mm^3	$p < 0.01$
		Oropharyngeal volume **RME** T1: 10262.3 ± 2421.1 mm^3 T3: 12955.1 ± 2942.8 mm^3 **Control** T1: 7531 ± 1535 mm^3 T3: 7572.4 ± 1526.4 mm^3	$p < 0.01$
Almuzian et al.[21] (2016)	CBCT	• **Lower nasal cavity volume** Males T1: 5512 ± 3065 mm^3 T2: 7123 ± 4596 mm^3 Females T1–4277 ± 1266 mm^3 T2–4533± 1755 mm^3	*t* values • **Lower nasal cavity volume** Males: 0.08 Females: 0.11
		• **Upper nasopharyngeal volume** Males T1: 2856 ± 1439 mm^3 T2: 3290 ± 1111 mm^3 Females T1–2652 ± 1435 mm^3 T2–2969 ± 1576 mm^3	• **Upper nasopharyngeal volume** Males: 0.11 Females: 0.25
Izuka et al.[19] (2015)	CBCT	**VNN** T1: 6114.4 ± 3490.4 mm^3 T2: 7760.5 ± 3841.4 mm^3	$p < 0.001$
		Oropharyngeal volume T1: 6378.2 ± 2357.5 mm^3 T2: 7828.8 ± 4109.9 mm^3	$p = 0.066$
Zeng et al.[22] (2013)	CBCT	**Lower nasal cavity volume** T1: 16521.7 ± 1729.1 mm^3 T3: 17870.2 ± 1996.6 mm^3	$p = 0.000$*
		Nasopharyngeal volume T1: 2627.9 ± 1145.6 mm^3 T3: 2449.2 ± 1210.5 mm^3	$p = 0.447$
		Oropharyngeal volume T1: 10883.0 ± 3631.1 mm^3 T3: 9558.0 ± 2750.7 mm^3	$P = 0.037$*

Contd…

Contd…

Study	Method for evaluating upper airway	Airway volumes at each time point	Outcome (statistical test values)
Bouserhal et al.[18] (2014)	CT	**Nasal cavity volume** T1: 4.98 ± 0.90 mm^3 T2: 5.83 ± 1.00 mm^3	$p = 0.000$*
Gorgulu et al.[23] (2011)	CT	**Nasal cavity volume** T1: 11693.27 ± 1941.37 mm^3 T3: 13112.73 ± 2026.29 mm^3	$p < 0.001$* 95% CI values mentioned difference (1060.79, 1778.14) mm^3
Pangrazio-Kulbersh et al.[17] (2012)	CBCT	**Posterior airway volume** **Group I: banded RME** T1: 11,858.93 ± 3988.74 mm^3 T2: 19,277.53 ± 17,421.86 mm^3	$p = 0.16$
		Group II: bonded RME T1: 11,518.73 ± 4742.75 mm^3 T2: 11,423.56 ± 2544.65 mm^3	$p = 0.93$
Ribeiro et al.[24] (2012)	CBCT	**Nasopharyngeal volume** T1: 7624.50 ± 3301.35 mm^3 T3: 8504.27 ± 2760.69 mm^3	$p = 0.11$
		Oropharyngeal volume T1: 1474.34 ± 754.77 mm^3 T3: 1713.70 ± 958.85 mm^3	$p = 0.05$
Doruk et al.[25] (2007)	CT	**Nasal cavity volume** T1: 38.9 ± 7.14 cm^3 T3: 43.9 ± 8.26 cm^3	$p < 0.05$*
Palaisa et al.[26] (2007)	CT	**Left nasal cavity volume** T1: 9.75 ±1.96 cm^3 T2: 10.98 ± 2.06 cm^3 T3: 13.42 ± 2.48 cm^3	$p = 0.0016$*
		Right nasal cavity volume T1: 9.76 ± 1.80 cm^3 T2: 10.59 ± 2.09 cm^3 T3: 13.08 ± 2.74 cm^3	$p = 0.0001$*
		Total nasal cavity volume T1: 19.51 ± 3.48 cm^3 T2: 21.58 ± 3.89 cm^3 T3: 26.50 ± 4.86 cm^3	$p = 0.0001$*

*$p < 0.05$, statistically significant

that is, pre-RME (T1) and post-expansion/post-retention (T2/T3). We also attempted to perform subgroup analysis for studying the effects of RME separately after active expansion and after retention period. However, since only one study assessed the volume at T2, we could not perform subgroup analysis for comparing T1 and T2. Hence, subgroup analysis was performed just to compare T1 and T3.

Nasal Cavity Volume

A total of 108 subjects were evaluated to assess the effect of RME on nasal cavity volume. Although, few of the included studies showed that standard mean difference (SMD) crossed zero but the total random effects SMD was −0.740 (95% −1.07 to −0.42), favoring T2/ T3. This indicates that there is a significant increase in nasal cavity volume post-RME ($p < 0.00001$). The subgroup assessment for post-retention period (T3) comprising 91 subjects showed SMD of a few studies crossing zero, but the total random effects SMD was −0.84 (95% −1.17 to −0.51) favoring T3. There was a statistically significant increase in nasal cavity volume in retention period ($p < 0.00001$), indicating the long-term positive effect of RME on nasal cavity. The heterogeneity tests also indicated acceptable homogeneity of data (Figs 3 and 4).

Nasopharyngeal Volume

A total of 48 subjects were considered for assessing the effect of RME on nasopharyngeal volume, and among these, 31 subjects were assessed post-retention as well. The heterogeneity test revealed homogeneous data ($I^2 = 0\%$). Standard mean difference of all included studies crossed zero and showed no statistically significant difference in pre-RME and post-RME volumes (Figs 5 and 6).

Oropharyngeal Volume

The heterogeneity tests revealed nonhomogeneous data. The meta-analysis revealed no statistically significant increase in volume after RME (T2/T3) and also when assessed exclusively post-retention (T3) (Figs 7 and 8).

The aforementioned results must be interpreted cautiously owing to the lesser number of studies included.

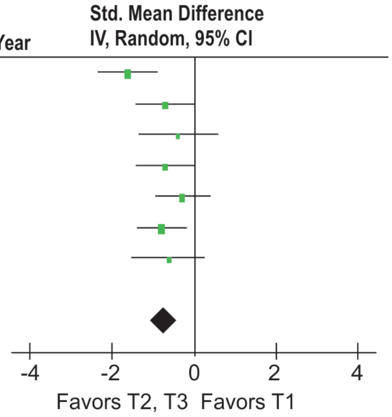
Discussion

Summary of Evidence

Mouth breathing is one of the most extensively studied deleterious habits in children by various medical and dental specialties. Despite the vast literature, the habit still remains underexplored

Study or subgroup	T1 Mean	T1 SD	T1 Total	T2,T3 Mean	T2,T3 SD	T2,T3 Total	Weight	Std. Mean Difference IV, Random, 95% CI Year
Palaisa et al. (2007)	19,510	3,480	19	26,500	4,860	19	14.4%	-1.62 [-2.36,-0.88]
Gorgulu et al. (2011)	11,69327	1,941.37	15	13,11273	2,026.29	15	14.5%	-0.70 [-1.44, 0.04]
Lo Giudice et al. (2017)	17,840	4,210	8	19,520	4,140	8	9.0%	-0.38 [-137,0.61]
Zeng et al. (2013)	16,521	1,729	16	17,870.2	1,996.6	16	15.2%	-0.70 [-1.42,0.01]
Almuzian et al. (2016)	4,785	2,195	17	5,600	3,374	17	16.6%	-0.28 [-0.96,0.40]
Cappellette Jr. et al.(2017)	33,4187	6,107	23	38,450.6	6,329.1	23	19.6%	-0.80 [-1.40,-0.19]
Doruk a et al. (2007)	38,900	7,140	10	43,900	8,260	10	10.6%	-0.62 [-152, 0.28]
Total (95% CI)			**108**			**108**	**100.0%**	**-0.74 [-1.07,-0.42]**

Heterogeneity $Tau^2 = 0.04$, $Chi^2 = 7.78$, df = 6 (P = 0.25); $I^2 = 23\%$
Test for overall effect Z = 4.53 (p < 0.00001)



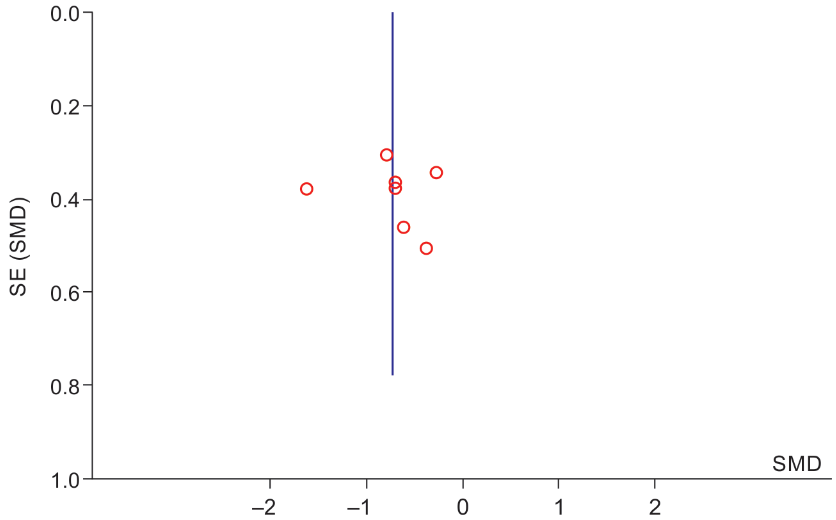


Fig. 3: Forest and funnel plot assessing the effect on nasal cavity volume before (T1) and after (T2/T3) RME

in terms of diagnosis, treatment, and ultimate alleviation of the habit. It has been commonly observed that the habit continues to persist even after successful removal of obstructive causes like enlarged adenoids and tonsils. This persistence of habit has been attributed to transverse maxillary deficiency, which is reported to cause an alteration in upper airway morphology. Researchers have established a correlation between mouth breathing and maxillary constriction with each being both cause and consequence of the other forming a vicious cycle.[28]

Rapid maxillary expansion is a routinely used orthopedic procedure in order to correct transverse maxillary deficiency in growing patients. However, numerous authors have also reported additional benefits of RME to the upper airway due to the intimate anatomical relationship. This observation of RME resulting in improvement of airway was not a recent finding. It dates way back to the early observation by Timms, who made subjective analysis of patients with breathing difficulty who were then treated with RME. It was reported that with RME, the improvement rate was 82%.[29]

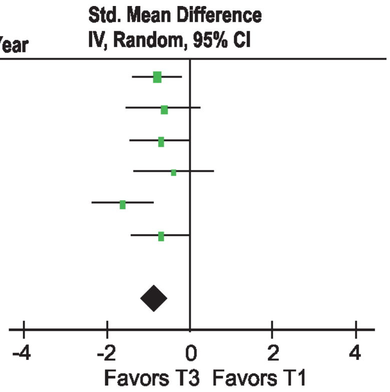
Buck et al.[9] had conducted a systematic analysis to explore the effect of RME on upper airway volumetric dimensions. It was concluded that RME could lead to an increase in volume of separate airway components as well as the total upper airway volumetric dimension in short term. However, the authors warned regarding cautious interpretation of results due to serious methodological issues. They had defined the upper airway comprising nose, nasal passages, paranasal sinuses, oral cavity, pharynx (nasopharynx, oropharynx, and hypopharynx), and the portion of the larynx above the vocal cords. However, literature search revealed that RME majorly influences the nasal and pharyngeal morphology. Hence for this purpose, this systematic review focused on upper airway comprising nasal cavity, nasopharynx, and oropharynx.

Alyessary et al.[30] concluded in their systematic review that RME appeared to improve breathing, increase nasal cavity geometry, and reduce nasal resistance. Despite the innumerable claims of RME resulting in correction of the mouth breathing habit, there is dearth in objective data for the same. Another systematic review was conducted by Baratieri et al.[31] to assess the long-term effects of RME on airway dimension and breathing. He concluded that changes in airway dimension and functions might improve the conditions for nasal breathing, but it cannot be solely indicated for this purpose. This conclusion prompted us to conduct a systematic review to evaluate the effect of RME on mouth breathing. To our surprise, only two trials conducted by Cappellette et al.[27] and Izuka et al.[19] included mouth breathers in the experimental group and conducted end point assessment of correction of mouth breathing. Cappellette et al.[27] (using CT) assessed the improvement in mouth breathing using a standardized questionnaire assessing the physical suffering, sleep disturbance, sleep or swallowing problems, emotional distress, activity limitation, and degree of parent's concern regarding their child's snoring. This six domain questionnaire was administered

Study or subgroup	T1 Mean	T1 SD	T1 Total	T3 Mean	T3 SD	T3 Total	Weight	Std. Mean Difference IV, Random, 95% CI Year
Cappellette Jr. et al.(2017)	33,4187	6,107.6	23	38,450.6	6,329.1	23	24.8%	-0.80 [-1.40,-0.19]
Doruk a et al. (2007)	38,900	7,140	10	43,900	8,260	10	12.1%	-0.62 [-152, 0.28]
Gorgulu et al. (2011)	11,693.27	1,941.37	15	13,11273	2,026.29	15	17.3%	-0.70 [-1.44, 0.04]
Lo Giudice et al. (2017)	17,840	4,210	8	19,520	4,140	8	10.2%	-0.38 [-137,0.61]
Palaisa et al. (2007)	19,510	3,480	19	26,500	4,860	19	17.2%	-1.62 [-2.36,-0.88]
Zeng et al. (2013)	16,521.7	1,729.1	16	17,870.2	1,996.6	16	18.4%	-0.70 [-1.42,0.01]
Total (95% CI)			**91**			**91**	**100.0%**	**-0.84 [-1.07,-0.51]**

Heterogeneity: Tau^2 = 0.02; Chi^2 = 5.58, df = 6 (P = 0.35); I^2 = 10%

Test for overall effect Z = 5.04 (p < 0.00001)



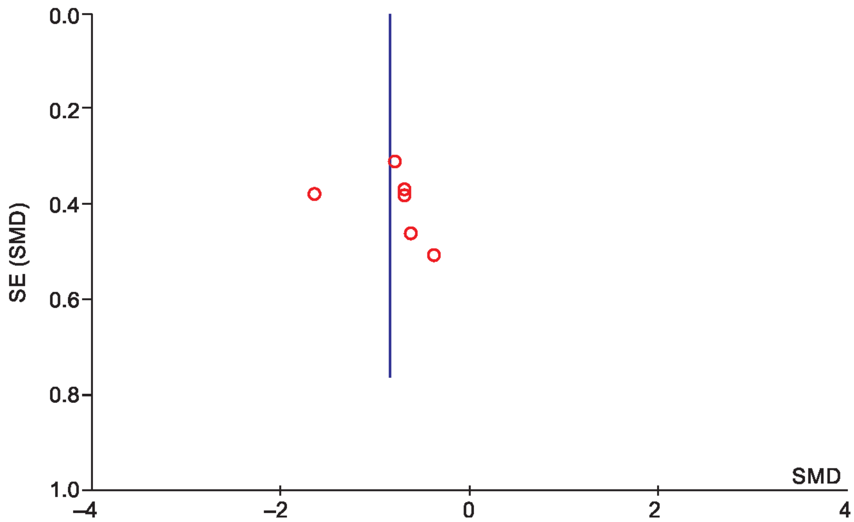


Fig. 4: Forest and funnel plot assessing the effect on nasal cavity volume before RME (T1) and after retention period (T3)

to the parent before and in the period 3 months after RME. Additionally, children were also subjected to ENT evaluation, orthodontic examination, and certain clinical tests, including water holding test and mirror test. Izuka et al.[19] (using CBCT) also administered the same questionnaire to assess the quality of life among mouth breathers before and immediately after active expansion. However, both studies did not follow up on long-term stability of RME in actually alleviating the habit and improving the quality of life among mouth breathers.

Among the studies included in this review, effects of RME in different regions of upper airway (nasal cavity, nasopharynx, oropharynx) were assessed. The trials showed a consistent increase in nasal cavity volume after RME, whereas nasopharyngeal and oropharyngeal volume showed mixed outcomes. The nasal cavity volume showed statistically significant increase after RME and also maintained the increase after retention period as well (p-value < 0.00001). Maxillary expansion promotes the improvement in nasal dimensions both horizontally as well as vertically which contributes to overall increase in nasal cavity volume. The increase in horizontal dimension is achieved by widening of nasal floor and increase in the distance between nasal walls and nasal septum, and the vertical dimension is increased by the rotation of the palate.[32,33] The nasopharyngeal volume did not show a statistically significant increase after RME in any of the included studies except the study conducted by Izuka et al.,[19] wherein it was evaluated as a single entity with nasal cavity. The third component, that is, oropharyngeal volume did not show a significant increase after active expansion as well as post-retention (p-value > 0.05). The above observations could also be explained based on the conclusions derived by Bazargani et al.[34] that structures articulating directly with maxilla have a tendency to show larger displacement compared to the ones located farther from it.

The time point of assessment of airway volume also varied among the included studies, wherein few studies assessed immediately after expansion whereas others after the retention period. But Palaisa et al.[26] assessed the nasal cavity volume at all three time points. Through this systematic review, it was observed that major diversity exists in the type of RME appliance given, its activation protocol, and the duration of active expansion. Only one trial conducted by Pangrazio-Kulbersh et al.[17] compared the results obtained from bonded and banded RME. Both methods did not show a statistically significant difference in posterior airway volume after RME, however banded RME showed a rise in volume, and bonded RME showed a reduction in posterior airway volume of 100 mm^3 after RME.

Literature search dictates the use of RME in growing individuals to achieve maximum effect.[35] Hence growth assessment is a major parameter which was included only in two studies conducted by Guidice et al.[20] and Pangrazio-Kulbersh et al.[17] Additionally, there is a lack of standardization of the image acquisition protocol and landmarks used for evaluating upper airway volume. Buck et al.,[9] in their systematic review also discussed the lack of international consensus on region limits, especially the landmarks used for demarcating the nasal cavity

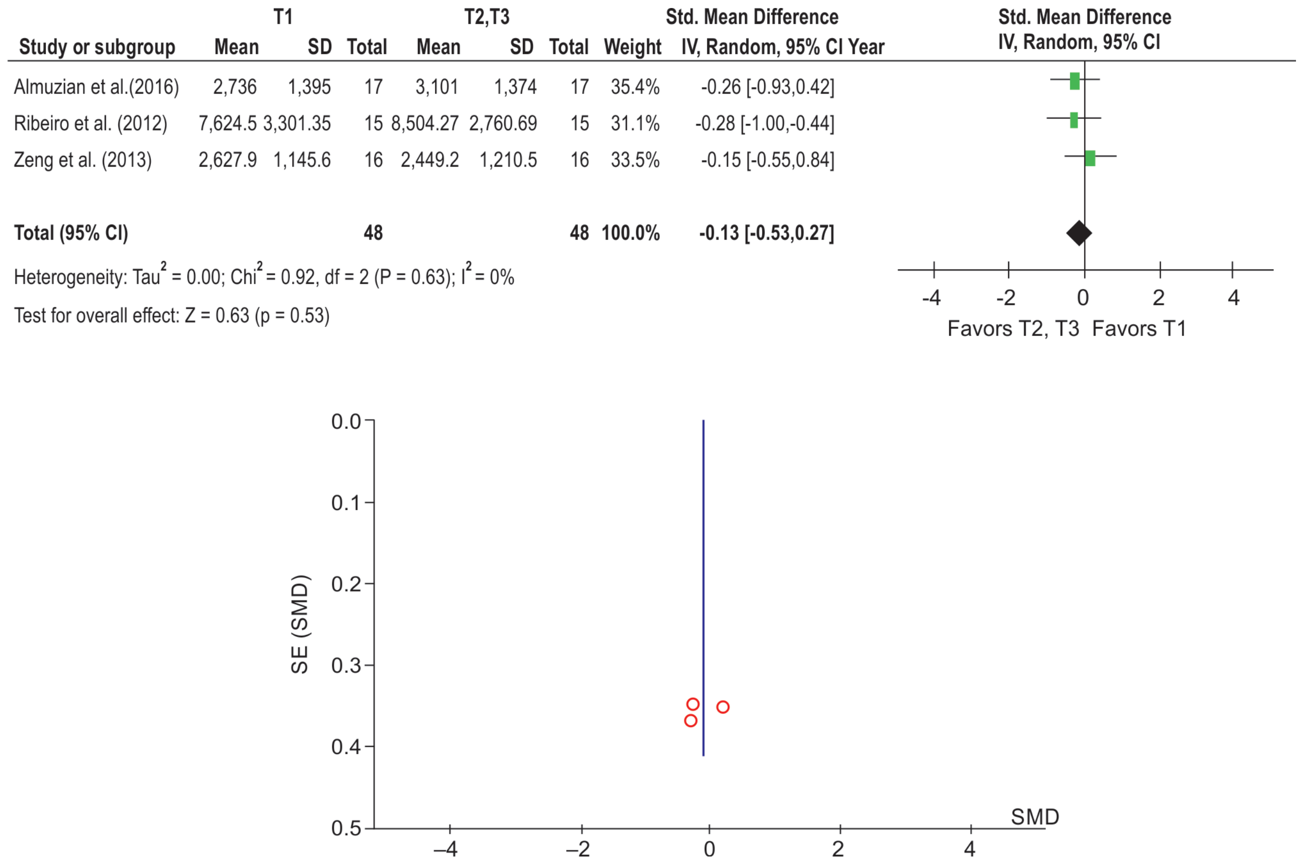


Fig. 5: Forest and funnel plot assessing the effect on nasopharyngeal volume before (T1) and after (T2/T3) RME

from nasopharynx and also various regions of pharynx. It has been specially observed with studies using CT where the limits have either been inadequately defined[18,23] or not defined at all.[25–27] In contrast to this, studies using CBCT have attempted to adequately define the limits, but there exists inconsistency in the definition of regions of airway. This could lead to discrepancy between studies referring to similar airway spaces and show misleading results causing difficulties in comparing the studies to assess the effect of RME. This lack of standardization was also reported by Carlo et al.,[36] who systematically reviewed the effects of RME based on airway assessment performed using only CBCT. They reported lack of standardization in image acquisition and also inappropriate segmentation of nasal cavity.

The aforementioned heterogeneities in the timing of initiation of therapy, type of RME appliance, its activation protocol, image acquisition, and inaccurate airway calculation pose an impediment in drawing definitive conclusions on the effect of RME on airway and mouth breathing.

Limitations of Existing Studies and Future Perspective

The included studies were majorly nonrandomized studies with major methodological discrepancies, and also the included RCTs showed poor methodological adequacy. Additionally, most existing studies had a small sample size, and a lack of control group failed to reduce the confounding effect of normal growth patterns. It was also not possible to correlate the overall change in volume with the type of RME appliance and amount of activation as a result of lack of data provided by the studies. There was prominent heterogeneity in the appliance assessed, expansion protocol, outcomes chosen, as well as the methods of measurement, which precludes any robust clinical suggestions on the effect of RME on upper airway volume. Therefore, it was judged that the overall quality of evidence was low owing to inconsistencies in methodology and absence of an untreated control group.

Therefore, through this systematic review, we would suggest conducting more consistent and well-designed randomized control trials with experimental and control groups comprising mouth breathers. It is necessary to standardize the type of RME appliance, activation protocol, retention period, form of retention appliance given, and the time point of airway assessment. To diagnose mouth breathing, both standardized questionnaires assessing quality of life and diagnostic tests should be used in unison. It is also necessary to standardize the CBCT/CT acquisition protocol and the landmarks used to define various parts of upper airway.

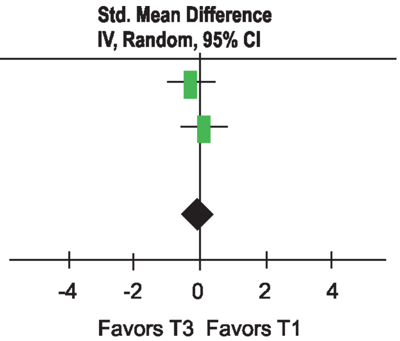
Strengths and Limitations

First and foremost, strength of this review is its diligent adherence to the PRISMA guidelines. This review only considered prospective clinical trials assessed using 3D imaging. This adds to the validation of the review due to the increased reliability and accuracy of the imaging techniques. This review also attempted to address an important end point of RME, which is to alleviate mouth breathing habit. This aspect has always been neglected, and conclusions on improvement of nasal breathing have been solely based on the resultant increase in the upper airway volumes. We also ensured to assess independently the effect of RME on upper airway, because of which we excluded the studies which used concomitant treatment modalities like comprehensive orthodontic therapy, facemask therapy, etc. Furthermore, meta-analysis of the included studies

Study or subgroup	T1 Mean	T1 SD	T1 Total	T3 Mean	T3 SD	T3 Total	Weight	Std. Mean Difference IV, Random, 95% CI Year
Ribeiro et al. (2012)	7,624.5	3,301.35	15	8,504.27	2,760.69	15	48.2%	-0.28 [-1.00,-0.44]
Zeng et al. (2013)	2,627.9	1,145.6	16	2,449.2	1,210.5	16	51.8%	-0.15 [-0.55,0.84]
Total (95% CI)			**31**			**31**	**100.0%**	**-0.06 [-0.56,0.44]**

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.71$, df = 1 (P = 0.40); $I^2 = 0\%$

Test for overall effect: Z = 0.23 (p = 0.82)



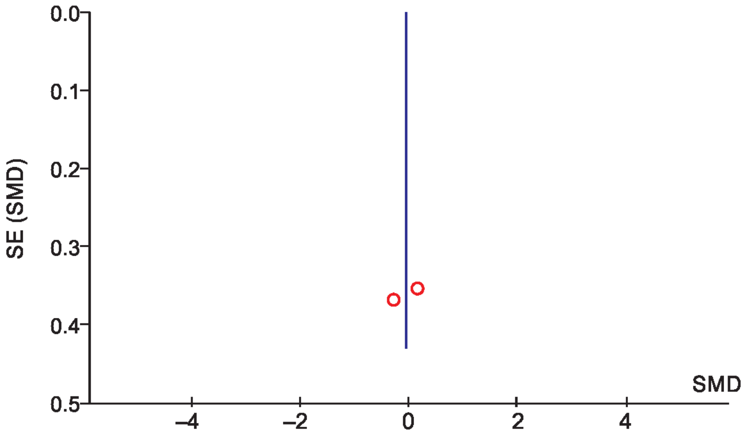
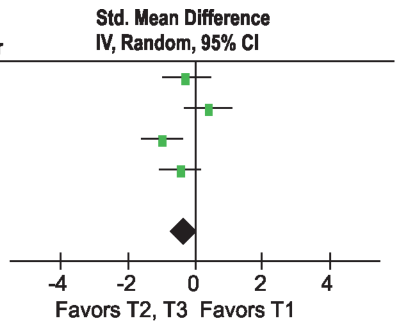


Fig. 6: Forest and funnel plot assessing the effect on nasopharyngeal volume before RME (T1) and after retention period (T3)

Study or subgroup	T1 Mean	T1 SD	T1 Total	T2,T3 Mean	T2,T3 SD	T2,T3 Total	Weight	Std. Mean Difference IV, Random, 95% CI Year
Ribeiro et al. (2012)	1,474.34	754.77	15	1,713.7	958.85	15	23.1%	-0.27 [-0.99,-0.45]
Zeng et al. (2013)	10,883	3,631.1	16	9,558	2,750.7	16	23.6%	-0.40 [-0.30,1.10]
Cappelete Jr. et al.(2017)	10,262.3	2,421.2	23	12,955.1	2,942.8	23	25.9%	-0.98 [-1.60,-0.37]
Izuka et al.(2015)	6,378.2	2,357.5	25	7,828.8	4,109.9	25	27.4%	-0.43 [-0.99,0.13]
Total (95% CI)			**79**			**79**	**100.0%**	**-0.34 [-0.88,0.21]**

Heterogeneity: $Tau^2 = 0.20$; $Chi^2 = 8.57$, df = 3 (P = 0.04); $I^2 = 65\%$

Test for overall effect: Z = 1.22 (p = 0.22)



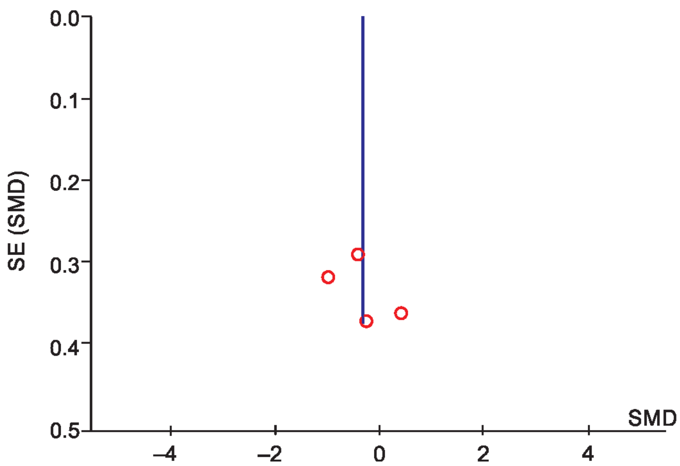


Fig. 7: Forest and funnel plot assessing the effect on oropharyngeal volume before (T1) and after (T2/T3) RME

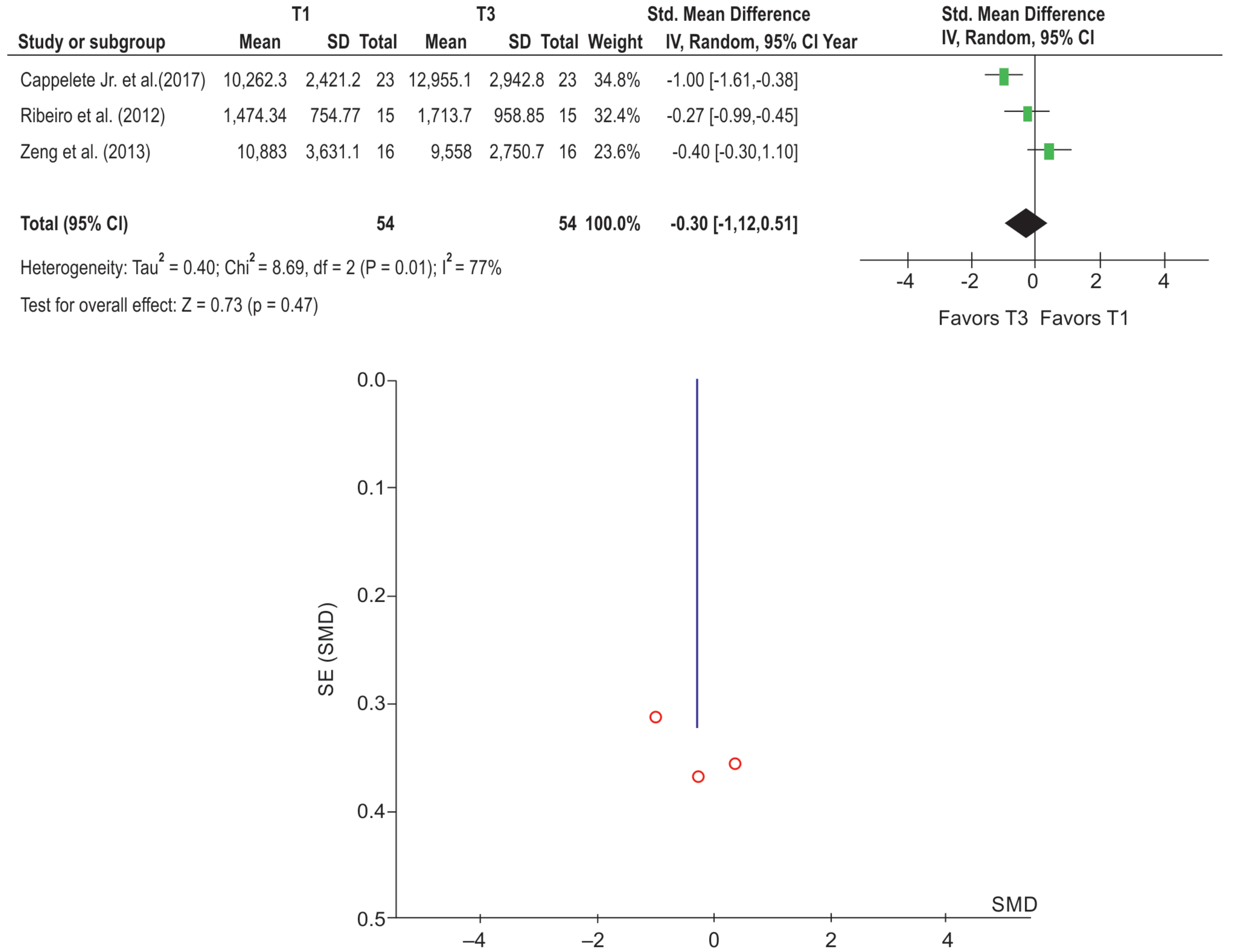


Fig. 8: Forest and funnel plot assessing the effect on oropharyngeal volume before RME (T1) and after retention period (T3)

was also performed, and subgroup analysis post-retention period was done, which enabled a better understanding on long-term effects of RME on airway volumes.

The main shortcoming of this systematic review was the limited number of database searches and the limited number of existing studies.

Conclusion

Based on this systematic review, it can be concluded that RME causes a significant increase in nasal cavity volume, but its effect on nasopharyngeal and oropharyngeal volume is not statistically significant in majority of studies. A meager increase in airway volume with RME does not establish its usage as an airway enhancement procedure. In order to establish its significance in the improvement of breathing, it is necessary to conduct more well-designed RCTs with samples actually comprising mouth breathers. In these trials, it is also necessary to diagnose mouth breathing based on more objective methods rather than subjective or perception-based methods. It becomes imperative that definitive conclusions on the true stability of RME on the breathing pattern should only be made after a long-term follow-up. However, based on the current level of evidence, it is advocated to limit the use of RME for purely orthodontic indication.

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References

1. Basheer B, Hegde KS, Bhat SS, et al. Influence of mouth breathing on the dentofacial growth of children: a cephalometric study. J Int Oral Health 2014;6(6):50–55.
2. Fernandes P, Pinto J, Ustrell-Torrent J. Relationship between oro and nasopharynx permeability and the direction of facial growth. Eur J Paediatr Dent 2017;18(1):37–40. DOI: 10.23804/ejpd.2017.18.01.08
3. Limme M. Orthognathic and orthodontic consequences of mouth breathing. Acta Otorhinolaryngol Belg 1993;47(2):145–155.
4. Bishara SE, Staley RN. Maxillary expansion: clinical implications. Am J Orthod Dentofacial Orthop 1987;91(1):3–14. DOI: 10.1016/0889-5406(87)90202-2
5. Baccetti T, Leonardi M, Armi P. A randomized clinical study of two interceptive approaches to palatally displaced canines. Eur J Orthod 2008;30(4):381–385. DOI: 10.1093/ejo/cjn023
6. Basciftci FA, Mutlu N, Karaman AI, et al. Does the timing and method of rapid maxillary expansion have an effect on the changes in nasal dimensions? Angle Orthod 2002;72(2):118–123. DOI: 10.1043/0003-3219(2002)072<0118:DTTAMO>2.0.CO;2
7. Warren DW, Hershey G, Turvey TA, et al. The nasal airway following maxillary expansion. Am J Orthod Dentofacial Orthop 1987;91(2):111–116. DOI: 10.1016/0889-5406(87)90467-7

8. Felippe NLOD, Silveira ACD, Viana G, et al. Relationship between rapid maxillary expansion and nasal cavity size and airway resistance: short- and long-term effects. Am J Orthod Dentofacial Orthop 2008;134(3):370–382. DOI: 10.1016/j.ajodo.2006.10.034
9. Buck LM, Dalci O, Darendeliler MA, et al. Volumetric upper airway changes after rapid maxillary expansion: a systematic review and meta-analysis. Eur J Orthod 2017;39(5):463–473. DOI: 10.1093/ejo/cjw048
10. Ozbek MM, Memikoglu UTT, Altug-Atac AT, et al. Stability of maxillary expansion and tongue posture. Angle Orthod 2009;79(2):214–220. DOI: 10.2319/010908-12.1
11. Carlo GD, Polimeni A, Melsen B, et al. The relationship between upper airways and craniofacial morphology studied in 3D. A CBCT study. Orthod Craniofac Res 2015;18(1):1–11. DOI: 10.1111/ocr.12053
12. Guijarro-Martinez R, Swennen GR. Cone-beam computerized tomography imaging and analysis of the upper airway: a systematic review of the literature. Int J Oral Maxillofac Surg 2011;40(11):1227–1237. DOI: 10.1016/j.ijom.2011.06.017
13. Weissheimer A, Menezes LMD, Sameshima GT, et al. Imaging software accuracy for 3-dimensional analysis of the upper airway. Am J Orthod Dentofacial Orthop 2012;142(6):801–813. DOI: 10.1016/j.ajodo.2012.07.015
14. Liberati A, Altman DG, Tetzlaff J, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. J Clin Epidemiol 2009;62(10):e1–e34. DOI: 10.1016/j.jclinepi.2009.06.006
15. Higgins JPT, Altman DG, Gøtzsche PC, et al. The Cochrane collaboration's tool for assessing risk of bias in randomised trials. BMJ 2011;343:d5928. DOI: 10.1136/bmj.d5928
16. Almuzian M, Ghatam HMA, Al-Muzian L. Assessing the validity of ITK-SNAP software package in measuring the volume of upper airway spaces secondary to rapid maxillary expansion. J Orthod Sci 2018;7:7. DOI: 10.4103/jos.JOS_93_17
17. Pangrazio-Kulbersh V, Wine P, Haughey M, et al. Cone beam computed tomography evaluation of changes in the naso-maxillary complex associated with two types of maxillary expanders. Angle Orthod 2012;82(3):448–457. DOI: 10.2319/072211-464.1
18. Bouserhal J, Bassil-Nassif N, Tauk A, et al. Three-dimensional changes of the naso-maxillary complex following rapid maxillary expansion. Angle Orthod 2014;84(1):88–95. DOI: 10.2319/011313-36.1
19. Izuka EN, Feres MFN, Pignatari SSN. Immediate impact of rapid maxillary expansion on upper airway dimensions and on the quality of life of mouth breathers. Dental Press J Orthod 2015;20(3):43–49. DOI: 10.1590/2176-9451.20.3.043-049.oar
20. Giudice AL, Fastuca R, Portelli M, et al. Effects of rapid vs slow maxillary expansion on nasal cavity dimensions in growing subjects: a methodological and reproducibility study. Eur J Paediatr Dent 2017;18(4):299–304. DOI: 10.23804/ejpd.2017.18.04.07
21. Almuzian M, Ju X, Almukhtar A, et al. Does rapid maxillary expansion affect nasopharyngeal airway? A prospective cone beam computerised tomography (CBCT) based study. Surgeon 2016;16(1):1–11. DOI: 10.1016/j.surge.2015.12.006
22. Zeng J, Gao X. A prospective CBCT study of upper airway changes after rapid maxillary expansion. Int J Pediatr Otorhinolaryngol 2013;77(11):1805–1810. DOI: 10.1016/j.ijporl.2013.07.028
23. Görgülü S, Gokce SM, Olmez H, et al. Nasal cavity volume changes after rapid maxillary expansion in adolescents evaluated with 3-dimensional simulation and modeling programs. Am J Orthod Dentofacial Orthop 2011;140(5):633–640. DOI: 10.1016/j.ajodo.2010.12.020
24. Ribeiro ANC, Paiva JBD, Rino-Neto J, et al. Upper airway expansion after rapid maxillary expansion evaluated with cone beam computed tomography. Angle Orthod 2012;82(3):458–463. DOI: 10.2319/030411-157.1
25. Doruk C, Sökücü O, Biçakçi AA, et al. Comparison of nasal volume changes during rapid maxillary expansion using acoustic rhinometry and computed tomography. Eur J Orthod 2007;29(3):251–255. DOI: 10.1093/ejo/cjl069
26. Palaisa J, Ngan P, Martin C, et al. Use of conventional tomography to evaluatechanges in the nasal cavity with rapid palatal expansion . Am J Orthod Dentofacial Orthop 2007;132(4):458–466. DOI: 10.1016/j.ajodo.2005.05.016
27. Cappellette M Jr, Alves FEMM, Nagai LHY, et al. Impact of rapid maxillary expansion on nasomaxillary complex volume in mouth-breathers. Dental Press J Orthod 2017;22(3):79–88. DOI: 10.1590/2177-6709.22.3.079-088.oar
28. Calvo-Henriquez C, Capasso R, Chiesa-Estomba C, et al. The role of pediatric maxillary expansion on nasal breathing. A systematic review and meta-analysis. Int J Pediatr Otorhinolaryngol 2020;135:110139. DOI: 10.1016/j.ijporl.2020.110139
29. Timms DJ. Rapid maxillary expansion in the treatment of nasal obstruction and respiratory disease. Ear Nose Throat J 1987;66(6):242–247.
30. Alyessary AS, Othman SA, Yap AUJ, et al. Effects of non-surgical rapid maxillary expansion on nasal structures and breathing: a systematic review. Int Orthod 2019;17(1):12–19. DOI: 10.1016/j.ortho.2019.01.001
31. Baratieri C, Alves M, Souza MMGD, et al. Does rapid maxillary expansion have long-term effects on airway dimensions and breathing? Am J Orthod Dentofacial Orthop 2011;140(2):146–156. DOI: 10.1016/j.ajodo.2011.02.019
32. Haralambidis A, Ari-Demirkaya A, Acar A, et al. Morphologic changes of the nasal cavity induced by rapid maxillary expansion: a study on 3-dimensional computed tomography models. Am J Orthod Dentofac Orthop 2009;136(6):815–821. DOI: 10.1016/j.ajodo.2008.03.020
33. Smith T, Ghoneima A, Stewart K, et al. Three-dimensional computed tomography analysis of airway volume changes after rapid maxillary expansion. Am J Orthod Dentofac Orthop 2012;141(5):618–626. DOI: 10.1016/j.ajodo.2011.12.017
34. Bazargani F, Feldmann I, Bondemark L. Three-dimensional analysis of effects of rapid maxillary expansion on facial sutures and bones. Angle Orthod 2013;83(6):1074–1082. DOI: 10.2319/020413-103.1
35. Haas AJ. Palatal expansion just the beginning of dentofacial orthopedics. Am J Orthod 1970;57(3):219–255. DOI: 10.1016/0002-9416(70)90241-1
36. Carlo GD,Saccucci M, Ierardo G, et al. Rapid maxillary expansion and upper airway morphology: aystematic review on the role of cone beam computed tomography s. Biomed Res Int 2017;2017:5460429. DOI: 10.1155/2017/5460429