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Effects of rapid maxillary expansion on hearing: a systematic review and meta-analysis

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Aim: This systematic review aimed to evaluate the effects of Rapid Maxillary Expansion (RME) on hearing improvement in children and adolescents with conductive hearing loss. **Methods**: A comprehensive search was conducted across eleven databases and grey literature. Studies included randomized controlled trials, cohort studies, and observational studies involving patients with maxillary atresia and conductive hearing loss due to otitis media. The primary outcome was hearing improvement measured in decibels (dB), assessed at pre-intervention, immediately post-intervention, and follow-up intervals of 3 to 24 months. The risk of bias was assessed using RoB 2.0 and ROBINS-I tools, while the GRADE system was used to evaluate the certainty of the evidence. A random-effects meta-analysis was performed, and heterogeneity was quantified using I^2 statistics. **Results**: Twelve studies, including 337 participants, were included. The meta-analysis demonstrated a significant improvement in hearing thresholds following RME, with a pooled mean difference of -6.56 dB (95% CI: -10.32 to -2.81). The RME vs. control group comparison showed a mean difference of -5.25 dB (95% CI: -9.89 to -0.62). However, high heterogeneity (I^2 = 88%) was noted. Some studies reported a relapse in auditory improvements after the retention period. The GRADE assessment indicated moderate certainty of evidence due to methodological limitations. **Conclusion:** RME improves hearing in patients with conductive hearing loss, but high-quality studies are needed to confirm long-term benefits and assess specific populations. Future research should address the variability in treatment protocols and follow-up durations.

Keywords: Palatal expansion technique. Hearing loss. Hearing loss, conductive. Audiometry. Systematic reviews as topic. Meta-analysis as topic.

Introduction

Maxillary deficiency in the transverse plane, commonly known as maxillary constriction, is a condition characterized by the narrowing of the maxilla relative to the mandible. This condition can be triggered by various factors, including oral habits such as mouth breathing and thumb sucking, as well as atypical patterns of phonation and swallowing[1-3]. The harmonious development of the craniofacial complex largely depends on the interaction between proper nasal breathing and tongue function, which promotes the maxilla's transverse growth[1-3]. When this growth is compromised, maxillary atresia occurs, often associated with a posterior crossbite, a malocclusion negatively impacting aesthetics and oral function[4].

Otitis media with effusion (OME) is one of the most common otologic conditions in children, affecting 10% to 17% of those aged 2 to 4 years[4,5]. Among children with cleft palate, the incidence can reach up to 91% within the first two years of life[4]. This condition often leads to conductive hearing loss (CHL), with severity ranging from mild to moderate, depending on the degree of Eustachian tube dysfunction[6,7]. Eustachian tube dysfunction impairs middle ear ventilation and drainage, contributing to the onset and persistence of OME[8,9]. Rapid maxillary expansion (RME) has demonstrated efficacy in improving auditory function, with reductions in hearing thresholds of up to 15–17 dB, comparable to those achieved with ventilation tube placement[10,11]. Moreover, approximately 68% of cases show recovery of Eustachian tube function following RME[9,12], reinforcing the relevance of this intervention in addressing auditory impairments associated with maxillary constriction.

Rapid maxillary expansion (RME) is a widely employed orthodontic procedure to correct maxillary atresia[13]. Its history dates back to the 19th century with the development of fixed expander appliances that apply controlled forces to stimulate the separation of the mid-palatal suture and the consequent widening of the maxilla[13,14]. The effectiveness of RME is influenced by various factors, including the patient's age, the choice of expander type, and individual craniofacial structural characteristics[13,15]. Careful selection of the technique and expander device is crucial to ensuring treatment success and minimizing the risk of complications, especially in patients with consolidated bone growth[13,15].

In addition to the direct benefits of occlusion and facial aesthetics, RME has positively affected respiratory and auditory function. Studies have shown that maxillary expansion can significantly improve nasal airway permeability and upper airway ventilation, positively impacting patients' quality of life[16,17]. The literature suggests that RME may play an important role in improving auditory function, particularly in cases of conductive hearing loss associated with inflammatory conditions of the nasopharynx that may compromise the function of the Eustachian tube and predispose to hearing loss[16-19]. By promoting the widening the maxilla and nasal cavity, RME may facilitate middle ear ventilation and improve Eustachian tube function, contributing to the resolution of auditory problems and hearing recovery[18].

Despite the growing evidence on the effects of RME on auditory function, the literature still lacks a comprehensive synthesis that evaluates the magnitude and consistency

of these effects across different populations and clinical contexts. Therefore, this study aims to systematically review the literature to investigate the effects of rapid maxillary expansion on the hearing of children and adolescents, focusing on improving auditory function associated with the correction of maxillary constriction.

Thus, this study will assess the effect of rapid maxillary expansion on hearing improvement in patients with maxillary atresia and conductive hearing loss, comparing hearing levels before and after the intervention and six months or more after the intervention. The positive hypothesis is that rapid maxillary expansion (RME) significantly improves the hearing of patients with maxillary atresia and conductive hearing loss, observable immediately after the intervention and sustained for up to six months or more.

Methods

Protocol and Registration

The protocol for this systematic review was developed following the "Cochrane Handbook for Systematic Review of Interventions"[20] and followed the "Preferred Reporting Items for Systematic Reviews and Meta-Analyses" (PRISMA) checklist[21], which guides transparency and completeness in the reporting of systematic reviews and meta-analyses. This protocol was registered on the "International Platform of Registered Systematic Review and Meta-Analysis Protocols" (INPLASY) on May 23, 2024, under the registration number INPLASY202450110[22].

Focused Question

This systematic review aims to answer the question: "In patients with maxillary atresia and conductive hearing loss due to otitis media, does rapid maxillary expansion improve hearing compared to hearing levels prior to the intervention?"

Eligibility Criteria

This systematic review selected studies based on specific inclusion and exclusion criteria. The inclusion criteria encompassed randomized clinical trials, non-randomized controlled studies, cohort studies, case-control studies, and case series. The population of interest included patients diagnosed with maxillary atresia and conductive hearing loss caused by otitis media, while the intervention focused on rapid maxillary expansion (RME). The studies were required to assess patients' hearing before the intervention, immediately after the intervention, and three months or more post-intervention, with hearing improvement as the primary outcome. Articles published in English, Portuguese, and other relevant languages were considered, with no restrictions on the publication date.

Conversely, studies that did not involve patients with maxillary atresia and conductive hearing loss due to otitis media or did not investigate RME as the main intervention were excluded. Studies that did not conduct hearing assessments at the three specified time points and those that did not have hearing level changes before and after RME as the primary outcome were also excluded. Reviews, editorials, commen-

taries, and other non-original publications were discarded. Studies in inaccessible or non-translatable languages and those that did not provide sufficient data for analysis were not considered.

Databases Searched, Search Strategies, and Article Selection Process

The following databases were analyzed: National Library of Medicine (PubMed/Medline), Scientific Electronic Library Online (SCIELO), LILACS, EBSCO, Web of Science, Scopus, Cochrane, EMBASE, and ScienceDirect. Grey literature was assessed through ProQuest and Google Scholar.

The search strategy was developed using a single key for all databases, incorporating a combination of MESH terms, DECS descriptors, and synonyms relevant to the research question, structured by the PICO model. Boolean operators (AND, OR) were employed to refine the results. All details of the final search strategy, including the number of works found in each database, were meticulously documented and are presented in Table 1. The final search was completed on September 10, 2024, ensuring all relevant studies up to that date were included.

After the initial database search, duplicate articles were identified and removed using Mendeley Reference Manager (Mendeley®, Elsevier, London, UK).

Two reviewers (LASL and JMG) independently worked using the Mendeley and SysRev platforms for the initial screening. Each reviewer examined the titles and abstracts of the studies to determine their eligibility, reaching a consensus on the articles selected for initial inclusion in conjunction with a specialist (JAC-M).

Subsequently, the same reviewers proceeded to a full-text reading of the articles. Considering the predefined eligibility criteria, they selected potentially eligible studies and decided on their final inclusion in the data extraction, according to Prisma Flow 2020. Any conflict during this phase was resolved by consensus, ensuring a balanced and objective evaluation.

Table 1. Search Strategies Used and Number of Results.

Search Argument	Database	Retrieved Articles
("maxillary expansion" OR "rapid maxillary expansion" OR "palatal expansion") AND ("hearing improvement" OR "hearing loss" OR "audiometry")	PubMed	24
	ScienceDirect	226
	Web of Science	31
	Scopus	33
	EMBASE	34
	Scielo	02
	LILACS	03
	EBSCO	07
	Cochrane	03
	ProQuest	03
	Google Scholar	120

Data extraction and synthesis

Two reviewers (LASR and JMG) performed data extraction independently using a **standardized data extraction form** designed to ensure consistency and reliability throughout the review process. This form was structured according to Cochrane guidelines. It included the following eight predefined fields: (1) study characteristics (e.g., author, year of publication, country), (2) study design (e.g., randomized controlled trial, observational study), (3) participant demographics (e.g., age, gender, condition), (4) intervention details (e.g., type of expander, activation protocol), (5) follow-up periods (e.g., pre-intervention, immediate post-intervention, and three months or more post-intervention), (6) methods used to assess outcomes (e.g., pure-tone audiometry, tympanometry, air-bone gap analysis), (7) primary outcome results (e.g., hearing threshold improvements), and (8) additional observations (e.g., relapse after retention, improvements in Eustachian tube function). Reviewer discrepancies were resolved through discussion or consulting a third expert (JAC-M).

Risk of Bias Analysis

The risk of bias in the included studies was independently assessed by two researchers (LASL and JMG) based on the RoB 2.0[23] tool for randomized controlled clinical trials and the ROBINS-I[24] tool for observational studies, as recommended by the Cochrane Handbook for Systematic Reviews of Interventions[20]. Discrepancies were resolved by a third researcher (JAC-M).

The RoB 2.0 tool allowed for a detailed analysis of seven key domains, including selection bias (randomization and allocation concealment), performance bias (blinding of participants and personnel), detection bias (blinding of outcome assessors), attrition bias (incomplete outcome data), reporting bias (selective reporting of results), and other potential biases. The ROBINS-I tool analyzed biases related to confounding, participant selection, intervention classification, deviations from intended interventions, missing data, outcome measurement, and reporting of selected results.

Each domain in both tools was classified as having a 'low risk of bias,' 'moderate risk of bias,' or 'high risk of bias' based on the detailed description of the methodological procedures in the studies. The overall risk of bias for each study was determined through the evaluation of these domains, providing a comprehensive understanding of the methodological quality of the studies included in the systematic review.

Geographic and Bibliometric Mapping

Bibliometric networks were constructed using VOSviewer software (v. 1.6.20, CWTS, Leiden University, Netherlands)[25]. The full citation of each included study in a '.ris' format was uploaded into the VOSviewer software. The co-occurrence analysis of keywords was performed using fractional counting, considering a minimum of three co-occurrences. The co-authorship analysis was performed using full counting with at least two documents from an author. A co-occurrence map based on title and abstract was constructed using the full counting method for a minimum of ten occurrences of a term, ignoring structures, abstract labels, and copyright statements

Meta-analysis

The meta-analysis was conducted to synthesize the results related to auditory thresholds and the air-bone gap (ABG) following Maxillary Expansion (ME). All included studies reported outcomes in the same unit, decibels (dB), allowing the use of mean difference (MD) as the effect metric. Given the expected variation among studies, such as differences in the assessed populations, follow-up times, and interventions performed, a random effects model was employed. This model is suitable when it is assumed that studies estimate effects of different magnitudes, allowing for considering variability within and between studies.

To assess heterogeneity among the studies, the I^2 statistic was calculated, quantifying the percentage of total variability among studies attributable to heterogeneity rather than chance. I^2 values greater than 50% indicated moderate to high heterogeneity. The chi-squared test (χ^2) was also used to determine whether the observed variability among studies was greater than expected by chance. In cases of high heterogeneity, sensitivity analyses were conducted to investigate potential sources of discrepancies among the studies.

Results were presented in forest plots, which displayed the mean difference (MD) and 95% confidence intervals (CI) for each study and a combined estimate of the overall effect. Funnel plots were utilized to investigate potential publication bias and check the symmetry in the distribution of studies around the estimated mean effect.

Evidence Quality Assessment - GRADE Method

The quality of evidence was evaluated using the GRADE system, classifying evidence into four categories: very low, low, moderate, and high. The assessment considered factors such as risk of bias, inconsistency of results, indirectness of evidence, and imprecision. Studies were downgraded for issues like lack of randomization, high heterogeneity, small sample sizes, or indirect relevance to the clinical question. Publication bias was also considered, noting the tendency for positive results to be published more frequently. The GRADE system allowed for a transparent and structured evaluation of the overall quality of evidence, aiding in the formulation of clinical recommendations.

Results

The systematic review was conducted using 11 databases, including grey literature. From this search, 486 references were found, of which 150 were duplicates. After removing the duplicates, the titles and abstracts of 279 studies were carefully reviewed, and 257 articles were excluded for not meeting the eligibility criteria. Thus, 22 articles were thoroughly analyzed and assessed for eligibility. The references of the selected studies were also evaluated to identify any potential studies not found in the databases used in this research. At the end of the review, 12 studies were included for qualitative analysis, following the parameters of the PICO strategy (Figure 1).

Details of the excluded articles and the reasons for their exclusion are provided in Supplementary Material Table S1[17,18,26-33]. Table 2 summarizes the key information from the 12 studies included in this systematic review[4-12,34-36], published between

1996 and 2021, of which 55% were published in the last 10 years (Figure 2). Sample sizes ranged from 14 to 42 patients, totaling 337 participants aged between 4.5 and 16 years. All studies investigated the effects of rapid maxillary expansion (RME) on auditory function, with different outcomes and patient populations.

The expanders used (Figure 3) included the Hyrax (n=6), Haas (n=2), bonded acrylic expander (n=3), and the McNamara distractor (n=1). Activation protocols varied among the studies, with most using twice-daily activations, with increments ranging from 0.2 to 0.5 mm per activation.

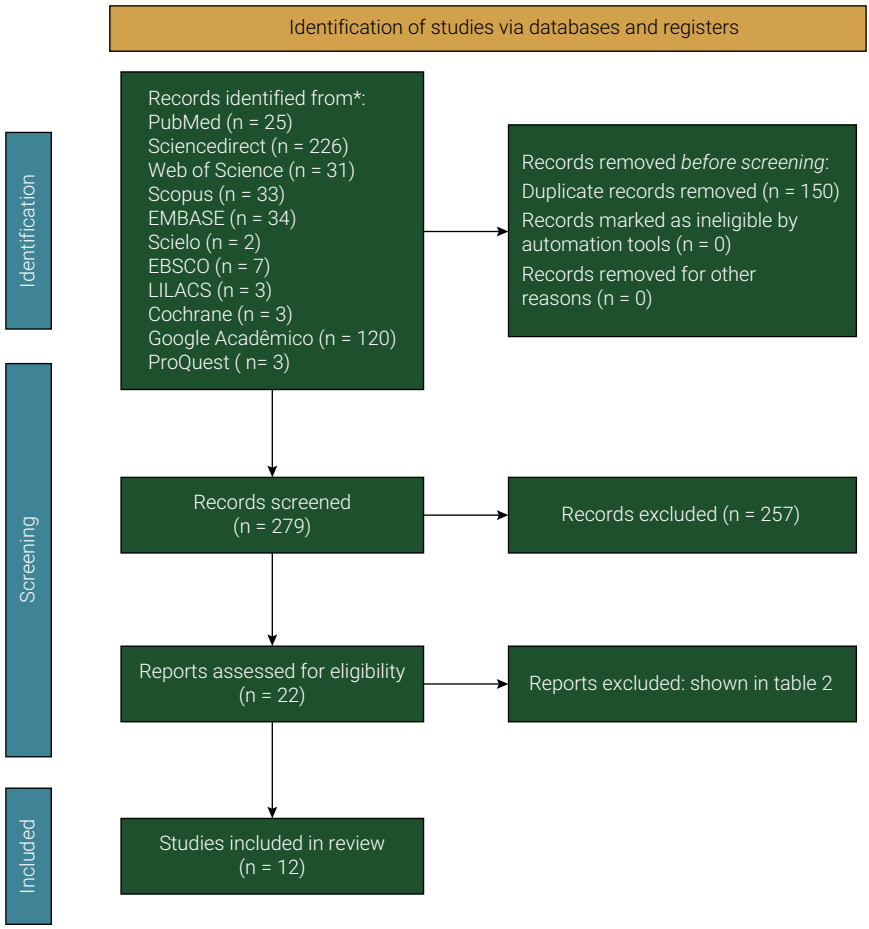

Figure 1. Flowchart - summary of the selection process of articles for systematic review.

The expanders used included the Hyrax (n=6), Haas (n=2), bonded acrylic expander (n=3), and the McNamara expander (n=1). The activation protocols varied among the studies, with most performing activations twice daily, with 0.2 to 0.5 mm increments per activation.

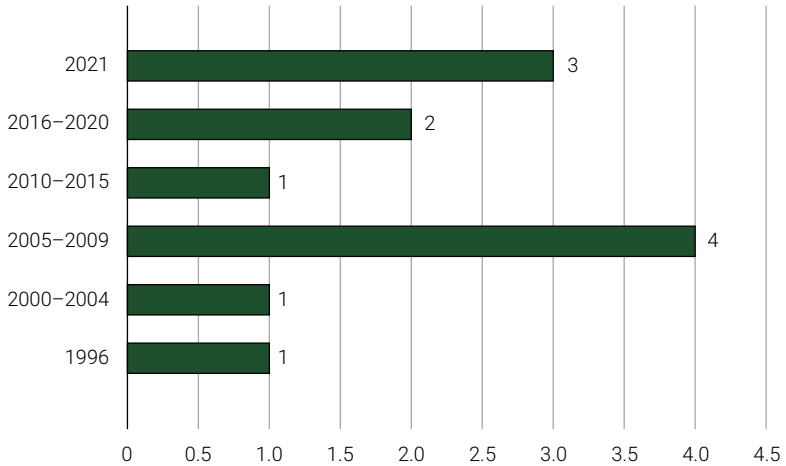

Figure 2. Distribution of studies included in the systematic review by publication period.

Table 2. General characteristics of the studies included in the systematic review

Author/Year	Country	General Objective of the Study	Number and Characteristics of Patients	Patient Age	Characteristics of the Expander Used
Ceylan et al.[34] (1996)	Turkey	To determine whether rapid maxillary expansion (RME) affects conductive hearing loss.	14 patients (11 females and 3 males) aged between 10 years and 4 months and 16 years and 9 months, with narrow maxillary arches and conductive hearing loss.	Mean age of 12 years and 11 months (± 1 year and 9 months).	Biedermann-type expander with Hyrax screw (Dentaurum 602-813), activated 0.2 mm three times per day for 3 days.
De Stefano et al.[8] (2009)	Italy	To evaluate rapid maxillary expansion (RME) in managing recurrent otitis media in children with skeletal development syndrome (SDS) and adenoid hypertrophy.	27 children (15 boys and 12 girls) with a mean age of 7 years (age range 6-8 years) with recurrent otitis media associated with skeletal development syndrome (SDS) and adenoid hypertrophy.	Mean age of 7 years (age range 6-8 years).	Hyrax expander, activated twice daily (0.25 mm per turn) for 10 to 12 days, followed by a retention period of three months.
Kiliç et al.[6] (2008)	Turkey	To test the null hypothesis that rapid maxillary expansion (RME) with a bonded rigid appliance does not affect conductive hearing loss (CHL) in growing children.	Fifteen individuals, 12 female, and 3 male, in the growth phase (mean age 13.43 ± 0.86 years), with narrow maxillary arches and conductive hearing loss.	Age range from 11.25 to 14.83 years, with a mean of 13.43 ± 0.86 years.	A bonded acrylic appliance was activated twice daily, in the morning and at night, until the appropriate expansion was achieved.
Kılıç et al.[10] (2016)	Turkey	To compare the effects of rapid maxillary expansion (RME) and ventilation tube placement on hearing thresholds in children with resistant otitis media with effusion (OME).	42 children (ages 4.5 to 15 years) divided into three groups: RME (15 children with maxillary constriction and resistant OME), ventilation tube (16 children), and control (11 children).	Mean age of 10.07 ± 2.72 years in the RME group, 9.14 ± 3.04 years in the ventilation tube group, and 8.34 ± 2.46 years in the control group.	The conventional Hyrax expander and bonded acrylic expander were activated twice daily until 2-3 mm of overexpansion was achieved.

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Kılıç et al.[9] (2021)	Turkey	To determine whether dysfunctional Eustachian tubes in children with resistant otitis media with effusion, indication for ventilation tube placement, and maxillary constriction would recover after rapid maxillary expansion (RME).	15 children (mean age: 10.07 years) with maxillary constriction, Eustachian tube dysfunction, and resistant OME. The control group had 11 healthy children (mean age: 8.34 years) without orthodontic and/or rhinological problems.	Mean age of 10.07 years in the RME group and 8.34 years in the control group.	The conventional Hyrax expander and bonded acrylic expander were activated twice daily until 2-3 mm of overexpansion was achieved. Patients were instructed to activate the expansion screw twice daily until adequate expansion was achieved.
Micheletti et al.[5] (2012)	Brazil	To evaluate the effects of rapid maxillary expansion (RME) on middle ear function before, after, three months, and one year after the expansion procedure.	Of 18 patients with a mean age of 8.1 years (± 3.7) and posterior crossbite, 9 had middle ear dysfunction, and 9 had a normal function before RME.	Mean age of 8.1 years (± 3.7).	Haas expander activated with two turns per day (0.5 mm/day) for 15-20 days.
Moura et al.[35] (2008)	Portugal	To evaluate the effects of rapid maxillary expansion on otorhinolaryngological disorders in children with Down syndrome.	26 children with Down syndrome, divided into three age groups: 4-6 years, 7-9 years, and 10-12 years, randomized to receive rapid maxillary expansion or not. Otorhinolaryngology and speech therapy assessments were performed before expansion and after device removal.	4 to 6 years, 7 to 9 years, and 10 to 12 years.	Rapid maxillary expansion device used to separate the maxillary bones at the mid-palatal suture, with activation rates of 0.3-0.5 mm per day.
Rosso et al.[4] (2021)	Italy	To evaluate the effects of rapid maxillary expansion (RME) on conductive hearing loss and otitis media in children with cleft palate.	34 patients with surgically corrected cleft palate (CP/CLP), aged 5 to 12 years, were indicated for RME treatment due to conductive hearing loss.	Median age of 8 years, with an interquartile range (IQR) of 1 year.	McNamara expander activated with two full turns per week until 10 mm of expansion was achieved.
Sancaktar et al.[12] (2021)	Turkey	To compare the improvement in hearing loss levels in patients treated with rapid maxillary expansion (RME) and patients observed for spontaneous resolution.	22 patients with Otitis Media with Effusion (OME) were divided into two groups: Group 1 (12 patients) treated with RME and Group 2 (10 patients) observed for spontaneous resolution.	The mean age is 12 years and 4 months overall. In Group 1, the mean was 12 years and 7 months; in Group 2, 12 years and 1 month.	The bonded acrylic expander was activated twice daily until 3 mm of overexpansion was achieved. The same device was used for retention after the active expansion period of three months.

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Singh et al.[7] (2019)	India	To evaluate the effects of rapid maxillary expansion on auditory and vocal function in children without cleft lip and palate and bilateral cleft lip and palate with transverse maxillary deficiency.	53 patients (26 without cleft and 27 with bilateral cleft lip and palate), with a mean age of 11.1 ± 1.8 years, requiring rapid maxillary expansion to correct narrow maxillary arches.	Mean age of 11.1 ± 1.8 years.	The bonded Hyrax expander was activated twice daily, one turn in the morning and another at night (0.5 mm/day) for 7-14 days until the required expansion was achieved.
Taspınar et al.[36] (2003)	Turkey	To evaluate the effects of rapid maxillary expansion (RME) on conductive hearing loss in patients with maxillary constriction.	35 patients (21 girls and 14 boys) with a mean age of 14 years and 6 months, all with maxillary constriction and conductive hearing loss.	The mean age of 14 years and 6 months.	The hyrax-type expander was activated thrice daily for three days, followed by two daily activations until posterior crossbite elimination.
Villano et al.[11] (2006)	Italy	To evaluate the effects of rapid maxillary expansion (RME) on conductive hearing loss in patients with maxillary constriction.	25 patients (15 girls and 10 boys) aged between 6 years and 8 months and 8 years and 2 months, all with conductive hearing loss and maxillary constriction.	Mean age of 7 years and 2 months (± 0.58 years).	Expander with two or four bands, activated thrice daily for 7 to 14 days.

Audiological Studies

The reviewed studies employed audiological methods such as pure-tone audiometry (PTA), tympanometry, and air-bone gap analysis to assess the impact of rapid maxillary expansion (RME) on auditory function (Table 3). The results demonstrated that RME can improve hearing levels, particularly at mid and high frequencies, and reduce the air-bone gap in patients with conductive hearing loss and middle ear dysfunctions.

Specifically, pure-tone audiometry (PTA) indicated significant improvements in hearing thresholds following RME. Two studies, Sancaktar et al.[12] (2021) and Ceylan et al.[34] (1996) reported that the improvement after RME may be temporary, with partial reversal occurring after the retention period. One study by Moura et al.[35] (2008) revealed that tympanometry improved middle ear function, evidenced by the normalization of tympanometric curves and the recovery of tympanic membrane elasticity in some patients. The stability of these improvements varied among studies, with some indicating that hearing improvements remained stable in a significant percentage of patients after two years.

Table 3. Audiological Assessment Methods and Observed Outcomes in Studies on Rapid Maxillary Expansion

Author/Year	Audiological Assessment Method	Results	Conclusion
Ceylan et al.[34] (1996)	Pure-tone audiometry (PTA) and air-bone gap measurement.	Pure-tone audiometry (PTA): Statistically significant improvements in hearing levels were observed after the active rapid maxillary expansion (RME) phase. However, this improvement was partially reversed during the retention period, indicating that the hearing improvement was not sustained in all patients post-treatment. Air-bone gap measurement: A significant reduction in the air-bone gap was observed between measurements taken before treatment and after the retention period. However, similar to the PTA results, this improvement was not consistently maintained in all patients.	The study suggests that RME may positively affect hearing in patients with conductive hearing loss, but this effect may be transient and reversed during the retention phase.
De Stefano et al.[8] (2009)	Pure-tone audiometry (PTA) and tympanometry	The main findings indicated that rapid maxillary expansion resulted in a significant reduction in air-bone gaps measured by PTA and a normalization of tympanometric curves from type B and C2 to type A and C1. This suggests significant improvement in Eustachian tube function and middle ear ventilation, reducing conductive hearing loss and recurrent otitis media.	RME may be an effective treatment for recurrent otitis media in children with SDE and adenoid hypertrophy, improving auditory function, middle ear function, and nasal breathing. In many cases, RME may even avoid the need for adenoidectomy.
Kiliç et al.[6] (2008)	Pure-tone audiometry (PTA) and tympanometry	Hearing levels of patients with conductive hearing loss (CHL) improved, and air-bone gaps significantly decreased ($P < 0.001$) during the active expansion phase (T2–T1) and the retention period (T2–T3). Middle ear volume increased across all observation periods; however, a statistically significant increase occurred only during the retention period. The RME procedure provides positive and stable effects on hearing functions and Eustachian tube function in growing children with CHL and transverse maxillary discrepancies.	The hypothesis is rejected. RME treatment has a positive and statistically significant effect on hearing improvement and the normal functioning of the Eustachian tube in patients with transverse maxillary deficiency and CHL.
Kılıç et al.[10] (2016)	Pure-tone audiometry (PTA)	The main findings indicated that hearing thresholds significantly decreased after rapid maxillary expansion (RME) and ventilation tube placement. Specifically, hearing thresholds decreased by approximately 15 decibels in the RME group and 17 decibels in the ventilation tube group, with insignificant differences between the two groups regarding hearing improvement.	It was shown that RME might be considered a primary treatment option for children with maxillary constriction and resistant OME, offering similar benefits to ventilation tube placement regarding hearing improvement.

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Kılıç et al.[9] (2021)	Williams' tubal function test conducted via tympanometry.	Significant improvement in Eustachian tube function after RME: In the RME group, there was a significant improvement in Eustachian tube function after expansion, and this improvement remained stable during the 10-month observation period. Normal Eustachian tube function in the control group: In the control group, all ears had normal Eustachian tube function at the start of the study, with no deterioration or changes during the observation period.	It is suggested that RME may be an effective treatment option for children with maxillary constriction and resistant OME, promoting recovery of Eustachian tube function in most cases and avoiding the need for ventilation tube placement.
Micheletti et al.[5] (2012)	Air and bone conduction audiometry and tympanometry	Rapid maxillary expansion did not have a deleterious effect on auditory quality and appeared to improve middle ear function in children with posterior crossbite from a one-year perspective. Regarding audiometry, there were no significant changes in hearing threshold levels throughout the study, either for air conduction or the air-bone gap. Tympanometry showed significant improvement in middle ear function in children who initially had auditory dysfunction. Maintenance of normal function in the NF group: In the NF group, all patients had acoustic reflex and type A tympanometric curve in all assessments, indicating that RME did not have a deleterious effect on middle ear function. Absence of significant changes in hearing thresholds: In both groups, no significant changes in hearing thresholds were observed throughout the study, suggesting that RME does not cause hearing loss.	In the middle ear dysfunction group, there was a significant improvement in middle ear function after RME, evidenced by the appearance of the acoustic reflex and the normalization of the tympanometric curve in all patients after one year.
Moura et al.[35] (2008)	Pure-tone audiometry (PTA) and tympanometry.	The main results show a significant improvement in hearing in children who underwent rapid maxillary expansion. Specifically, the mean hearing thresholds (PTA) significantly improved in the expanded group compared to the non-expanded group. Additionally, tympanometry demonstrated a reduction in the prevalence of type B traces (indicative of middle ear effusion) in the expanded group, suggesting an improvement in middle ear function.	It was concluded that RME may reduce hearing loss in children with Down syndrome, possibly due to improved middle ear function and upper airway patency.
Rosso et al.[4] (2021)	Pure-tone audiometry (PTA) and tympanometry	The main findings showed a significant improvement in air-bone gaps and tympanometry results after treatment with rapid maxillary expansion (RME). Specifically, there was a significant reduction in the air-bone gap at the evaluated frequencies, particularly at 250, 500, 1000, and 4000 Hz, and an improvement in tympanogram classification, with an increase in the number of type A (normal) tympanograms over time.	It has been demonstrated that RME effectively improves conductive hearing loss and middle ear function in children with cleft palate, with benefits that persist in the medium term.

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Sancaktar et al.[12] (2021)	Pure-tone audiometry (PTA) and tympanometry	The main findings in the article showed that, in the group of patients who underwent rapid maxillary expansion, there was a significant improvement in hearing levels and a reduction in the air-bone gap immediately after expansion. However, this improvement showed some relapse after the retention period. Hearing levels did not change significantly in the control group, which was observed for spontaneous resolution, but there was a significant decrease in the air-bone gap.	RME improved hearing levels and reduced the air-bone gap after expansion in children with OME; however, a relapse occurred after retention. The air-bone gap levels in both groups showed similar decreases after retention.
Singh et al.[7] (2019)	Pure-tone audiometry (PTA) and tympanometry	The study's main findings indicated that rapid maxillary expansion resulted in significant improvements in hearing levels and middle ear volumes in patients without cleft palate and with bilateral cleft palate, particularly in those with mild conductive hearing loss. There were also improvements in the fundamental frequency and jitter percentage in vocal analysis in the non-cleft group, but these changes were not significant in the cleft group.	Correction of palatal anatomy through RME therapy improves hearing and normal middle ear function in patients with and without bilateral cleft palate. However, this effect seems more pronounced in patients with normal hearing levels or mild conductive hearing loss.
Taspınar et al.[36] (2003)	Pure-tone audiometry (PTA) and air-bone gap analysis.	The study observed significant improvements in hearing levels and air-bone gap differences after the active expansion period. These improvements were maintained in 74% of patients two years after the retention period, indicating stable hearing improvement.	RME positively and significantly affected the hearing levels of individuals with conductive hearing loss after the expansion period. Improvements in hearing and reduction of the air-bone gap were evident and remained stable in 74% of patients, even two years after treatment.
Villano et al.[11] (2006)	Audiometry, tympanometry, and video-otoscopy.	Audiometric recordings indicated improved hearing levels at higher frequencies after maxillary expansion but not at lower frequencies. After the retention period, functional improvement occurred in all patients for all frequencies. Recovery of tympanic membrane elasticity occurred only after the retention period, as evidenced by the standard tympanogram pattern.	Correction of palatal anatomy through RME may positively influence the muscular function of the tubal ostia, enabling normal activity of the tympanic membrane and auditory apparatus. Improvement in auditory function in patients with conductive hearing loss is a potential additional benefit of RME treatment. However, this does not indicate that patients with conductive hearing loss without maxillary constriction should consider RME as a treatment approach.

Geographic and Bibliometric Mapping

Most studies were conducted in Turkey (n=6), followed by Italy (n=3). The remaining studies were conducted in Brazil, India, and Germany (n=1).

The bibliometric analysis was conducted using the VOSviewer software based on the titles and abstracts of the 12 selected articles. In the first stage, a text data analysis was performed using a .RIS file extracted from EndNote. The analysis focused on the titles and abstracts of the articles, excluding labels from structured abstracts and copyright statements to ensure the relevance of the terms. A binary counting method was employed, considering each term only once per document, regardless of frequency. The minimum number of occurrences of a term was set at 5, resulting in 16 eligible terms.

The choice of a minimum threshold of 5 occurrences for term inclusion in the bibliometric analysis is justified by the need to balance relevance and specificity in identifying significant patterns within the dataset. Setting a minimum number of occurrences helps filter out terms that are more common and, therefore, likely more representative of the central topics addressed in the selected articles. If the threshold were too low, there would be a higher risk of including less relevant terms that appear sporadically and do not reflect significant trends. Conversely, a very high threshold could exclude potentially important terms that appear frequently enough to be considered relevant but are still specific enough to provide valuable insights. Thus, by setting the threshold at 5, it was possible to capture a range of terms that are representative of the recurring topics in the analyzed literature, ensuring that the conclusions of the analysis are based on consistent and meaningful patterns.

A relevance score was calculated for each term, and the top 60% of the most relevant terms were selected, totaling 10. The clustering analysis identified two distinct clusters comprising seven terms (Supplementary Material Figure S1).

Subsequently, the bibliometric analysis created a co-occurrence map of keywords from the 12 selected articles. The minimum number of co-occurrences required for a keyword to be included was set at 2, resulting in 25 keywords out of 66. The total strength of each keyword's association with others was calculated, and only keywords with the highest total strength of association were selected, resulting in 21 terms grouped into 3 clusters (Supplementary Material Figure S2).

Risk of Bias Analysis

The risk of bias assessment of the included randomized clinical trials, Moura et al.[35] (2008) and Singh et al.[7] (2019), revealed a predominance of moderate risk of bias (Figure 3A). Specifically, both studies implemented adequate randomization but were unclear regarding allocation concealment. Additionally, participant and clinical team blinding was inadequate in both studies, resulting in a high risk of performance bias. Outcome assessor blinding was only reported in Singh et al.[7] (2019).

In contrast, attrition bias, related to incomplete outcome data, was considered low, suggesting that loss to follow-up or exclusions did not significantly affect the results. However, the possibility of reporting bias and other biases, such as unreported conflicts of interest, raised some concerns in these studies.

In summary, the risk of bias analysis indicated an overall moderate risk of bias in the studies by Moura et al.[35] (2008) and Singh et al.[7] (2019). These findings highlight the need for caution when interpreting the results and underscore the importance of considering the potential impact of bias on evaluating the available evidence.

The bias analysis of the 10 observational studies, as illustrated in Figure 3B, showed that most studies had a moderate risk of bias. The main limiting factor was the lack of adjustments for confounding factors, especially in the study by Ceylan et al.[34] (1996), which was the only one classified as having a high risk of confounding. Additionally, there was a moderate risk in outcome measurement, primarily due to the lack of blinding of the assessors. Despite this, the studies maintained a low risk of bias in the classification and execution of interventions and in the selection of reported outcomes. Overall, the absence of randomization and adjustments for confounding variables reduces the robustness of the presented evidence.

A

References	Selection Bias – Randomization	Selection Bias - Allocation Concealment	Performance Bias - Blinding of Participants and Staff	Detection Bias - Blinding of Outcome Assessors	Attraction Bias - Incomplete Outcome Data	Reporting Bias - Selective Reporting of Results	Other biases	Conclusion of Risk of Bias
Moura et al.[35] (2008)								
Singh et al.[7] (2019)								

B

References	Confusion bias	Bias in participant selection	Bias in intervention classification	Bias due to deviations from the intervention	Bias due to missing data	Bias in measuring outcomes	Bias on reporting results	Global judgement of studies
Ceylan et al.[34] (1996)								
De Stefano et al.[8] (2009)								
Kiliç et al.[6] (2008)								
Kiliç et al.[10] (2016)								
Kiliç et al.[9] (2021)								
Rosso et al.[4] (2021)								
Micheletti et al.[5] (2012)								
Sancaktar et al.[12] (2021)								
Taspinar et al.36 (2003)								
Villano et al.[11] (2006)								

Figure 3. Assessment of the risk of bias in the studies included in the systematic review. (A) Risk of bias assessment for randomized controlled trials using the RoB 2.0 tool. (B) Risk of bias assessment for observational studies using the ROBINS-I tool. The colors represent the risk of bias in each domain: green (low risk), yellow (moderate risk), and red (high risk).

Meta-analysis

The data regarding pure-tone hearing thresholds and the air-bone gap (ABG) in the analyzed studies were obtained through a standardized information extraction strategy from the tables in the articles. Each study was reviewed to identify hearing thresholds, measured in decibels (dB), before the intervention (T0, pre-rapid maxillary expansion - RME) and at different follow-up times after the intervention (e.g., 3, 6, and 12 months). The tables from the articles were used to extract the mean hearing thresholds, standard deviations (SD), and the number of participants (N) in each group. These data were organized into a spreadsheet with the means and standard deviations for T0 and the corresponding follow-up times.

In the meta-analysis, the use of Mean Difference (MD) was chosen, as all studies measured the outcome of interest (hearing thresholds) in the same unit, in decibels (dB). This allowed for a direct comparison of absolute values between studies without standardizing the results through the Standardized Mean Difference (SMD). Thus, the mean difference reflects the absolute change in hearing thresholds after RME, facilitating the interpretation of the results and enabling an objective comparison between studies.

The meta-analysis included eight of the 12 studies selected to provide complete and compatible data on pure-tone hearing thresholds and air-bone gap across follow-up periods ranging from 4.5 to 24 months[6,7,10-12,34-36]. The Mean Difference (MD) between hearing thresholds before and after the intervention was analyzed. This strategy was considered important in assessing the effect of RME at each stage of treatment (Figure 4).

The meta-analysis results indicate that Rapid Maxillary Expansion is associated with significantly improving hearing thresholds, with a combined mean difference of -6.56 dB (95% CI: -10.32 to -2.81, p = 0.0006). Of the eight included studies, five, Kiliç et al.[6] (2008), Kiliç et al.[10] (2016), Moura et al.[35] (2008), Taspinar et al.[36] (2003), and Villano et al.[11] (2006) demonstrated a significant reduction in hearing thresholds after RME, with variations ranging from -1.67 dB to -15.13 dB. The greatest effect was observed in the study by Villano et al.[11] (2006) with -15.13 dB (95% CI: -17.44 to -12.82).

The high heterogeneity (I^2 = 88%) observed among the included studies suggests substantial variability, likely due to differences in patient demographics, expander types, and follow-up periods. Sensitivity analysis revealed that excluding the study by Villano et al.[11] (2006) significantly reduced heterogeneity to I^2 = 32% and the combined effect to -4.85 dB (95 % CI -6.68 to -3.03). The risk of bias varied across studies, with participant selection and outcome assessment presenting the highest risks.

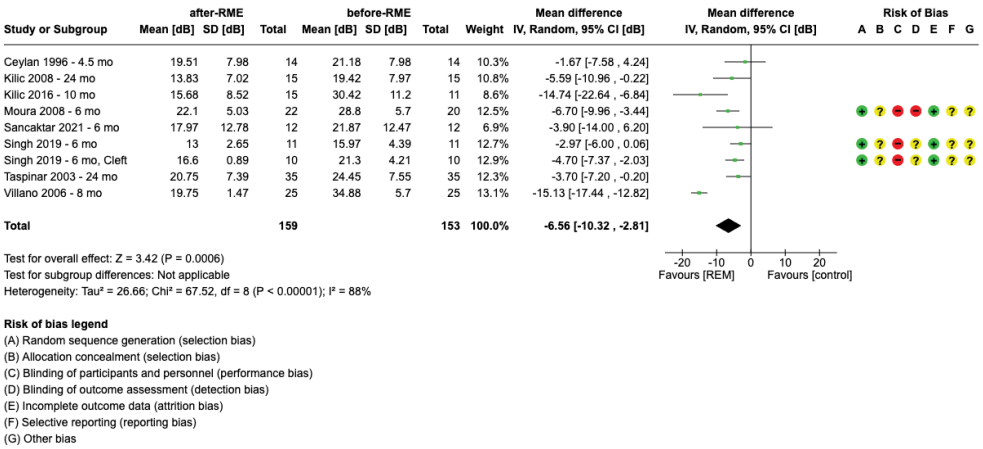

Figure 4. Meta-analysis of hearing thresholds after Rapid Maxillary Expansion (RME) at different follow-up periods, using Mean Difference (MD) and the Random Effects model. The analysis for the period of 4.5 to 24 months indicates a significant improvement ($p < 0.05$) in hearing thresholds, with an average reduction of 6.56 dB after RME (95% CI: -10.32, -2.81). High heterogeneity was observed ($p < 0.00001$ with df = 8, I^2 = 88%)—bias analysis: ROB 2.0.

The funnel plot was used to assess the risk of publication bias in the studies included in the meta-analysis (Supplementary Material Figure S3). The asymmetrical distribution of the points suggests a potential publication bias, as studies with smaller effects and higher standard errors (SE) are concentrated on the right side of the plot. In comparison, studies with larger effects tend to be on the left. The absence of studies in the lower right quadrant also indicates that studies with smaller effects may not have been published, contributing to the observed asymmetry.

Among the selected studies, Kiliç et al.[10] (2016), Moura et al.[35] (2008), Sancaktar et al.[12] (2021) included a control group of participants submitted to no treatments (Figure 5). The meta-analysis revealed a statistically significant improvement in hearing thresholds in the RME group compared to the control group (MD = -5.25 dB, 95% CI: -9.89 to -0.62, p = 0.03). Although the reduction in hearing thresholds appears modest, it may have clinically meaningful implications, particularly in pediatric populations where even small improvements in hearing can enhance language development and overall quality of life. However, the moderate heterogeneity observed (I^2 = 74%) suggests that these effects may vary depending on the specific characteristics of the patient population and treatment protocols.

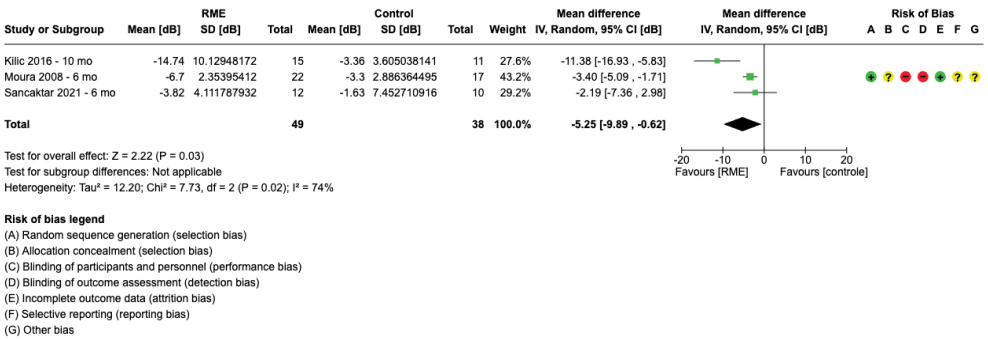

Figure 5. Forest plot showing the meta-analysis of three studies comparing Rapid Maxillary Expansion (RME) with control on hearing improvement (in dB). The mean difference (MD) and 95% confidence intervals (CI) reflect changes in each group's hearing thresholds pre- and post-intervention. A negative MD favors the RME group. The pooled effect estimate indicates a significant improvement in hearing thresholds for the RME group (MD = -5.25 dB, 95% CI: -9.89 to -0.62, p = 0.03). Moderate heterogeneity was observed (I^2 = 74%). The risk of bias is summarized using colored dots: green (low), yellow (unclear), and red (high).

The sensitivity analysis using the Standardized Mean Difference (SMD) compared the effects of Rapid Maxillary Expansion (RME) to a control group on hearing improvement across three studies (not shown). The pooled SMD was -1.02 (95% CI: -1.63 to -0.41, p = 0.001), indicating a moderate to large improvement in hearing thresholds favoring the RME group. Individual studies demonstrated varying effects, with Kilic et al.[10] (2016) and Moura et al.[35] (2008) showing significant improvements, while Sancaktar et al.[12] (2021) exhibited a smaller, non-significant effect. Heterogeneity was moderate (I^2 = 42%), suggesting reasonable consistency among the studies.

Altogether, RME significantly improves hearing thresholds compared to no intervention, with a moderate overall effect size and relatively consistent results across studies. This supports using RME as an effective intervention for improving hearing in patients with maxillary constriction.

GRADE Analysis

Figure 6 presents the certainty of evidence analysis based on eight studies, including two controlled clinical trials Moura et al.[35] (2008) and Singh et al.[7] (2019) and six observational studies Ceylan et al.[34] (1996), Kiliç et al.[18] (2008), Kiliç et al.[10] (2016), Sancaktar et al.[12] (2021), Taspinar et al.[36] (2003), and Villano et al.[11] (2006).

The risk of bias was classified as moderate due to the lack of control for confounding factors and blinding in some studies[10-12,18,34,36]. Inconsistency, indirect evidence, and imprecision were classified as low, indicating relative homogeneity in the results and methodological robustness. However, the lack of adjustments for confounding factors and blinding in some observational studies was considered.

The results indicate an average improvement in hearing thresholds of -6.56 dB (95% CI: -10.32 to -2.81) after rapid maxillary expansion (RME) compared to pre-intervention. The number of participants analyzed was 159 post-RME and 153 pre-RME. The overall certainty of the evidence was rated as moderate, reflecting a general confidence in the conclusions of the analysis.

Analysis of Certainty of Evidence							Results Summary			
Studies	Experimental design	Risk of Bias	Inconsistency	Indirect Evidence	Inaccuracy	Other considerations	Number of Participants		Absolute Effect (IC95%)	Certainty of Evidence
							Post-RME	Pre-RME		
8	2 CT, 6 Observational	Moderate	Low	Low	Low	Absences: adjustments for confounding and blinding factors	159	153	MD -6.56 dB [-10.32 , -2.81]	Moderate ⨁⨁⨁◯

Note: The risk of bias is mainly due to a lack of adjustments for confounding factors and blinding. Hearing Threshold (follow-up: 4.5 to 24 months; analysis by audiometry).
Figure 6. Evidence quality assessment - GRADE method

Discussion

This systematic review aimed to evaluate the effects of Rapid Maxillary Expansion (RME) on auditory function, particularly in cases of conductive hearing loss and middle ear dysfunction. Given the prevalence of maxillary constriction in orthodontic patients and its association with hearing issues, the included studies explored how RME influences hearing levels and middle ear health. These studies demonstrated improvements in hearing thresholds and reductions in the air-bone gap (ABG), providing evidence of enhanced middle ear ventilation and Eustachian tube function.

Unlike previous reviews, such as Calvo-Henriquez et al.[37] (2022), which did not account for follow-up times, our meta-analysis provided a detailed assessment at different intervals (3, 6, 12, and 24 months). Significant improvements in hearing thresholds were observed in the short- and medium-term follow-ups, particularly in ABG reduc-

tion. However, studies such as Sancaktar et al.[12] (2021) and Ceylan et al.[34] (1996) reported a relapse in hearing improvements after the retention phase, indicating variability in long-term outcomes.

Hearing improvements were more pronounced at mid and high frequencies, as reported by Ceylan et al.[34] (1996), Kılıç et al.[10] (2016), Micheletti et al.[5] (2012), and De Stefano et al.[8] (2009). These findings align with reductions in ABG and improvements in tympanometric curves and acoustic reflexes, as noted by Rosso et al.[4] (2021) and De Stefano et al.[8] (2009). The meta-analysis across eight studies demonstrated a pooled mean difference (MD) of -6.56 dB (95% CI: -10.32 to -2.81), confirming significant auditory gains. Although modest in some cases, these improvements are clinically meaningful, particularly for children with moderate conductive hearing loss.

Long-term stability remains uncertain. While older studies, such as Laptook[16] (1981), suggested that auditory improvements after RME could be sustained, others[12,34] documented relapses. Variations in expander types (e.g., Hyrax, Haas), retention periods, and patient characteristics, including conditions like Down syndrome[35], may account for these discrepancies.

The included studies exhibited considerable heterogeneity (I^2 = 88%), likely due to differences in study populations, expander protocols, and follow-up periods. Methodological issues, such as moderate risks of bias from inadequate blinding and randomization, were also present. For example, Ceylan et al.[34] (1996) had a high risk of bias due to insufficient control of confounding factors like hearing loss severity and comorbidities. Additionally, small sample sizes and differences in audiometric assessments contributed to variability in findings.

Our meta-analysis confirmed a statistically significant improvement in hearing thresholds, with a pooled MD of -6.56 dB. The comparison between RME and control groups showed an MD of -5.25 dB (95% CI: -9.89 to -0.62), indicating clinically relevant improvements, particularly for speech and language development in children. However, the outcome variability (I^2 = 74%) underscores the need for individualized treatment approaches. Factors such as expander type, retention duration, and patient anatomy should be carefully considered.

Future research should include larger, rigorously designed randomized controlled trials with standardized protocols. These studies should focus on consistent audiometric evaluations and long-term follow-ups to confirm the sustained benefits of RME. Research on specific populations, such as children with syndromic conditions, would provide valuable insights due to their unique anatomical characteristics. Additionally, innovations in expander designs and retention protocols may enhance clinical outcomes and reduce the risk of relapse.

These findings are consistent with previous reviews, including those by Bueno et al.[38] (2016) and Fagundes et al.[39] (2017), which emphasized the auditory benefits of RME. However, unlike those studies, our review used the ROBINS-I tool for observational studies, offering a more detailed assessment of methodological limitations. Including recent studies[4,9,12] ensures that this review reflects the most current evidence. The GRADE assessment indicated that most studies provided low to moderate-quality

evidence, emphasizing the importance of cautious interpretation and the need for high-quality trials.

In conclusion, this systematic review suggests that Rapid Maxillary Expansion (RME) may improve hearing in patients with maxillary atresia and conductive hearing loss, particularly in mid and high frequencies, with a reduced air-bone gap. However, the long-term sustainability of these benefits remains uncertain due to the observed variability in study methodologies, patient populations, and expander types, with some studies reporting a relapse in hearing improvement following the retention period. The moderate risk of bias and limitations in study design, such as lack of blinding and control for confounding factors, combined with the moderate certainty of the evidence as evaluated by GRADE, highlight the need for cautious interpretation of these results and for further high-quality randomized controlled trials to confirm the findings. Although the results are promising, the evidence is insufficient to recommend RME as a standard intervention for conductive hearing loss without further individualized patient assessments and high-quality research confirming long-term outcomes. Future high-quality randomized clinical trials with extended follow-up are necessary to confirm the efficacy of RME in improving hearing and to establish protocols that ensure the durability of its positive effects.

Data availability

The dataset related to this article will be available upon request to the corresponding author.

Conflict of interest

The authors have no conflict of interest to disclose.

Author contribution

Luciana Alves de Souza Leite, José Mauro Granjeiro, and **José de Albuquerque Calasans-Maia:** contributed significantly to all major activities related to the development of this article: Study conception and design, data collection and analysis, interpretation of results, manuscript writing and revision, approval of the final version. The authors assume responsibility for the published content and are available to respond to any queries regarding the integrity and accuracy of the work.

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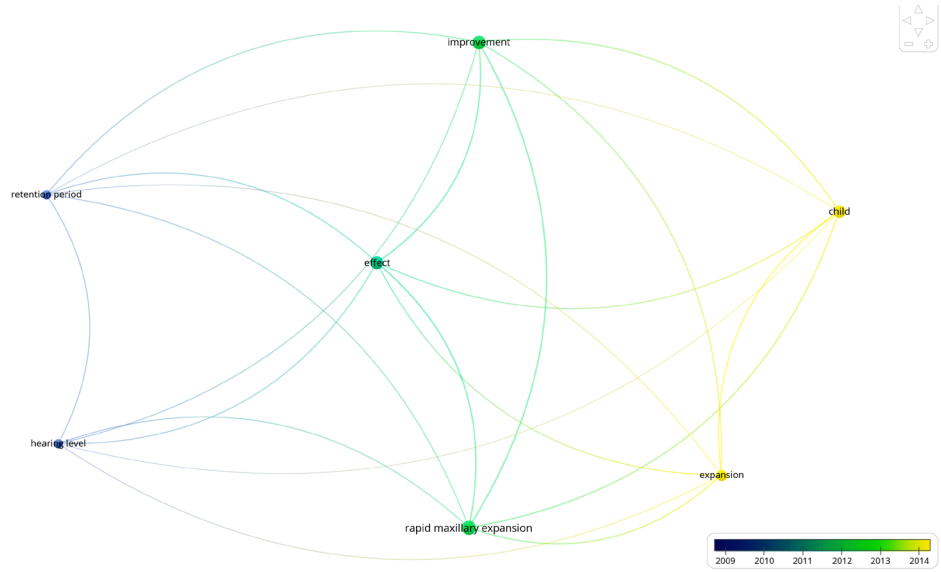
Supplementary Material

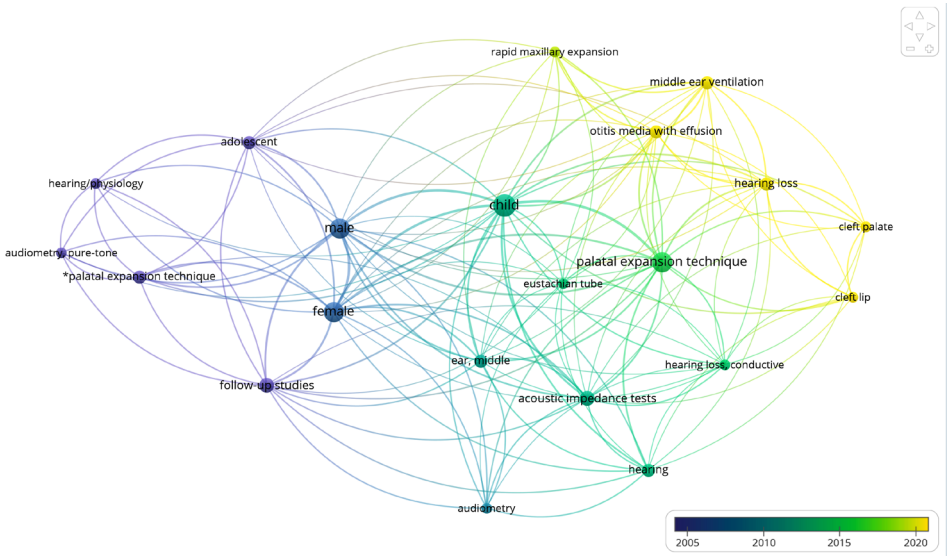
Supplementary Material Table S1. Reasons for exclusion of articles after full-text reading.

Author/Year	Title	Reason for Exclusion
Fatima et al.[26] (2022)	Effects of RME on Hearing in UCLP Patients: A Pilot Study. Cleft Palate.	The study was conducted on patients without hearing loss.
Kilic et al.[18] (2008)	Effects of semirapid maxillary expansion on conductive hearing loss.	The study used semi-rapid maxillary expansion as the intervention.
Çoban Büyükbayraktar et al.[27] (2022)	Evaluation of rapid maxillary expansion or alternating rapid maxillary expansion and constriction on Eustachian tube function with audiological tests: A randomized clinical trial.	Patients included in the study did not have hearing loss.
Kamińska et al.[28] (2008)	Laryngological effects of palatal suture expansion	Inaccessible language.
Zhang et al.[29] (2010)	A potential therapeutic method for conductive hearing loss in growing children—orthodontic expansion treatment.	The study did not provide sufficient data for analysis.
Cozza et al.[17] (2007)	Orthodontist-otorhinolaryngologist: an interdisciplinary approach to solving otitis media.	The study did not evaluate hearing at the time points determined by eligibility criteria.
Sharma et al.[30] (2022)	Rapid maxillary expansion, sleep-disordered breathing, and conductive hearing loss in children: a correlation.	The study did not evaluate hearing at the time points determined by eligibility criteria.
Ghafari et al.[31] (2012)	The benefits of consulting with an ear, nose, and throat (ENT) specialist before and during orthodontic treatment.	The study did not perform maxillary expansion.
Neri et al.[32] (2009)	Rapid maxillary expansion in the treatment of recurrent middle ear otitis.	Study not found for full-text reading.
Peyvandi et al.[33] (2014)	Relationship between conductive hearing loss and maxillary constriction.	The study did not perform rapid maxillary expansion.

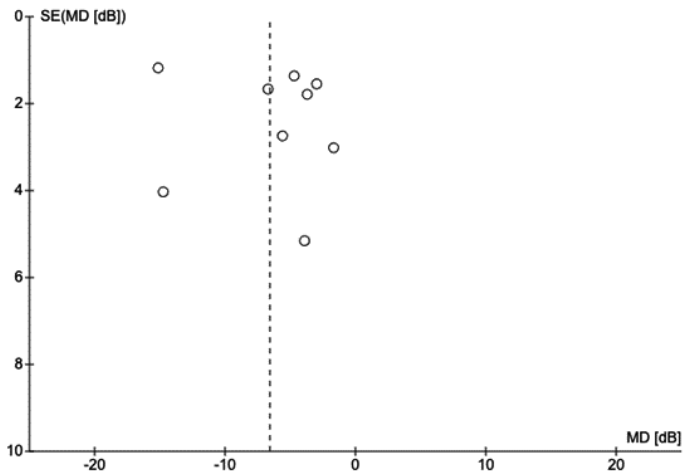


Supplementary Material Figure S1. Co-occurrence Map of Terms Extracted from the Titles and Abstracts of the Articles Included in the Systematic Review.

The bibliometric analysis identified two main clusters: one related to rapid maxillary expansion and its effects (green) and another related to hearing and otitis media (blue). The size of the nodes represents the frequency of term occurrence, while the thickness of the lines indicates the strength of co-occurrence between terms. The color gradient bar (blue to yellow) represents the year of publication of the articles.



Supplementary Material Figure S2. Co-occurrence Analysis of Keywords from the Articles Included in the Systematic Review Using VOSviewer Software. Three main clusters were identified, representing the predominant themes in the literature: effects of rapid maxillary expansion (purple), otitis media with effusion and hearing loss (green), and nasal obstruction and airway issues (blue). The color gradient bar (blue to yellow) represents the year of publication of the articles.



Supplementary Material Figure S3. The funnel plot was used to assess the risk of publication bias in the studies included in the meta-analysis. The X-axis represents the Mean Difference (MD) in decibels (dB), and the Y-axis represents the standard error (SE) of the studies. The dashed line indicates the combined mean difference.