Impact of rapid maxillary expansion on mouth-breathing children and adolescents: A systematic review

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Abstract
Background: Rapid maxillary expansion (RME) is an orthodontic procedure used to correct transverse maxillary deficiency. Due to the anatomical relationship between the palate and the nasal cavity, RME promotes an increase in nasal dimensions, which should hypothetically improve nasal respiratory function. Objective: This review aimed to systematically verify studies that assessed the effects of RME on nasal patency in mouth-breathing children and adolescents.

Material and Methods: An electronic search was performed in the MEDLINE databases via OVID, Scopus and EMBASE. The terms were: “children and adolescents”, “rapid maxillary expansion” and “mouth breathing”. The search was conducted in October 2019, according to the criteria of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). The assessment of the quality of the studies was conducted by two evaluators, using the Fowkes & Fulton’s guidelines for critical appraisal of medical research.

Results: 475 titles were identified and 18 articles were selected. All of them showed high methodological quality, but without randomized clinical trials. The instruments evaluated were: teleradiography, frontal postero-anterior radiography, computed tomography, acoustic rhinometry and computed rhinomanometry.

Conclusions: This review shows that RME promotes the enlargement of dental arches and of the nasal and maxillary structures, with improved mouth breathing in the short term. However, its long-term benefits could not be proved so far. More robust results of the effectiveness of RME in mouth breathing can be achieved with meta-analysis studies, with a consensual definition of the long-term follow-up period after RME.

Key words: Child, adolescent, maxillary expansion, palatal expansion, mouth breathing.
Introduction
Mouth-breathing children often have a narrow upper arch with high palate. These reduced nasal and maxillary transverse dimensions may be related to the increase in nasal flow resistance, observed in these children (1). Transverse maxillary deficiency (TMD), also called maxillary atresia, when corrected at an early stage, improves the child’s craniofacial and stomatognathic development, with beneficial effects on nasal breathing (2,3,4). The most frequently used orthodontic procedure for the correction of TMD is the rapid maxillary expansion (RME), which, through a fixed orthodontic expander positioned on the palate, causes the opening of the median palatal suture (5). Due to the anatomical relationship between the palate and the nasal cavity, RME promotes an increase in nasal dimensions, which should hypothetically improve nasal respiratory function (6-8).
Radiographic exams have proved the effects of RME on dental, nasal and maxillary structures (9). Three-dimensional CT imaging techniques have been increasingly used, with more accurate measurements, without overlapping structures of two-dimensional radiographs, but with a larger amount of radiation (10). International protocols are still being researched with the aim to optimize the amount of radiation used in volumetric cone-beam computed tomography (CBCT), especially in children and adolescents (11).
Several authors (12-14) report the immediate improvement in mouth breathing due to the increase in the nasal base with RME. However, some studies have not provided evidence of its stability in the long term (15,16). The evaluation of the respiratory function of the functional changes of children and adolescents mouth breathers (MB) allows these patients to be followed up, based on medical evaluations and complementary exams. The importance of evaluating these individuals is emphasized, with the possibility of respiratory function being reestablished with the early performance of ERM.
The present systematic review aimed to verify the effects of RME in MB (children and adolescents) on naso-maxillary structures and on nasal respiratory function, as well as to verify if RME remains unchanged in the long term.

Material and Methods
-Search strategy
The search for scientific articles was conducted using the MEDLINE databases via Ovid, Scopus and EMBASE. The search included descriptors and their variant forms based on the Medical Subject Headings (MeSH), DeCs (Health Descriptors) and Emtree (Embase Subject Headings) that identified “rapid maxillary expansion”, “mouth breathing” and “children and adolescents”. Studies in English and French were selected, without date restrictions. The search was carried out from November 2018 to October 2019. The detailed search strategy with the terms used can be found in the APPENDIX.
-Study selection
The systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) criteria (17). Two independent evaluators conducted the selection of the studies according to pre-established criteria. In case of disagreement, a third evaluator was consulted for a final decision (Fig. 1). At first, the duplicates were selected and removed, and then, the titles and abstracts were screened. Subsequently, the remaining articles were read in full, following the inclusion and exclusion criteria described below. Ultimately, a manual search of the references of the selected studies was performed.
-Inclusion and exclusion criteria
The following inclusion criteria were used: (i) original studies; (ii) studies with mouth-breathing children and adolescents, which evaluated the effects of mouth breathing on nasal respiratory function using RME; (iii) cohort, controlled or randomized longitudinal studies; and (iv) studies published in full in English or French.
The following exclusion criteria were used: (i) book chapters, theses, dissertations, retrospective studies, editorials, letters, abstracts, comments, editorials, presentations in congress, symposia, seminars, round table and debates, post scripts, patents, case reports and case series; (ii) studies that were not available in full on the internet even after contacting the authors; (iii) systematic reviews, literature reviews or meta-analyses; (iv) qualitative studies; (v) studies in which the RME procedure was performed only on nasal breathers and not on mouth breathers; (vi) studies without a diagnosis of nasal breathing pattern; (vii) studies without assessing nasal respiratory function before and after RME; (viii) studies that did not perform RME; and (ix) studies that included adult populations.
-Data extraction
The following data were extracted from the selected studies: nationality, study design, sample size, age and sex of the study group and the control group and instruments evaluated (Table 1, 1 cont). More detailed information such as objective of the study, main results and conclusions were summarized in Table 2, 2 cont., 2 cont.-1, 2 cont.-2.
-Evaluation of Methodological Quality of Studies
The quality of the studies was assessed by two evaluators, using the guidelines for appraisal of medical research proposed by Fowkes & Fulton (18). The questions associated with the evaluated parameters were scored as major (++), minor (+), absent (0) or not applicable (NA).
Each study received an initial score of 46 points, with one parameter subtracted from each parameter (+) and two points from each parameter scored with (++). After this process, the evaluators proceeded to the final score, to classify the studies as: low quality (0–14), middle quality (15–30) and high quality (31–46) (Table 3).
All studies analyzed in this systematic review were classified as controlled clinical trials, as they are experimental studies that used the RME orthodontic intervention (Table I). Fowkes and Fulton (16) proposes that in this type of study the results of the treatment group should be compared with another group with similar characteristics that have not received the intervention. Thus, the studies that did not include any comparison group received the score (++) in this first stage of assessment of methodological quality. Studies with a divergent comparison group of mouth breathers with TMD received a score (+).

Studies with a wide age range, which did not separately analyze groups of children with groups of adolescents, received a score (++) in the item source of sample. Articles with less than 20 individuals and without a sample size calculation received a score (++) in the sample size item.

**Results**

**-Search and Selection**

This systematic review identified 490 titles in the databases, making a total of 18 articles for this systematic review (Fig. 1).

The abstract screening process excluded articles that did not meet the pre-established criteria. For the full articles, one study was excluded as the language did not meet the eligibility criteria: the abstract was in English, but the full article was in Chinese. Other studies were also excluded due to inadequate methodology: retrospective studies, absence of diagnosis of mouth breathing, sample without history of respiratory diseases of the upper airways, nasal hypertrophy or respiratory allergies, absence of nasal respiratory function assessment after RME. Ultimately, one article was excluded because it included adults.
### Table 1: Analysis of samples, orthodontic appliances and instruments used in each study.

| Study                  | Country | Design               | Population | N   | Age in years (a) | Orthodontic Appliances | Instruments                                      |
|------------------------|---------|----------------------|------------|-----|------------------|------------------------|--------------------------------------------------|
| Helal et al. 2019 (27) | USA     | Controlled Trial     | MB         | 91  | 5-13a. mean=7.6a | Bonded Hyrax Expander  | Pediatric Sleep Questionnaire                     |
| Badreddine et al. 2018 (2) | Brazil | Controlled Trial     | MB         | 39  | 6.5-14.7a. mean=9.7±2.28a | Hyrax | Computed tomography                               |
|                        |         |                      |            |     |                  |                        |                                                  |
|                        |         |                      |            |     |                  |                        |                                                  |
|                        |         |                      |            |     |                  |                        |                                                  |
| Cappellette et al. 2017 (3) | Brazil | Controlled Trial     | MB         | 23  | 6.4-14.2a. mean=9.6±2.3a | Hyrax | Computed tomography                               |
|                        |         |                      |            |     |                  |                        |                                                  |
|                        |         |                      |            |     |                  |                        |                                                  |
| Cappellette et al. 2017 (12) | Brazil | Controlled Trial     | MB         | 61  | 6.5-13.1a. mean=9.6a | Hyrax | Postero-anterior radiography                      |
|                        |         |                      |            |     |                  |                        |                                                  |
| Izuka et al. 2015 (6)  | Brazil  | Controlled Trial     | MB         | 25  | 6-13a. mean=10.5±2.2a | Modified Biedermann | Cone-beam tomography and Questionnaire           |
|                        |         |                      |            |     |                  |                        |                                                  |
|                        |         |                      |            |     |                  |                        |                                                  |
| Itikawa et al. 2012 (21) | Brazil | Longitudinal Controlled Trial | MB | 29  | 7-10a            | Hass | Postero-anterior radiography, acoustic rhinometry and active anterior computed rhinomanometry |
|                        |         |                      |            |     |                  |                        |                                                  |
|                        |         |                      |            |     |                  |                        |                                                  |
| Pereira et al. 2012 (7) | Brazil  | Longitudinal Controlled Trial | MB | Group A: 20 | 6-12a | Hyrax | Postero-anterior radiography and cephalometric analysis |
|                        |         |                      |            |     |                  |                        |                                                  |
|                        |         |                      |            |     |                  |                        |                                                  |
| Torre et al. 2012 (14) | Spain   | Longitudinal Controlled Trial | MB | 44  | mean=10.57a | Hyrax | Orthodontic model analysis and peak inspiratory nasal flow |
|                        |         |                      |            |     |                  |                        |                                                  |
|                        |         |                      |            |     |                  |                        |                                                  |
| Langer et al. 2011 (15) | Brazil  | Longitudinal Controlled Trial | MB | 25  | 7.10a, mean=8.2a | Modified Hass | Active anterior computed rhinomanometry and cephalometric analysis |
|                        |         |                      |            |     |                  |                        |                                                  |
| Matsumoto et al. 2010 (16) | Brazil | Longitudinal Controlled Trial | MB | 27  | 7.10a           | Modified Hass | Active anterior computed rhinomanometry, acoustic rhinometry and postero-anterior radiography |

- MB: Maxillary Expansion
- NB: Maxillary Closure
**Table 1 cont.:** Analysis of samples, orthodontic appliances and instruments used in each study.

| Study                          | Country     | Study Design          | Grouping/Inclusion Criteria                                                                 | Sample Size | Age | Orthodontic Model | Instruments                                                                 |
|--------------------------------|-------------|-----------------------|-------------------------------------------------------------------------------------------|-------------|-----|------------------|------------------------------------------------------------------------------|
| Monini et al. 2009             | Italy       | Longitudinal Controlled Trial | MB 65, NB 50 controls without TMD                                                         | 5-10a, mean=7,85 ± 2,15a |     | Modified Hyrax   | Cephalometric analysis and active anterior computed rhinomanometry          |
| Giuca et al. 2009              | Italy       | Longitudinal Controlled Trial | MB without allergies 17                                                                 | 6-12a       |     | Modified Hyrax   | Cephalometric analysis, postero-anterior radiography and active anterior computed rhinomanometry |
| Cappellette et al. 2008        | Brazil      | Controlled Trial      | MB 50                                                                                     | 4-14a       |     | Modified Biedermann | Acoustic rhinometry                                                         |
| Cozza et al. 2007              | Italy       | Controlled Trial      | MB with hearing loss due to middle ear otitis 24                                            | 6-8a, mean=7a |     | Butterfly Expander | Orthodontic model analysis, audiometry, acoustic rhinometry and impedance |
| Compadretti et al. 2006        | Italy       | Longitudinal Controlled Trial | MB 27, NB 24 controls without TMD                                                         | 5-13a, mean=9,5 ± 2,1a |     | Hynax            | Active anterior computed rhinomanometry, acoustic rhinometry. Postero-anterior radiography was performed in 15 patients |
| Compadretti et al. 2006        | Italy       | Longitudinal Controlled Trial | MB with non-allergic deviated septum 14                                                   | 7-10a, mean=8,2a |     | Hynax            | Acoustic rhinometry and postero-anterior radiography                         |
| Enoki et al. 2006              | Brazil      | Longitudinal Controlled Trial | MB 29                                                                                     | 7-10a       |     | Hass              | Cephalometric analysis and acoustic rhinometry                               |
| Pirelli et al. 2005            | Italy       | Longitudinal Controlled Trial | MB with snoring and sleep apnea 42                                                         | 6-13a, mean=7,3a |     | Modified Hyrax   | Audiometry, tympanometry, active anterior computed rhinomanometry, daytime sleepiness questionnaire and polysomnography |

Note: MB – mouth breathers; NB – nasal breathers; RME – rapid maxillary expansion; TMD – transverse maxillary deficiency.
| Study                        | Objective                                                                 | Variables                                                                 | Follow-up period                      | Main findings                                                                 | Conclusions                                                                 |
|-----------------------------|---------------------------------------------------------------------------|---------------------------------------------------------------------------|---------------------------------------|-------------------------------------------------------------------------------|-------------------------------------------------------------------------------|
| Helal N et al. 2019 (27)    | To investigate parents’ perceptions of breathing pattern changes after their children had undergone RME | 1) sleep apnea and breathing patterns, (2) sleep quality and fatigue (3) behavior | Pre-RME and 6 months after RME        | SC: The increase in nasal area assessed by CBCT was 4.1mm², analyzed in only six children FC: The symptoms of mouth breathing perceived by the parents decreased by 31.5% | Parents noticed improvement in sleep quality and breathing patterns with RME |
| Badreddine et al. 2018 (2)  | To evaluate effects of RME on the skeletal and soft tissue structures in MB | CT: Nasal height and width measurements of bone and soft tissues of the nose | Pre-RME and 3 months after RME       | SC: Significant increases in all the skeletal and soft tissue variables and width of the piriform aperture when compared with the control group | RME caused alterations in skeletal and soft tissue structures in the short term |
| Cappellette et al. 2017 (3) | To evaluate the volumetric changes of the nasomaxillary complex in MB with RME | CT: Nasomaxillary, nasal, oropharyngeal and maxillary sinus volumes | Pre-RME and 3 months after RME      | SC: The experimental group had a significant increase in the variables analyzed in comparison with the control group | RME caused volumetric increases in the nasal cavity, oropharynx and maxillary sinuses |
| Cappellette et al. 2017 (12) | To evaluate the effects of RME on the skeletal dimensions of the nasal cavity and to compare the differences between males and females | OMA: intermolar distance; PAR: nasal height, nasal and maxillary widths | Pre-RME and 3 months after RME       | SC: Increases in all linear maxillary measurements and nasal cavity dimensions | RME promoted increases in nasal cavity volume. Nasal transverse alterations were not significant in association with sex |
| Izuka et al. 2015 (6)       | To assess short-term changes in the upper airways and quality of life in MB after RME | CBCT: nasal base widths; volume of the nasopharynx and oropharynx airways; QLQ | Pre-RME and immediately after RME | SC: Increases in the width of the nasal floor, volumes of the nasopharynx and nasal cavities FC:QLQ indicated improvement in patients’ quality of life after RME | RME promoted a significant dimensional increase in the nasal cavities and nasopharynx and improved the patients’ quality of life |
Table 2 cont.: Analysis of objectives, variables, follow-up period, main results and conclusions.

| Study               | Objective                                                                 | Variables                                                                 | Follow-up Period                                                                 | Main Results                                                                                   | Conclusion                                                                                     |
|---------------------|---------------------------------------------------------------------------|---------------------------------------------------------------------------|----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|
| Itikawa et al. 2012 | To assess the effects of RME on nasal cavity dimensions and facial        | PAR: nasal width, intermaxillary and interzygomatic distances; CR: inspiratory and expiratory nasal resistance; AR: MCA1; MCA2 | Pre-RME, immediately after RME and 90 days after RME | SC: Increases in the dimensions of the nasal cavity and jaw bone. There were no significant differences in the nasal area using AR FC: CR showed a decrease in nasal resistance after RME | RME increased the maxillary and nasal bone area, but did not improve nasal resistance.       |
|                     | morphology using AR and CR                                               |                                                                           |                                                                                  |                                                                                               |                                                                                               |
|                     |                                                                           |                                                                           |                                                                                  |                                                                                               |                                                                                               |
| Pereira et al. 2012 | To observe craniofacial changes after adenotonsillectomy and to verify   | PAR: nasal and intermaxillary widths; CM: cephalometric measurements       | Pre-RME and 14 months after adenotonsillectomy                                  | SC: Adenotonsillectomy balanced transversal, sagittal and vertical growth in both groups, and was more effective in the group undergoing combined treatment (RME and Adenotonsillectomy) | Adenotonsillectomy improved facial growth in children with obstructive hypertrophy, being more effective when associated with RME |
|                     | the importance of adding RME to treatment                                |                                                                           |                                                                                  |                                                                                               |                                                                                               |
|                     |                                                                           |                                                                           |                                                                                  |                                                                                               |                                                                                               |
| Torre et al. 2012   | To analyze changes in nasal airflow after RME                            | OMA: intercanine, premolar and intermolar widths; PINF: peak inspiratory nasal flow | Pre-RME, 6 after RME and 12 months after RME                                    | SC: Increases in maxillary widths. FC: Six months after RME, there was a significant improvement in PINF in the RME group in relation to control | Nasal airflow improved in mouth-breathing children, six months and one year after RME        |
|                     |                                                                           |                                                                           |                                                                                  |                                                                                               |                                                                                               |
|                     |                                                                           |                                                                           |                                                                                  |                                                                                               |                                                                                               |
| Langer et al. 2011  | To assess the effects of RME on the dimension of the nasopharyngeal space | CM: nasopharyngeal space; CR: inspiratory and expiratory nasal resistance | Pre-RME, immediately after RME, 90 days after RME and 30 months after RME       | SC: Differences in the nasopharyngeal area observed only in 30 months could be explained by facial growth, and not because of the RME FC: Decreased nasal resistance immediately after RME, without remaining stable 30 months after RME | RME did not interfere with nasal resistance and nasopharyngeal area in the long-term evaluation |
|                     | and its relationship with nasal resistance                              |                                                                           |                                                                                  |                                                                                               |                                                                                               |
Table 2 cont.-1: Analysis of objectives, variables, follow-up period, main results and conclusions.

| Study                  | Objective                                                                 | Variables                                                                 | Follow-up Period | Main Results                                                                                               | Conclusion                                                                 |
|-----------------------|---------------------------------------------------------------------------|---------------------------------------------------------------------------|------------------|------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------|
| Matsumoto et al. 2010 (16) | To assess the effects of RME in the nasal cavity using AR and CR and to determine nasal and maxillary widths 30 months after RME. | PAR: nasal width and interzygomatic distance; CR: inspiratory and expiratory nasal resistance; AR: MCA1 and MCA2 | Pre-RME, immediately after RME, 90 days after RME and 30 months after RME | SC: Increased nasal and maxillary widths. AR values did not show any difference between the evaluation times after RME | The decrease in nasal resistance in 90 days did not remain stable in the period of 30 months after RME |
| Monini et al. 2009 (13) | To assess the effects of RME on nasal flow and nasal resistance and correlate with anterior and/or posterior nasal obstruction. | Inspiratory and expiratory nasal pressure; nasal flow in the standing and supine positions | Pre-RME, immediately after RME and 1 year after RME | FC: Improvement of nasal flow and nasal resistance in supine position. Less noticeable changes were observed in isolated forms of obstruction in the standing position | RME was efficient in improving nasal breathing due to enlargement in the nasopharyngeal cavity |
| Giuca et al. 2009 (25) | To assess the relationship between crossbite and upper airway permeability, and to observe cephalometric changes in the rhinopharyngeal space after RME. | CM: Lateral analyses of Ricketts, Woodside, Linder-Aronson and Lundstrom; PAR; CR: inspiratory flow and resistance | CM: Pre-RME, 6 and 12 months after RME; CR: Pre-RME and 12 months after RME | SC: CM showed an increase in the rhinopharynx and the PAR showed an increase in the nasal dimension | FC: Three children had improved nasal flow and resistance, six children showed no changes and there was a worsening of nasal breathing in eight children. The enlargement in the nasal structures did not correspond to the improvement in airway resistance. |
| Cappellette et al. 2008 (19) | To analyze possible increases in nasal dimensions after RME using AR | AR: MCA1, MCA2, VOL1 and VOL2 | Pre-RME, immediately after RME | SC: Increase in most variables of nasal area and volume after RME within the treatment group, except MCA1 and VOL2 in the left nostril. Increase in VOL2 only in the right nostril after RME when compared to the control group | Children with transverse maxillary deficiency, undergoing RME had a longitudinal maxillary and alveolar arch enlargement, associated with enlarged nasal dimensions |
### Table 2 cont.-2: Analysis of objectives, variables, follow-up period, main results and conclusions.

| Cozza et al. 2007 (24) | To investigate MB with atypical chewing, the effects of RME on inspiratory nasal resistance and hearing loss | OMA: intercanine and intermolar distances, maxillary depths | Pre-RME, immediately after RME | SC: increases in nasal cavity width and in transverse dimension of the upper arch. FC: Reduced nasal resistance, increased nasal flow and improved hearing loss | RME promoted improvement in nasal resistance and hearing loss |

| Compadretti et al. 2006 (23) | To assess the effects of RME using AR, CR and cephalometry. | PAR: nasal width, intermaxillary and interzygomatic distances; CR: inspiratory and expiratory nasal resistance; AR: MCA, VOL | Pre-RME and 12 months after RME | SC: Significant increase in nasal areas and volumes, nasal and intermolar distances FC: Significant reduction in inspiratory nasal resistance | RME was an effective procedure in increasing nasal width and improving mouth breathing |

| Compadretti et al. 2006 (22) | To assess the effects of RME on the nasal geography using AR | AR: MCA; PAR: nasal width and intermaxillary distance | AR: Pre-RME and 12 months after RME; PR: Pre-RME and 3 months after RME | SC: Increase in maxillary width in all patients. Rhinometric and cephalometric measurements showed an increase in the total decongested nasal volume and in the width of the nasal cavity. Only eight children became nasal breathers | RME promoted significant increases in nasal volumes and maxillary width. However, the improvement in breathing pattern remained debated |

| Enoki et al. 2006 (20) | To assess the effects of RME on the nasal cavity using AR and CR | AR: MCA1, MCA2; CR: inspiratory and expiratory resistance | Pre-RME, immediately after RME and 90 days after RME | SC: There was no difference in the nasal area between the periods analyzed FC: There was statistically significant reduction in nasal resistance after the expansion | RME lessened nasal resistance, although there was no difference in nasal geometry in AR |

| Pirelli et al. 2005 (26) | To assess whether RME can improve patency of nasal airway and OSAS | PAR: nasal, intermaxillary and intermolar widths; CBCT; Polysomnography; AR | Pre-RME, 30 days and 4 months after RME | SC: RME enlarged the nasal fossa and released the septum FC: RME improved the nasal air flow and the OSAS | RME intervention was effective in children affected by OSAS, without any other obvious upper airway obstruction |

**Note:** AR – acoustic rhinometry; CBCT – cone-beam computed tomography; CM – cephalometric measurements performed with teleradiography; CR – active anterior computed rhinomanometry; CT – computed tomography; FC – functional changes; MB – mouth breathers; MCA – minimal cross-sectional area; OMA – orthodontic models analysis; OSAS – obstructive sleep apnea syndrome; PAR – postero-anterior radiography; PINF – peak inspiratory nasal flow; QLQ – quality of life questionnaire; RME – rapid maxillary expansion; SC – structural changes; VOL – nasal volume.
**Table 3: Analysis of the quality of the studies according to Fowkes and Fulton.**

| Study design appropriate to objectives? | Hand et al. | Badreddine et al. | Cappelletti et al. | Irike et al. | Ikuta et al. | Ikuta et al. | Kondo et al. | Komatsu et al. | Komatsu et al. | Komatsu et al. | Monti et al. | Monti et al. | Monani et al. | Parati et al. | Parati et al. | Parati et al. | Parati et al. | Parati et al. |
|----------------------------------------|------------|-------------------|-------------------|-------------|-------------|-------------|-------------|---------------|---------------|---------------|-------------|-------------|--------------|-------------|-------------|--------------|--------------|-------------|
| Objective | Common Design | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Prevalence | Cross-sectional | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Prognosis | Cohort | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Treatment | Controlled trial | ++ | 0 | ++ | ++ | ++ | 0 | ++ | ++ | ++ | ++ | ++ | ++ | ++ | ++ | ++ | ++ | ++ |
| Cause | Cohort, case-control, cross-sectional | NA | NA | NA | NA | NA | NA | NA | NA | NA | 0 | NA | NA | NA | NA | NA | NA | NA | NA |
| Study sample representative? | Source of sample | 0 | + | + | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | + | 0 | 0 | 0 | 0 | 0 |
| Sampling method | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ++ | 0 | 0 | 0 | ++ | 0 |
| Sample size | 0 | 0 | 0 | 0 | + | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Entry criteria/exclusions | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Non-respondents | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Control group acceptable? | Definition of controls | NA | 0 | 0 | NA | NA | NA | NA | 0 | NA | NA | NA | NA | 0 | NA | NA | NA | NA |
| Source of controls | NA | 0 | 0 | NA | NA | NA | NA | 0 | 0 | NA | NA | NA | 0 | NA | 0 | NA | NA | NA |
| Matching/randomization | NA | ++ | ++ | NA | NA | NA | NA | ++ | 0 | NA | NA | 0 | NA | 0 | NA | 0 | NA | 0 | NA | NA |
| Comparable characteristics | NA | 0 | NA | NA | NA | NA | 0 | + | 0 | NA | 0 | NA | 0 | 0 | 0 | 0 | NA | 0 | NA | NA |
| Quality of measurements and outcomes? | Validity | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Reproducibility | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Blindness | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Quality control | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Compliance | + | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Drop-outs | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Deaths | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Missing data | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Distorting influences? | Extraneous treatments | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Contamination | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Changes over time | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Confounding factors | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Summary questions | Bias—Are the results erroneously biased in a certain direction? | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| any serious confounding or other distorting influences? | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| the results occurred by chance? | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| FINAL SCORE | 43 | 43 | 43 | 43 | 42 | 42 | 44 | 44 | 43 | 43 | 44 | 40 | 43 | 42 | 41 | 40 | 44 | 43 | 43 | 43 |

0: No problem, +: Minor problem, ++: Major problem, NA: Not Applicable

- **Study characteristics**
  Most studies (10/18) were conducted in Brazil (2,3,6,12,15,19,20,21), six in Italy (13, 22-26), one in Spain (14) and one in the USA (27). The studies dated from 2005 to 2019 (Table 1).
  Only seven articles included a control group without the intervention of RME, but these varied according to the type of breathing (nasal or mouth) and as to the presence or absence of TMD (Table I). Four studies (2,3,7,19) included MB (three with TMD (2,3,7). Some studies (13,23,14) assessed nasal breathers (NB), one with TMD (23).
- **Evaluated Instruments**
  The main instruments evaluated were: teleradiography (cephalometric measurements) (7,13,15,20,25), frontal postero-anterior radiography (nasal and maxillary widths) (3,16,21-computed tomography (three-dimen- sional airway measurements) (2,3), acoustic rhinometry (minimal cross-sectional area (MCA) and nasal volume (VOL)), computed rhinomanometry (respiratory resistance), analysis of orthodontic models (intercanine, intermolar and palate depth) and questionnaires on mouth breathing and quality of life (6). Only three studies evaluated using computed tomography scans (2,3,6) with only one using cone-beam computed tomography (6) (Table 2).
- **Quality of Studies**
  The 18 selected studies were classified with high methodological quality (Table III) according to the appraisal guidelines proposed by Fowkes and Fulton (18).
Discussion

In order to assess the effects of RME on naso-maxillary structures and nasal patency in MB as well as to verify the stability of these variables in the long term, the present review found that most studies (16/18) showed an increase in naso-maxillary structures (nasal cavity, oropharynx, nasopharynx, maxillary sinuses, maxillary width and dental arches) with RME (2,6,16,27). The effects on soft tissue structures of the nose were found on computed tomography scans three months after RME in the study by Badreddine et al. (2), for example.

Structural changes were detected by postero-anterior radiographic examinations, teleradiographs, conventional CT scans, cone-beam CT scans, dental arch models and acoustic rhinometry examinations (3,19,12,22,23).

In the study by Langer et al. (15), differences in nasopharyngeal space were found only after 30 months of RME, and could be explained by facial growth, and not because of the orthodontic procedure. In the study carried out by Enoki et al. (20), no statistically significant differences were observed in the measurements of the minimum cross-sectional area of the nasal valve and the inferior nasal concha with acoustic rhinometry, despite the improvement in nasal resistance with RME.

Functional changes were evaluated in eleven studies, through tests that provide objective data on nasal breathing such as active anterior computed rhinomanometry and peak inspiratory nasal flow, in addition to subjective tests. Among the studies analyzed, only Izuka et al. (6) and Helal et al. (27) used standardized questionnaires on respiratory patterns and symptoms, answered by the parents, showing improvement in the outcomes of the respiratory variables with RME.

Eight studies reported improvement in nasal respiratory function immediately after RME (6,13,14,21,22,24,26,). Monini et al. (13), in a study with 65 children submitted to RME compared to 50 children in the control group, found differences in nasal flow and resistance in the supine and orthostatic positions immediately and 12 months after RME. Likewise, Compadretti et al. (23) found a similar result in nasal resistance after the same follow-up period.

There was little evidence of absence of variation in respiratory flow after RME. In the study by Itikawa et al. (21), inspiratory nasal resistance returned to baseline values 90 days after RME. The same fact was observed by Matsumoto et al. (16), in the follow-up period of 30 months after RME, with the values of nasal resistance practically returned to baseline values. Such effects were related to the hypertrophied nasal mucosa, given that allergic rhinitis was the main cause of mouth breathing in these children.

Giuca et al. (25) reported a decrease in airway resistance in the active anterior rhinomanometry test in only three children, with six children showing no changes; airway resistance worsened in eight children during a follow-up period of 12 months after RME. In this study, no analysis was performed immediately after RME, showing an increase in structures. Therefore, no correlations were noted between nasal function and the RME procedure. The enlargement of nasal structures with RME may cause an immediate improvement in breathing, but the persistence of the inflammatory process in the nasal mucosa is likely to favor the recurrence of hypertrophy of the nasal mucosa. When RME is indicated, it must be performed during the treatment or after treating the cause of the nasal obstruction (16).

For RME to be effective, it must be performed before the fusion of the median palatal suture begins. Studies with cone-beam computed tomography found the beginning of the fusion of the median palatal suture in the palatal bone (a stage of sutural ossification called stage D (28)) in some female individuals at 11 years of age and male from 14 years of age. Therefore, in cases of RME, the structural bone age should be evaluated and not only the chronological age. Individuals who have advanced stages of sutural ossification may need complementary treatments such as RME, with the need for surgical intervention, either with micro-implant assisted rapid palatal expander (MARPE) or surgically assisted rapid maxillary expansion (SARPE) (28).

Imaging exams are important to assess the effects of RME on the medial palatal suture. CT scans allow better visualization of anatomical structures even in the presence of the palatal expander, minimizing the effects of radiographic artifacts (29).

In this review, the following orthodontic appliances were used: the Hyrax and modified Hyrax orthodontic appliances (14 studies) and the Hass and modified Hass appliances (4 studies). Also, the modified Biederman and Butterfly appliances were considered as modified Hyrax appliances.

The studies showed diverging results between the follow-up periods, namely, immediately after, one month, three, fourth, six, 12, 14 and 30 months after RME, showing temporal heterogeneity. Although methodologically adequate, they were not controlled and randomized.

Despite the adequate methodological quality, a great difference in the study methods used was observed. The present review showed that RME improves mouth breathing. On the other hand, there were no randomized controlled trials in MB with TMD, both in the short and long term, highlighting the need for further studies in this area.

Conclusions

The use of ERM promotes the enlargement of the dental arches and of the nasal and maxillary structures, and improves mouth breathing in the short term. However,
its long-term benefits have not been proved so far. More robust results of the effectiveness of RME with MB can be achieved in meta-analysis studies, with a consensual definition of the long-term follow-up period after RME.

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EMBASE
(‘palatal expansion technique’ OR ‘rapid maxillary expansion’ OR ‘maxillary expansion’ OR ‘palatal expansion techniques’) AND (‘mouth breathing’ OR ‘mouth breathers’) AND (child OR child* OR pediatrics OR ‘school aged child’ OR kids OR ‘preschool child’ OR adolescent OR adolescent*).

SCOPUS
(“Palatal Expansion Technique” OR “rapid maxillary expansion” OR “maxillary expansion” OR “palatal expansion techniques”) AND (“Mouth Breathing” OR “mouth breathers”) AND (child OR child* OR pediatrics OR “school aged child” OR kids OR preschool OR adolescent OR adolescent*).

Conflict of interest
Non declared.