Does rapid maxillary expansion have long-term effects on airway dimensions and breathing?

Carolina Baratieri,[a] Matheus Alves, Jr,[a] Margareth Maria Gomes de Souza,[b] Mônica Tirre de Souza Araújo,[b] and Lucianne Cople Maia[b]
Rio de Janeiro, Rio de Janeiro, Brazil

Introduction: In this systematic review, we identified and qualified the evidence of long-term reports on the effects of rapid maxillary expansion (RME) on airway dimensions and functions. **Methods:** Electronic databases (Ovid, Scirus, Scopus, Virtual Health Library, and Cochrane Library) were searched from 1900 to September 2010. Clinical trials that assessed airway changes at least 6 months after RME in growing children with rhinomanometry, acoustic rhinometry, computed tomography, or posteroanterior and lateral radiographs were selected. Studies that used surgically assisted RME and evaluated other simultaneous treatments during expansion, systemically compromised subjects, or cleft patients were excluded. A methodologic-quality scoring process was used to identify which studies would be most valuable. **Results:** Fifteen articles fulfilled the inclusion criteria, and full texts were assessed. Three were excluded, and 12 were assessed for eligibility. Four articles with low methodologic quality were not considered. The remaining 8 were qualified as moderate. The posteroanterior radiographs showed that nasal cavity width increases; in the lateral radiographs, decreased craniocervical angulation was associated with increases of posterior nasal space. Cone-beam computed tomography did not show significant increases of nasal cavity volume. Rhinomanometry showed reduction of nasal airway resistance and increase of total nasal flow, and acoustic rhinometry detected increases of minimal cross-sectional area and nasal cavity volume. **Conclusions:** There is moderate evidence that changes after RME in growing children improve the conditions for nasal breathing and the results can be expected to be stable for at least 11 months after therapy. (Am J Orthod Dentofacial Orthop 2011;140:146-56)

Rapid maxillary expansion (RME) is an effective orthopedic procedure that has been routinely used in growing patients in orthodontics. The goal of RME is to open the midpalatal suture, providing correct and stable maxillary width.[1-4] Although this therapy is carried out to correct dental and skeletal maxillary transverse discrepancies, some authors showed that treatment outcomes could also increase nasopharyngeal airway dimensions and improve patients' nasal breathing.

It has been hypothesized that, since the maxillary bones form half of the nasal cavity's structures, when the midpalatal suture is open, the nasal cavity's lateral walls are also displaced apart, and its volume increases, and upper airway resistance decreases over time.[5] Head posture had also been associated with respiratory function, and increased craniocervical angulation was observed as a functional response to facilitate oral breathing to compensate for nasal obstruction.[6] Once RME results in increased nasal airway patency and reduced nasal airway resistance (NAR), the airway flow increases, and the craniocervical angulation consequently is reduced. Another reported consequence after RME is higher tongue repositioning, which could increase airway volume.[7] Several studies have been conducted to evaluate these effects, but there is still controversy about the authentic long-term influence of RME on nasal cavity dimensions and functions.[5,8,9]

Differing measurement methods of nasal airway dimensions and function have been proposed and used, such as rhinomanometry (RMN), acoustic rhinometry (AR), radiography, and, recently, cone-beam computed tomography (CBCT). Each technique has its strengths and limitations. Both RMN and AR are objective tests for the assessment of nasal airway patency. RMN measures air pressure and airflow rate during breathing, calculating NAR, whereas AR uses a reflected sound

From the Department of Pediatric Dentistry and Orthodontics, School of Dentistry, Federal University of Rio de Janeiro, Rio de Janeiro, Rio de Janeiro, Brazil.
[a]Postgraduate student.
[b]Associate professor.
The authors report no commercial, proprietary, or financial interest in the products or companies described in this article.
Reprint requests to: Lucianne Cople Maia, Avenida Professor Rodolpho Paulo Rocco, 325-Ilha do Fundão, Department of Pediatric Dentistry and Orthodontics, School of Dentistry, Federal University of Rio de Janeiro, Rio de Janeiro, RJ, Brazil CEP: 21941-617; e-mail, rorefa@terra.com.br.
Submitted, October 2010; revised and accepted, February 2011.
0889-5406/$36.00

doi:10.1016/j.ajodo.2011.02.019

Table I. Electronic databases used and search strategy

Database	Search strategy: Key words/MeSH	Search strategy: Refining
OVID Medline www.ovidsp.tx.ovid.com	Rapid maxillary expansion OR rapid palatal expansion OR maxillary disjunction OR palatal disjunction OR Palatal Expansion Technique AND airway OR nasal OR respiration OR breathing	1950 to September, week 3, 2010 HUMAN
Scirus (Medline/PubMed; Science Direct; PubMed Central; BioMed) www.scirus.com/srsapp/advanced	"Rapid maxillary expansion" OR "rapid palatal expansion" OR "maxillary disjunction" OR "palatal disjunction" OR "Palatal Expansion Technique" AND "oropharyngeal airway" OR "nasal airway" OR "nasal cavity" OR "nasal volume" OR "respiration" OR "breathing"	1900-2011 Information type-abstracts, articles Sources-journal sources HUMAN
Scopus www.scopus.com/home.url	Rapid maxillary expansion OR rapid palatal expansion OR maxillary disjunction OR palatal disjunction OR Palatal Expansion Technique AND airway OR nasal OR respiration OR breathing	Articles, title, abstract, keyword All years to present
VHL (LILACS, IBECS, Medline, Scielo) www.regional.bvsalud.org/php/index.php	Palatal Expansion Technique AND Respiration (MeSH)	–
Cochrane Library www.thecochranelibrary.com/view/0/index.html	Rapid and maxillary and expansion and nasal	–

signal to measure the cross-sectional area and nasal passage volume.[10] Cephalometric radiographs are routinely used for orthodontic treatment evaluation. With posteroanterior (PA) headfilms, it is possible to measure nasal cavity width and, with lateral headfilms, airway length and craniocervical angulation. CBCT technology allows segmentation and visualization of the hollow airway in 3 dimensions and determines, in addition to lengths and angles, the airway volume and surface area.[11]

A maxillary transverse deficiency is a common skeletal problem in the craniofacial region, and it is often found in children with abnormal breathing.[12] Scientific evidence on the nasal airway would augment orthodontists' information to patients that RME could not only produce dentoalveolar changes, but also have implications for the nasal complex. Previously, a meta-analysis[13] and a systematic review[14] on the skeletal effects after RME found a significant increase in nasal cavity width. However, none of these studies aimed to associate this skeletal change with breathing function. Recently, another systematic review evaluated airway changes with AR but did not confirm the clinical breathing benefit after the therapy.[15] This study was not restricted to orthopedic expansion but included studies evaluating children and adults. Also, the follow-up period was not considered. So, there is still no evidence that children having orthopedic expansion can obtain any breathing benefit after a follow-up period.

The aim of our systematic review was to identify and qualify the evidence of long-term reports evaluating changes in airway dimensions and functions in patients having RME during the growth period. Studies using RMN, AR, radiography, and CBCT were considered for this purpose. The focused questions were the following. What are the effects on airway, nasal cavity, and NAR in children who underwent RME therapy? Are these changes stable in the long term? Do children undergoing RME therapy to correct a transverse discrepancy have any long-term benefit in breathing function?

MATERIALS AND METHODS

The method for this systematic review was based on the PRISMA guidelines (www.prisma-statement.org) recommended in the *American Journal of Orthodontics and Dentofacial Orthopedics*.[16] To identify relevant studies (from 1900 to the third week of September 2010), irrespective of language, a detailed search was conducted in the following electronic databases: Ovid Medline, Scirus, Scopus, Virtual Health Library, and Cochrane Library. The search strategy included appropriate changes in the key words and followed each database's syntax rules (Table I).

Table II outlines the populations, interventions, comparisons, and outcomes (PICO format) and the null hypothesis used for this systematic review. For the full articles to be selected from the abstracts, they had to

Table II. PICO format and null hypothesis

PICO format	
Population	Subjects during growth period with transverse maxillary deficiency
Intervention	RME
Comparison	Paired age and sex subjects who did not undergo to RME therapy
Outcome	Changes in airway dimension or function
Null hypothesis	
There was no long-term difference in airway changes between subjects who had RME and those who did not	

Table III. Methodologic-quality scoring protocol (maximum score, 14 points)

I. Study design (8)
A. Population adequately described (age, sex, brief medical history) (1)
B. Selection criteria described (1)
C. Sample size: ≥20/group (1) or ≥30/group (2)
D. Control with no orthodontic treatment (1)
E. Timing prospective (1)
F. Randomization stated (1)
G. RME adequately described (appliance, activation, retention) (1)
II. Study measurements (3)
H. Measurement method appropriate to the article objective (1)
I. Blinding: examiner and statistician (1)
J. Reliability described and adequate (1)
III. Statistical analysis (3)
K. Statistical test appropriate for data (1)
L. Confounders stated: radiography and CT evaluation (standardization of head and tongue position); RMN and AR (use of nasal decongestant) (1)
M. Significance: *P* value stated and confidence intervals provided (1)

Data from Lagravère et al.[4]

satisfy the following inclusion criteria: human controlled clinical trial; follow-up of at least 6 months after RME therapy; subjects during their growth period; and the use of RMN, AR, radiography, or CBCT to measure airway differences. The exclusion criteria were surgical or other simultaneous treatment during the active expansion phase; surgical treatment that could affect RME effects during the evaluation period; and systemically compromised subjects or cleft patients used as subjects.

The initial selection excluded all titles and abstracts not related to the topic or that involved any exclusion criteria. Theses, annals, reviews, and case reports were also excluded. The next step was a detailed review of the selected abstracts to screen those that respected all inclusion and exclusion criteria. Two researchers (C.B. and M.A.Jr.) made independent selections, and their results were compared to identify discrepancies. If the abstract contained insufficient information for a decision of inclusion or exclusion, the full article was obtained and reviewed before a final decision. Titles with no abstract available that suggested a relationship to the objectives of this review were selected to screen the full text. The reference lists of the retrieved articles were also hand searched for additional relevant publications that could have been missed in the databases.

A methodologic-quality scoring process was used to identify which selected studies would be most valuable. Our scoring process was a modified version of one previously used in a systematic review by Lagravère et al.[4] The full texts of articles selected for eligibility were assessed on the basis of study design, study measurements, and statistical analyses (Table III). When the article fulfilled satisfactorily 1 methodologic criterion, the maximum of the point was checked (1 or 2); when it partially fulfilled the criterion, half of a pointwas checked; and when it did not fulfill the methodologic criterion, 0 was checked. Before the assessment of the studies, 2 researchers (C.B. and M.A.Jr.) discussed all the criteria analyzed to reach consensus about their content. The most ambiguous topic was to define adequate descriptions of the population (item A, Table III) and the RME therapy (item G, Table III). In these 2 items, the criterion was considered fulfilled when all 3 selected aspects were described, and fulfilled partially when only 2 were described. No point was checked when just 1 aspect was described. Item C (sample size) was the only criterion with a maximum score of 2 points. It was scored as 2 points when both groups, treated and control, were larger than or equal to 30 subjects; when just 1 group was larger than or equal to 30 and the other was more than 20 and less than 30 subjects, 1.5 points was scored. When the sample was larger than or equal to 20 and less than 30 for both groups, 1 point was scored. When 1 group had less than 20 subjects, 0.5 point was scored. The methodologic-quality assessment scores ranged from 0 to 14 points. Studies were qualified as having high (score, >12), moderate (scores, ≥7 and ≤12), or low (score, < 7) methodologic quality.

RESULTS

A total of 232 titles or abstracts were identified in the electronic databases used (Fig). Duplicate records appearing in more than 1 database search were considered only once. From the titles, we excluded all records not related to the review topic, that used surgically assisted RME therapy, that evaluated other simultaneous treatments during expansion; that were not human studies, that evaluated systemically compromised subjects or cleft patients; and theses, annals, reviews, and case reports. From the 100 abstracts left, 15 fulfilled the

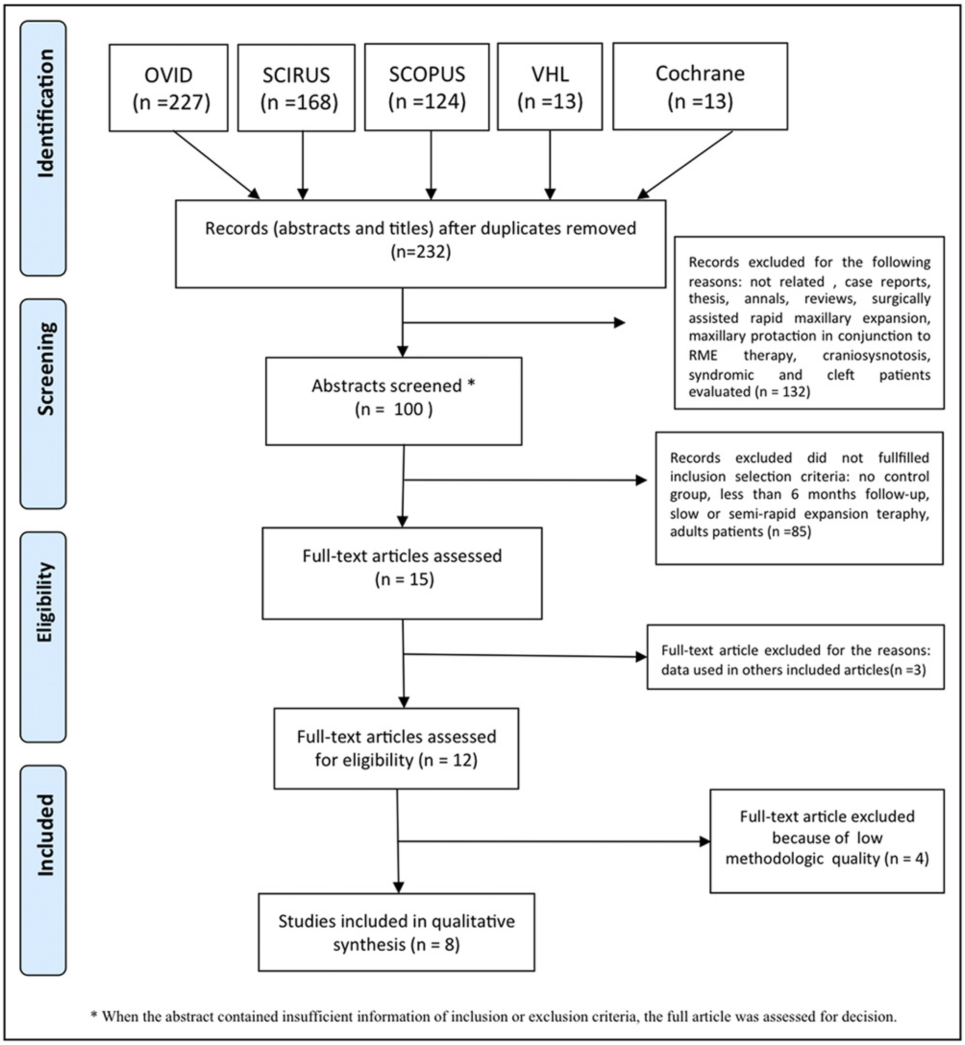

Fig. PRISMA flow diagram of the search results from the databases.

Table IV. Methodologic-quality scores of the selected articles

Authors	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*K*	*L*	*M*	*Total*	*Quality*
McGuinness and McDonald[22]	1	1	2	1	1	0	0.5	1	0	1	1	0	1	10.5	Moderate
Monini et al[23]	0.5	1	2	1	1	0	1	1	0	0	1	0.5	1	10	Moderate
Tecco et al[24]	1	1	1	1	1	1	1	1	0	0.5	1	0	0	9.5	Moderate
Baccetti et al[18]	0.5	1	1.5	1	0	0	1	1	0	1	1	1	0.5	9.5	Moderate
Cameron et al[28]	0.5	1	1.5	1	0	0	1	1	0	1	1	1	0.5	9.5	Moderate
Compradretti et al[19]	1	1	1	1	1	0	1	1	0	0	0.5	0.5	0.5	8.5	Moderate
Zhao et al[26]	1	1	1	0	0	0	1	1	0.5	1	1	0	0.5	8	Moderate
De Felippe et al[20]	1	1	1	1	0	0	0	1	0	1	0.5	0	0.5	7	Moderate
Altug-Atac et al[27]	1	1	0	1	0	0	0.5	1	0	1	1	0	0	6.5	Low
Chiari et al[29]	1	1	0	1	1	0	1	1	0	0	0.5	0	0	6.5	Low
Warren et al[25]	0.5	0	1	0	1	0	0.5	1	0	0	1	0	0	5	Low
Hartgerink et al[21]	0	0	1.5	0	1	0	0	1	0	0	1	0	0	4.5	Low

inclusion criteria, and the full texts were assessed.[17-31] Furthermore, 3 articles, those by Tecco et al,[17] Franchi et al,[30] and Hartgerink and Vig,[31] were excluded because the same data were reported in the finally selected articles: Tecco et al,[24] Cameron et al,[28] and Hartgerink et al,[21] respectively. The articles by Baccetti et al[18] and

Table V. Descriptions of the included studies

Authors	Participants: Total (female/male)	Participants: Mean age (range)	Participants: Brief medical history	Intervention RME (expander type, activation protocol, retention time)
McGuinness and McDonald [22]	39 (23/16)	10-16 years	General and dental health, no nasal obstruction history	Bonded expander; 2 turns per day (mean 3 weeks); no time retention given + orthodontic treatment
Monini et al[23]	38	7.85 years (5-10)	Primary snoring and nasal respiratory obstruction	Hyrax; 1 or 2 turns per day until overcorrection; 1 year
Tecco et al[24,*]	23 (only female)	8.1 years (8-15)	Reduced nasopharyngeal airway adeqacy (cephalometrically) and mouth breathing	R.E.P. (Dentaurum Italia s.r.l.); 4 turns (0.8 mm) on the first day followed by 2 turns per day until the required expansion was achieved; mean, 4.7 months
Cameron et al[28]	42 (25/17)	11.8 years	Not reported	Haas; 2 turns a day (0.5 mm) until 10.5 mm (mean, 3 weeks); mean 2 months + fixed orthodontic appliance
Baccetti et al[18,†]	ETG-29 (18/11) LTG-13 (10/3)	ETG -11 years LTG-13.6 years	Not reported	Haas; 2 turns a day (0.5 mm) until 10.5 mm (mean, 3 weeks); mean, 2 months + fixed orthodontic appliance
Compradretti et al[19]	27 (14/13)	9.5 years (5-13)	Presenting maxillary constriction and any cause for nasal obstruction was excluded	Hyrax; 2 turns a day (0.5 mm) during 2 weeks; 3 months
Zhao et al[26]	24 (18/6)	12.8 years (8.9-15.1)	Healthy	Hyrax; 1 or 2 turns per day until the required expansion with slight overcorrection; at least 3 months + fixed orthodontic appliance
De Felippe et al[20]	25 (14/11)	Initial: 13.16 years (8-16) Final: 18.28 years (13-22)	No history of nasal congestion and infection or cold during evaluation	Haas, hyrax, and bonded; 2 turns per day (50% of the sample), 1 turn per day (42%), and 1 turn every other day (8%), until 2 to 3 mm of overexpansion wasachieved; 3-6 months + full orthodontic treatment (95%)

*Some data were reported in the study of Tecco et al[17]; †Same sample used by Cameron et al[28] however, the treated group was divided into early treated group (*ETG*) and late treated group (*LTG*), and the control group was divided into early control group (*ECG*) and late control group (*LCG*).

Cameron et al[28] also used the same sample of subjects, but both studies were included because the authors ued different analyses. Then, 12 were assessed for eligibility (Table IV) and qualified according to Table III.[18-29] From these articles, 4 had low methodologic quality and were not considered.[21,25,27,29] Only 8 articles fulfilled all selection criteria and had adequate evidence to be considered in this systematic review.[18-20,22-24,26,28]

As shown in Table IV, all studies included were classified as having moderate evidence. None met all requirements in our specific methodologic scoring protocol. Only Tecco et al[24] stated the randomization of their sample. Blinding of the statistician was not reported in any studies, and only Zhao et al[26] had the examiner blinded. Samples larger than 30 children per group, treated and control, were used by McGuinness and McDonald[22] and Monini et al.[23] Baccetti et al[18] and Cameron et al[28] evaluated more than 30 children only in their treated groups and had 20 children in the groups without treatment; both scored 1.5 points for the sample-size requirement.

A summary of the participants, interventions, comparisons, and study design characteristics from each included study in the qualitative synthesis is shown in Table V. When specific data were necessary that were not specified in the article, the authors were contacted to obtain the required additional information.

Despite all the included studies that evaluated only subjects during growth periods, the mean initial chronologic age had the most heterogeneity between them. The range of the mean initial age was 7.85 (Monini et al[23]) to

Table V. Continued

Comparison (Subjects with no RME therapy)			Study design	
Total (female/male)	*Mean age (range)*	*Brief medical history*	*Follow-up (mean)*	*Evaluation method*
36 (24/12)	10-16 years	No orthodontic treatment	12 months	Lateral radiograph
50	Aimilar	Without nasal abnormalities and pathologic occlusions	12 months	RNM Lateral radiograph (13 patients)
22 (only female)	8.1 years (8-15)	Reduced nasopharyngeal airway adeqacy (cephalometrically) and mouth breathing; no orthodontic treatment	12 months	Lateral radiograph
20 (9/11)	11.8 years	No orthodontic treatment	At least 5 years	PA radiograph
ECG-11 (2/9) LCG- 9 (7/2)	ECG-11.25 years LCG-12.33 years	No orthodontic treatment	At least 5 years	PA radiograph
24 (16/8)	10.2 years (8-12)	Presenting maxillary constriction and any cause for nasal obstruction was excluded	11 months	RNM AR PA radiograph
24 (18/6)	12.8 years (8.6-15.8)	Orthodontic treatment	15 months	CBCT
25 (14/11)	Only compared the final data: 18.48 years (12-22)	No history of nasal congestion and infection or cold during evaluation; no orthodontic treatment	60 months	AR

13.16 (De Felippe et al[20]) years. Expander type, activation protocol, retention time, period that the expander was kept passively in mouth after the RME active phase also had variations between the studies. Basically, 4 expander types were used: hyrax, Haas, bonded, and R.E.P. (Dentaurum Italia s.r.l., Funo, Bologna, Italy). The most used protocol activation was 2 turns per day, with a slight overcorrection, and the retention time was 2 months (Cameron et al[28] and Baccetti et al[18]) to 1 year (Monini et al[23]).

The follow-up evaluation ranged from 11 months (Compradretti et al[19]) to 5 years (Cameron et al[28] and Baccetti et al[18]) after RME therapy. Only Zhao et al[26] evaluated the RME effects with CBCT. Lateral cephalometric radiographs were used by Monini et al,[23] Tecco et al,[24] and McGuinness and McDonald,[22] and PA radiographs were used by Compradretti et al[19] and Baccetti et al.[18] RMN evaluation was used by Monini et al[23] and Compradretti et al,[19] and AR was used by De Felippe et al[20] and Compradretti et al.[19] The only studies that used more than 1 evaluation method were those of Compradretti et al[19] (RMN, AR, and PA radiography) and Monini et al[23] (RMN and lateral radiography). The measurements, mean values, and outcomes from each article are shown in the tables according to the evaluation method used: radiographic in Table VI, CBCT in Table VII, and RMN and AR in Table VIII.

DISCUSSION

A significant increase in nasal cavity width immediately after RME was found in a previous meta-analysis,[13]

Table VI. Outcomes from the studies that used PA or lateral cephalometric radiographs as the measurement method

Authors	*Measurement method*	*Measurement*	*Mean measurement (P value)*	*Outcomes*
Compradretti et al[19]	PA	Nasal cavity width (Ln-Ln)*	Increased 2.2 mm (P = 0.001) Did not mention control group results	Increase in nasal cavity width was stable 11 months after RME
Cameron et al[28]	PA	Nasal cavity width (Ln-Ln)	Treated group increased 4.16 mm (P = 0.001); control increased 1.52 mm Changes greater than in control group (P <0.001)	Increase in nasal cavity width was maintained throughout 5 years of postexpansion.
Baccetti et al[18,†]	PA	Nasal cavity width (Ln-Ln)	ETG increased 4.5 mm; ECG increased 2.2 mm (P = 0.000) LTG increased 2.2 mm; LCG increased 0.7 mm (P = 0.011) Changes greater than control group (P <0.05)	ETG showed larger increase than in LTG
Monini et al[23]	Lateral	Posterior nasopharyngeal space: superior nasopharyngeal gradient (SNG) inferior nasopharyngeal gradient (ING)	SNG decreased in 70% (P = 0.02) and ING decreased in 77% (P = 0.008) of the patients Did not mention control group results	Posterior nasal space increase remained stable 12 months after RME
Tecco et al[24]	Lateral	Nasopharyngeal airway adequacy (pm-Ad 2)[‡] Craniocervical angulation[§]: SN/OPT°, SN/CVT°, PP/OPT°, PP/CVT°, MP/OPT°, MP/CVT°	Pm-Ad 2 increased 5.3 mm (P = 0.0001) SN/OPT decreased 5.1° (P = 0.0001) PP/OPT decreased 4.36° (P = 0.0001) MP/OPT decreased 5.12° (P = 0.0001) Mild correlation of Pm-Ad 2 increase and SN/OPT angle (r = 0.61, P <0.05) Changes greater than in control group (P <0.05)	Nasopharyngeal airway adequacy increased 6 months after RME and remained stable after 12 months
McGuinness and McDonald[22]	Lateral	Craniocervical angulation[§]: SN/OPT, SN/CVT, OPT/CVT, SN/VER, OPT/HOR, CVT/HOR	SN/VER decrease 3.14° (P = 0.005) OPT/HOR decrease 2.13° (P = 0.048) CVT/HOR decrease 2.55° (P = 0.025)	Indicates nasal airflow increased and nasal respiration improved 1 year after expansion

*Lateronasal (*Ln*), the most lateral point of the nasal cavity in a frontal view; *Ln-Ln*, distance between the right Ln and the left Ln landmarks; [†]The same sample used by Cameron et al[19] was analyzed individually in the early treated group (*ETG*), early control group (*ECG*), late treated group (*LTG*), and late control group (*LCG*); [‡]Approximate measure of the narrowest part of the nasopharyngeal airway; [§]*OPT*, upper segment of the cervical column is the line tangent to the posterior border of the odontoid process; *CVT*, middle segment of the cervical column is the line between the most inferoposterior point of the second cervical vertebra and that of the fourth cervical vertebra; *SN*, sella-nasion line; *PP*, palatal plane; *MP*, mandibular plane; *VER*, true vertical line; *HOR*, true horizontal line.

and its long-term results were confirmed in a previous systematic review.[14] However, this effect was not confirmed in a recent systematic review that evaluated the airway change only by means of AR.[15] Our systematic review focused on the long-term changes produced by RME on airway dimensions and functions. This included only controlled clinical studies with follow-ups of at least 6 months after the therapy, and that used measurement methods of RMN, AR, radiography, or CBCT. Because of the great complexity of airway anatomy and function, several measurement methods have different objectives and can complete each other to assess the real airway and breathing function changes.

PA radiography allows the evaluation of transverse changes in the nasal cavity. A mean nasal cavity width increase of 2.2 mm after RME therapy and long-term

Table VII. Outcome from the study that used CBCT as the measurement method

Authors	Measurement	Mean measurement (P value)	Outcome
Zhao et al[26]	Airway volume (cm^3): oropharyngeal, retropalatal, retroglossal Airway length (mm): oropharyngeal, retropalatal, retroglossal Minimum cross-sectional area (mm^2)	No difference in the absolute and percentage changes compared with controls ($P > 0.05$)	No evidence that RME enlarges the volume, length, and area of the airway

Table VIII. Outcomes from the studies that used RMN and AR as the measurement methods

Authors	Measurement method	Evaluation condition	Measurement	Mean measurement (P value)	Outcomes
Monini et al[23]	RMN	Basal condition Orthostatic and supine position	Total nasal flow Inspiratory NAR (INAR) Expiratory NAR (ENAR)	Total nasal flow increased ($P = 0.01$) INAR decreased 0.63 Pa ($P = 0.03$) in both positions ENAR decreased 0.39 Pa ($P = 0.04$) in supine position Immediate and late values were similar with high correlation rate Did not mention control group results	Improved nasal breathing and remained stable
Compradretti et al[19]	RMN	Basal condition and after nasal decongestant	Inspiratory NAR (INAR) Expiratory NAR (ENAR)	INAR decreased 0.11 Pa ($P > 0.05$) in basal condition ENAR decreased 0.14 Pa ($P > 0.05$) in basal condition INAR decreased 0.20 Pa ($P = 0.03$) after decongestion ENAR decreased 0.16 Pa ($P = 0.02$) after decongestion Changes greater than in control group ($P < 0.05$)	Improved nasal breathing and remained stable
	AR	Basal condition and after nasal decongestant	MCA (cm^2) NCV (cm^3)	MCA increased 0.15 ($P = 0.03$) in basal condition MCA increased 0.17 ($P = 0.02$) after decongestion NCV increased 0.65 ($P = 0.05$) in basal condition NCV increased 1.44 ($P = 0.003$) after decongestion Increase greater than in control group ($P < 0.05$)	Improved nasal breathing condition was stable after 11 months
De Felippe et al[20]	AR	Basal condition	NAR (cm H_20/L/sec) MCA (cm^2) NCV (cm^3)	NAR decreased 0.86 ($P = 0.001$) MCA increased 0.25 ($P < 0.001$) NCV increasad 3.96 ($P = 0.001$) No difference in values at the end with control group	Improved nasal breathing and remained stable after 9-12 months

maintenance of the results for 12 months[19] and 5 years[18] were reported in both studies that used this measurement method. Baccetti et al[18] divided the treated group and found that the lateronasal width showed a greater increase in the group treated before the peak of the pubertal growth spurt (2.3 mm) than in the group treated at or after the peak (1.5 mm), when compared with the control group. These findings confirmed that, when the midpalatal suture is opened in growing patients, the nasal cavity's lateral walls are also displaced apart, and this widening is stable over the long term. Transverse bone changes are more favorable when treatment is started before the pubertal growth peak, probably because less calcification of the craniofacial sutures promotes less resistance to splint the maxilla from adjacent structures.

The studies that used lateral radiographs to evaluate changes in head posture and verified nasopharyngeal airway size after RME found decreased craniocervical angulations associated with increased airway dimensions.[22-24] Tecco et al[24] were the only authors who randomized their subjects. The treated group had a significant increase in nasopharyngeal airway dimension (5.3 mm) compared with the control group (1.2 mm). This airway improvement occurred 6 months after RME and remained stable after 12 months of follow-up. The clinical significance of these findings is that RME causes a reduction in NAR, which results in a reduction of head elevation, suggesting improvement in nasal breathing. However, it is uncertain whether these changes represent clinically relevant magnitudes. The postural and morphologic changes remained stable, showing a long-term effect. One limitation of this kind of evaluation is that rotational or sideways components of cervical column curvature changes were not known because the examination was performed in the sagittal plane. This could have resulted in underestimation of the postural changes.

Although the frontal and lateral cephalometric radiographs in the selected studies were taken according to a standardized technique, the different structure superimpositions and image magnifications did not always allow accurate quantifications of the changes.[32] Zhao et al[26] was the only CBCT study included in the final selection. They compared absolute and percentage changes in the retropalatal and retroglossal airways after treatment and found no significant difference between the RME and the control matched pairs, although maxillary width increased significantly in the RME group. A possible confounding effect in this retrospective study was the absence of control over tongue position when the CBCT scans were taken. This limitation could have caused systematic measurement errors. In addition, a study comparing the reliability and the accuracy of software for measuring the airway volume from CBCT found highly reliable, but poor, accuracy.[33] There is no norm yet for airway volumes, perhaps because airway dimensions are extremely variable, depending on head posture and breathing stage. Further prospective studies providing control over these confounders should be performed to assess airway changes. CBCT requires the user's full knowledge to benefit from all of its advantages and resources.

Radiographic and CBCT images allow visualization of structural airway changes and can suggest associations with breathing functions by the results. However, these measuring methods did not attempt to quantify the function changes, such as NAR. The gold standard for nasal airflow measure is RMN.[34,35] It measures air pressure and rate of airflow during breathing, which are used to calculate NAR.[34] This evaluation is expensive and difficult to perform, but AR has the advantages of ease of use and minimal invasiveness.[36] It uses a reflected sound signal to measure minimal cross-sectional area (MCA) and nasal cavity volume (NCV).[37]

De Felippe et al[20] found, by means of AR evaluation under basal conditions, increases in the MCA and the NCV with a reduction of 34% of the NAR immediately after RME. These authors also observed stability of the results in a long-term follow-up (mean, 60 months after RME) and values comparable with those of subjects with normal nasal breathing conditions. Although it was stated that the basal condition during nasal cavity evaluation is more realistic when estimating anatomic-functional variability,[37] the use of a topical nasal decongestant was advocated to reduce the effects of the nasal mucosa cycle during the examinations.[36] The decongestant reduces a confounder effect of differing levels of congestion on the nasal mucosa, allowing measurement of individual nasal anatomy as opposed to the variable physiologic or pathologic state.

Compradretti et al[19] assessed nasal airways by means of RMM, AR, and PA radiography. During the AR evaluation, they found greater increases in MCA and NCV in the treated group than in the control group in basal conditions and after the use of a nasal decongestant. In the RMN assessment, the NAR had significant decreases during inspiration and expiration only after use of the decongestant. This improvement in nasal breathing after RME was a consequence of the significant nasal cavity expansion confirmed on the PA cephalogram. This finding remained stable 11 months after the therapy. Monini et al[23] found greater reductions in NAR even under basal conditions during RMN examinations.

The widening of the nasal cavity base[18,19,30] found after midpalatal suture opening in growing patients, especially during the prepubertal and pubertal growth periods, allowed the reduction in NAR[5,19,20,23] by the increases in MCA[5,19,20] and volume.[19] These nasal modifications are favorable to improve the respiratory pattern. In addition, the significant improvement of total nasal airflow, which remained stable 1 year after expansion, along with the increase in posterior nasal space assessed with lateral radiographs, suggests a fundamental role of RME in the treatment of not only maxillary constriction but also severe constrictions of the nasopharyngeal spaces associated with oral breathing, snoring, and obstructive sleep apnea syndrome in childhood.[17,23,24]

Although the mean increase in the nasal cavity dimension was small, the RMN provided moderate evidence of improved nasal breathing. The resulting change decreases airway resistance, improving natural physiologic function. However, it is difficult for clinicians to define whether these effects are clinical or merely statistically significant. Some studies reported that the decrease of nasal resistance values after expansion resulted in a more nasal respiratory pattern, reducing mouth breathing.[38,39] Gray[40] investigated the medical results of RME in 310 patients and found that over 80% of them changed their breathing pattern from mouth to nasal. Another study reported that most patients found that their nasal breathing was improved after RME, and those who perceived no change were generally patients whose NAR was initially nearer to normal, and the change was small.[36] Well-designed clinical trials evaluating patients' perceptions of their nasal respiratory function before and after RME therapy are essential to determine whether these changes are clinically significant. In addition, because of the wide variability of individual responses, this orthopedic therapy is not recommended alone if the main purpose is to improve nasal breathing. An interdisciplinary orthodontist-otorhinolaryngologist approach seems to be more rational to improve nasal breathing.

Differences in the long-term responses could be attributed to individual patient variations and to the RME protocol used. None of the studies could be used for a meta-analysis because of differences in mean initial ages, expander types, activation protocols, amounts of expansion, retention periods, and evaluation methods between the studies, making them not ideal to combine. The intervention timing seemed to be the most important variable for predicting RME orthopedics outcomes. Despite all the studies that evaluated patients during their growth periods, it is well known that skeletal maturation has great individual variations.

The maximum score used to qualify the included articles was not achieved by any of the studies, showing their methodologic deficiencies. Lack of a blinded statistician was common for all articles; only one had the measurements made by a blinded operator.[26] Randomization of the children in the treated and control groups was performed in just 1 study.[17] Therefore, the scientific evidence in this systematic review should be interpreted carefully. All results are restricted to patients who had RME therapy during the growth period (5-16 years of chronologic age) to correct a transverse maxillary deficiency.

CONCLUSIONS

There is a moderate level of evidence that RME therapy during the growth period causes increases in nasal cavity width and in the posterior nasal airway, associated with reduced NAR and increased total nasal flow. The stability of the results can be expected for at least 11 months after the orthopedic therapy. All changes in airway dimensions and functions might improve the conditions for nasal breathing but cannot be indicated only for this purpose. Further randomized and blinded controlled studies are needed to strengthen the evidence of the long-term RME effects on airway dimensions and functions.

REFERENCES

1. Haas AJ. The treatment of maxillary deficiency by opening the midpalatal suture. Angle Orthod 1965;35:200-17.
2. Haas AJ. Palatal expansion: just the beginning of dentofacial orthopedics. Am J Orthod 1970;57:219-55.
3. Haas AJ. Long-term posttreatment evaluation of rapid palatal expansion. Angle Orthod 1980;50:189-217.
4. Lagravère MO, Major PW, Flores-Mir C. Long-term dental arch changes after rapid maxillary expansion treatment: a systematic review. Angle Orthod 2005;75:155-61.
5. De Felippe NLO, Da Silveira AC, Viana G, Kusnoto B, Smith B, Evans CA. Relationship between rapid maxillary expansion and nasal cavity size and airway resistance: short- and long-term effects. Am J Orthod Dentofacial Orthop 2008;134:370-82.
6. Ricketts RM. Respiratory obstruction syndrome. Am J Orthod 1968;54:495-503.
7. Ozbek MM, Memikoglu UTT, Altug-Atac AT, Lowe AA. Stability of maxillary expansion and tongue posture. Angle Orthod 2009;79:214-20.
8. Matsumoto MAN, Itikawa CE, Valera FCP, Faria G, Alnselmo-Lima WT. Long-term effects of rapid maxillary expansion on nasal area and nasal airway resistance. Am J Rhinol Allergy 2010;24:161-5.
9. Doruk C, Sökücü O, Biçakçi AA, Yilmaz U, Tas F. Comparison of nasal volume changes during rapid maxillary expansion using acoustic rhinometry and computed tomography. Eur J Orthod 2007;29:251-5.
10. Clement PA, Gordts F. Consensus report on acoustic rhinometry and rhinomanometry. Rhinology 2005;43:169-79.
11. Alves P, Zhao L, O'Gara M, Patel P, Bolognese AM. Three-dimensional cephalometric study of upper airway space in skeletal Class II and III healthy patients. J Craniofac Surg 2008;19:1497-507.
12. McNamara JA. Maxillary transverse deficiency. Am J Orthod Dentofacial Orthop 2000;117:567-70.
13. Lagravère MO, Heo G, Major PW, Flores-Mir C. Meta-analysis of immediate changes with rapid maxxillary expansion treatment. J Am Dent Assoc 2006;137:44-53.
14. Lagravère MO, Major PW, Flores-Mir C. Long-term skeletal changes with rapid maxillary expansion: a systematic review. Angle Orthod 2005;75:1046-52.
15. Gordon JM, Rosenblatt M, Witmans M, Carey JP, Heo G, Major PW, et al. Rapid palatal expansion effects on nasal airway dimensions as measured by acoustic rhinometry. Angle Orthod 2009;79:1000-7.
16. Turpin DL. Updated CONSORT and PRISMA documents now available. Am J Orthod Dentofacial Orthop 2010;137:721-2.
17. Tecco S, Festa F, Tete S, Longhi V, D'Attilio M. Changes in head posture after rapid maxillary expansion in mouth-breathing girls: a controlled study. Angle Orthod 2005;75:171-6.

18. Baccetti T, Franchi L, Cameron CG, McNamara JA. Treatment timing for rapid maxillary expansion. Angle Orthod 2001;71:343-50.
19. Compadretti GC, Tasca I, Bonetti GA. Nasal airway measurements in children treated by rapid maxillary expansion. Am J Rhinology 2006;20:385-93.
20. De Felippe NLO, Bhushan N, Da Silveira AC, Viana G, Smith B. Long-term effects of orthodontic therapy on the maxillary dental arch and nasal cavity. Am J Orthod Dentofacial Orthop 2009;136:490.e1-8.
21. Hartgerink DV, Vig PS, Orth D, Abbott DW. The effect of rapid maxillary expansion on nasal airway resistance. Am J Orthod Dentofacial Orthop 1987;92:381-9.
22. McGuinness NJ, McDonald JP. Changes in natural head position observed immediately and one year after rapid maxillary expansion. Eur J Orthod 2006;28:126-34.
23. Monini S, Malagola C, Villa MP, Tripodi C, Tarentini S, Malagnino I, et al. Rapid maxillary expansion for the treatment of nasal obstruction in children younger than 12 years. Arch Otolaryngol Head Neck Surg 2009;135:22-7.
24. Tecco S, Caputi S, Festa F. Evaluation of cervical posture following palatal expansion: a 12-month follow-up controlled study. Eur J Orthod 2007;29:45-51.
25. Warren DW, Hershey G, Turvey T, Hinton VA, Hairfield WM. The nasal airway following maxillary expansion. Am J Orthod Dentofacial Orthop 1987;91:111-6.
26. 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(Supp):S71-8.
27. Altug-Atac AT, Atac MS, Kurt G, Karasud HA. Changes in nasal structures following orthopaedic and surgically assisted rapid maxillary expansion. Int J Oral Maxillofac Surg 2010;39:129-35.
28. Cameron CG, Franchi L, Baccetti T, McNamara JA. Long-term effects of rapid maxillary expansion: a posteroanterior cephalometric evaluation. Am J Orthod Dentofacial Orthop 2002;121:129-35.
29. Chiari S, Romsdorfer P, Swoboda H, Bantleon H, Freudenthaler J. Effects of rapid maxillary expansion on the airways and ears—a pilot study. Eur J Orthod 2009;31:135-41.
30. Franchi L, Baccetti T, Cameron CG, Kutcipal EA, McNamara JA Jr. Thin-plate spline analysis of short- and long-term effects of rapid maxillary expansion. Eur J Orthod 2002;24:143-50.
31. Hartgerink DV, Vig PS. Lower anterior face height and lip incompetence do not predict nasal airway obstruction. Angle Orthod 1989;59:17-23.
32. Broadbent BH. A new x-ray technique and its application to orthodontia. Angle Orthod 1931;1:45-66.
33. El H, Palomo JM. Measuring the airway in 3 dimensions: a reliability and accuracy study. Am J Orthod Dentofacial Orthop 2010;137(Supp):S50.e1-9.
34. Jones A, Lancer M. Rhinomanometry. Clin Otolaryngol 1987;12:233.
35. Neeley WW II, Edgin WA, Gonzales DA. A review of the effects of expansion of the nasal base on nasal airflow and resistance. J Oral Maxillofac Surg 2007;65:1174-9.
36. Timms DJ. The effect of rapid maxillary expansion on nasal airway resistance. Br J Orthod 1986;13:221-8.
37. Roithmann R, Cole P, Chapnik J, Shpirer I, Hoffstein V, Zamel N. Acoustic rhinometry in the evaluation of nasal obstruction. Laryngoscope 1995;105:275-81.
38. White BC, Woodside DG, Cole P. The effect of rapid maxillary expansion on nasal airway resistance. J Otolaryngol 1989;18:137-43.
39. Gray LP. Rapid maxillary expansion and impaired nasal respiration. Ear Nose Throat J 1987;66:248-51.
40. Gray LP. Results of 310 cases of rapid maxillary expansion selected for medical reasons. J Laryngol Otol 1975;89:601-14.