Systematic Review

Rapid Maxillary Expansion for Pediatric Obstructive Sleep Apnea: A Systematic Review and Meta-Analysis

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Objectives/Hypothesis: To perform a systematic review with meta-analysis for sleep study outcomes in children who have undergone rapid maxillary expansion (RME) as treatment for obstructive sleep apnea (OSA).

Data Sources: PubMed/MEDLINE and eight additional databases.

Review Methods: Three authors independently and systematically reviewed the international literature through February 21, 2016.

Results: Seventeen studies reported outcomes for 314 children (7.6 ± 2.0 years old) with high-arched and/or narrow hard palates (transverse maxillary deficiency) and OSA. Data were analyzed based on follow-up duration: ≤3 years (314 patients) and >3 years (52 patients). For ≤3-year follow-up, the pre- and post-RME apnea–hypopnea index (AHI) decreased from a mean ± standard deviation (M ± SD) of 8.9 ± 7.0/hr to 2.7 ± 3.3/hr (70% reduction). The cure rate (AHI <1/hr) for 90 patients for whom it could be calculated was 25.6%. Random effects modeling for AHI standardized mean difference (SMD) is −1.54 (large effect). Lowest oxygen saturation (LSAT) improved from 87.0 ± 9.1% to 96.0 ± 2.7%. Random effects modeling for LSAT SMD is 1.74 (large effect). AHI improved more in children with previous adenotonsillectomy or small tonsils (73–95% reduction) than in children with large tonsils (61% reduction). For >3-year follow-up (range = 6.5–12 years), the AHI was reduced from an M ± SD of 7.1 ± 5.7/hr to 1.5 ± 1.8/hr (79% reduction).

Conclusions: Improvement in AHI and lowest oxygen saturation has consistently been seen in children undergoing RME, especially in the short term (<3-year follow-up). Randomized trials and more studies reporting long-term data (≥3-year follow-up) would help determine the effect of growth and spontaneous resolution of OSA.

Key Words: Obstructive sleep apnea, sleep medicine, sleep apnea, systematic review, meta-analysis.

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INTRODUCTION

Obstructive sleep apnea (OSA) has been treated with medical therapies (e.g., continuous positive airway pressure devices,[1] oral appliances,[2] nasal devices, myofunctional therapy[3]) and sleep surgeries (e.g., soft tissue surgeries,[4] maxillomandibular advancements,[5] tonsillectomies,[6] hypoglossal nerve stimulation,[7] and tracheostomies[8]). Patients with high-arched and/or narrow hard palates (transverse maxillary deficiency) are predisposed to OSA and often have dental crowding and malocclusion, which can be treated with rapid maxillary expansion (RME).

In children, RME is generally performed without the need for surgery by using orthodontic appliances, which often have an expansion screw with multiple arms that apply forces directly to the maxillary suture through the anchor teeth.[9] RME causes palatal widening, flattening of the palatal arch with inferior displacement of the maxilla, and change in alignment of the mandible. A recent meta-analysis has been published with regard to the isolated effect of maxillary expansion in adults with OSA.[10] However, based on our searches, only two full-article systematic reviews[11,12] (one with meta-analysis[11]) have been performed evaluating RME

as treatment for pediatric OSA. The meta-analysis[11] evaluated the effect of orthodontic treatments to include RME, RME with myofunctional appliance, and orthopedic mandibular advancement appliances in children with OSA. Even with these two well-performed studies,[11,12] gaps in the academic literature relating to the pre versus post-RME outcomes remain, which include: 1) systematic review of non-English language studies, 2) updated apnea–hypopnea index (AHI) and oxygen saturation values (e.g., lowest oxygen saturation [LSAT]), 3) updated mean differences (MDs) and standardized mean differences (SMDs), 4) overall percentage change in AHI and LSAT, and 5) subanalyses evaluating variables affecting RME success.

Therefore, the objective of this study was to systematically review international literature for RME as treatment for pediatric OSA, followed by a meta-analysis on the available data.

METHODS/LITERATURE SEARCH

Guidelines

During this study, the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) statement[13] was adhered to as much as possible.

Information Sources

Book Citation Index (Science), CINAHL, Conference Proceedings Citation Index (Science), Embase, Google Scholar, PubMed, Scopus, the Cochrane Collaboration Databases, and Web of Science comprised the information sources.

Search

Searches were tailored to the specific databases. An example of a search on PubMed is: ((((("Sleep") OR ("Apnea") OR ("Apnoea") OR ("Hypopnea") OR ("Hypopnoea") OR ("Respiratory Disturbance Index")) AND (((("Biobloc") OR ("Palatal Expansion Technique"[Mesh]) OR ("Maxilla") OR ("Maxillary") OR ("Palatal") OR ("Palate") OR ("Orthodontic")) AND ((("Distraction") OR ("Widening") OR ("Expansion")))).

Study Selection

Inclusion criteria for this review were: 1) children (<18 years old) with OSA, 2) pre- and post-RME quantitative data are reported, 3) all languages, 4) all study designs and publication types were considered, 5) any year, and 6) both published and unpublished data were sought out. Exclusion criteria were: 1) studies that are not about RME as treatment for OSA, and 2) studies that do not provide quantitative data. Authors were contacted to obtain additional data as needed.

Outcomes Measures in This Analysis

The specific outcome measures we searched for included: AHI, apnea index, oxygen desaturation index, LSAT, and mean oxygen saturation.

ASSESSMENT OF STUDY QUALITY: METHODOLOGICAL STUDY QUALITY ASSESSMENT

For quality assessment, the National Institute for Health and Clinical Excellence (NICE) tool for case series was used.[14] We graded studies as having high quality if ≥6 NICE criteria were met.

Summary Measures

The null hypothesis for this review is that there is no difference in the pre or post-RME quantitative polysomnography data. Pre-RME data were compared to post-RME data by evaluating the mean (M), standard deviation (SD), mean difference, 95% confidence interval (CIs), standardized mean difference using Hedges g, and percentage change in assessed variables.

Synthesis of Results/Statistical Analyses

Statistical analyses were performed by using two programs: 1) STATA 14.1 (StataCorp, College Station, TX) and 2) Review Manager Software (REVMAN) version 5.3 (Nordic Cochrane Center, Copenhagen, Denmark; Cochrane Collaboration, 2014). REVMAN 5.3 was used for calculating MDs, SMDs, and 95% confidence intervals. The magnitude of the effect for the SMD was categorized by using Cohen's guidelines (small = 0.2, medium = 0.5, and large = 0.8).[15]

Heterogeneity and Risk of Bias

REVMAN was used to assess the heterogeneity and inconsistency between studies. The I^2 statistic values were categorized as follows: 1) low-inconsistency $I^2 = 25\%$, 2) moderate-inconsistency $I^2 = 50\%$, and 3) high-inconsistency $I^2 = 75\%$.[16] A Cochran Q statistic P-value $\leq .10$ was the cutoff value used to define statistically significant heterogeneity.[17] REVMAN funnel plots were visually inspected to evaluate for the risk of bias if 10 or more studies reported outcomes for the variable of interest, as recommended by the Cochrane Collaboration.

Data Collection Process

Three authors (M.C., J.A., and V.C.) independently and systematically searched the international literature from January 1, 2015 through February 21, 2016.

RESULTS

Study Selection

After searching through the databases, 213 study titles and abstracts were screened and 110 potentially relevant studies were downloaded for detailed review (see Supporting Fig. 1 in the online version of this article). After review of the downloaded studies, eight[18–25] had duplicate and/or cumulative data, whereas 17 studies[9,26–41] met criteria and had unique data.

Study Characteristics

The NICE quality assessment tool identified four studies of high quality (≥6 NICE criteria met), and nine studies met <6 NICE criteria (see Table I).

TABLE I.
General Characteristics and Quality Criteria of Included Studies.

Study, Design	Study Site	Outcomes Analyzed	Quality Assessment*							
			1	2	3	4	5	6	7	8
Fatsuca et al. 2015, PCS	Italy	AHI, LSAT	No	Yes	Yes	Yes	Yes	No	Yes	No
Pirelli et al. 2015, PCS	Italy	AHI, LSAT	No	Yes	Yes	Yes	Yes	No	Yes	No
Taddei et al. 2015, PCC	Italy	AHI, ESS, LSAT, ODI	No	Yes	Yes	Yes	Yes	No	Yes	No
Villa et al. 2015, PCC	Italy	AHI, LSAT	No	Yes	Yes	Yes	Yes	Yes	Yes	No
Kim 2014, RCR	Korea	AHI, LSAT, RDI, T < 90	NA	NA	NA	NA	NA	NA	NA	NA
Villa et al. 2014, PCC	Italy	AHI, MSAT	No	Yes	Yes	Yes	Yes	Yes	Yes	No
Guilleminault et al. 2013, RCC	Multiple	AHI, LSAT	Yes	Yes	Yes	Yes	No	No	Yes	No
Goncalves et al. 2012, PCS	Brazil	AHI	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Marino et al. 2012, RCS	Italy	AHI, CEPH	No	Yes	Yes	Yes	No	No	Yes	No
Pirelli et al. 2012, PCS	Italy	AHI, LSAT	No	Yes	Yes	Yes	Yes	No	Yes	No
Guilleminault et al. 2011, PRT	France-Italy	AHI, LSAT	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Villa et al. 2011, PCS	Italy	AHI, MSAT	No	Yes	Yes	Yes	Yes	No	Yes	No
Pirelli et al. 2010, PCS	Italy	AHI, LSAT	No	Yes	Yes	Yes	Yes	No	Yes	No
Hosselet et al. 2009, RCS	France	AHI	No	Yes	No	No	No	Yes	No	No
Miano et al. 2009, PCC	Italy	AHI, LSAT, MSAT	No	Yes	Yes	Yes	Yes	No	Yes	No
Villa et al. 2007, PCS	Italy	AHI, MSAT	No	Yes	Yes	Yes	Yes	No	Yes	No
Rose & Schessl 2006, RCR	Germany	LSAT	NA	NA	NA	NA	NA	NA	NA	NA

*Quality assessment of cases series studies checklist from National Institute for Health and Clinical Excellence: 1) Case series collected in more than one center, i.e., multi-center study? 2) Is the hypothesis/aim/objective of the study clearly described? 3) Are the inclusion and exclusion criteria (case definition) clearly reported? 4) Is there a clear definition of the outcomes reported? 5) Were data collected prospectively? 6) Is there an explicit statement that patients were recruited consecutively? 7) Are the main findings of the study clearly described? 8) Are outcomes stratified (e.g., by abnormal results, disease stage, patient characteristics)?

AHI = apnea–hypopnea index; CEPH = cephalograms; ESS = endoscopic sinus surgery; LSAT = lowest oxygen saturation; MSAT = mean oxygen saturation; NA = not applicable; ODI = oxygen desaturation index; PCC = prospective case control; PCS = prospective case series; PRT = prospective randomized trial; RCC = retrospective case control; RCR = retrospective case report; RCS = retrospective case series; RDI = respiratory disturbance index; T <90 = time spent under 90% oxygen saturation.

Outcomes

Seventeen pediatric studies with 314 unique patients met criteria (age = 7.6 ± 2.0 years). Data were analyzed based on follow-up duration: ≤3 years (314 patients) and >3 years (52 patients). Marino et al.[34] reported median values for 25 patients, and after contacting the authors, Ms and SDs were available for 15 patients. For Pirelli et al.,[33] the originally submitted manuscript's data (some unpublished) were obtained, which supplied additional polysomnography data allowing inclusion of 40 patients who underwent RME. Drs. Guilleminault, Villa, and Pirelli reviewed their articles and provided Ms and SDs if the data were not in the articles, and also assisted in identifying which articles published cumulative data. With regard to complications, only one study reported outcomes and stated that there were no complications.[33] The final overall outcomes (including newly obtained data) are presented in Table II.

AHI. For ≤3-year follow-up, the pre- and post-RME AHI decreased from an M ± SD of 8.9 ± 7.0/hr to 2.7 ± 3.3/hr (70% reduction) in 313 patients. The random effects model calculation (n = 312 patients) demonstrates a mean difference of −4.84/hr (95% CI = −8.47 to −1.21), overall effect z = 2.62, and P = .009. The Q statistic is $P < .00001$ (significant heterogeneity) and I^2 = 99% (high inconsistency; see Fig. 1). Random effects modeling (n = 312 patients) for the AHI SMD is −1.54 (large magnitude of effect using Cohen's guidelines; 95%

CI = −2.29 to −0.78, overall effect z = 3.99, $P < .0001$). The Q statistic is $P < .00001$ (significant heterogeneity) and I^2 = 94% (high inconsistency; see Fig. 1). For >3-year follow-up (range = 6.5–12 years), the AHI was reduced from an M ± SD of 7.1 ± 5.7/hr to 1.5 ± 1.8/hr (79% reduction; $P < .0001$).

Cure rate (AHI < 1/hr). Each article was reviewed to assess for success and cure rates, as reported by the authors. No success or cure rates were reported in the studies by Fatsuca et al.,[29] Guilleminault et al.,[37] Miano et al.,[38] Marino et al.,[34] Pirelli et al.,[9,28] Taddei et al.,[27] or Villa et al.[18,30,40] Guilleminault et al.[32] preselected patients who were cured of OSA as younger children and then followed them through their teenage years; therefore, the cure rate in that group was by definition 100% (29 of 29). Pirelli et al.[33] reported 15 of 40 patients (37.5%) of group 1 (no previous adenotonsillectomy) were cured, whereas six of 40 (15%) of group 2 (previous adenotonsillectomy) were cured, for an overall cure rate of 26.3%. Individual patient data were provided by Goncalves et al.,[35] Kim,[31] and Rose and Schessl.[41] For the nine patients in the study by Goncalves et al.,[35] if cure is set at ≤1/hr, then the cure rate is two of nine patients (22%), and if cure is set at ≤2/hr, then the cure rate is five of nine patients (55%). The case study by Kim[31] demonstrated a decrease in AHI from 18.9 to 1.0/hr, and the case study by Rose and Schessl[41] only reported LSAT. Excluding the study by Guilleminault et al.,[32] in which the patients were preselected based on being cured,

Study	No.	Age, yr	BMI, kg/m^2	F/U	Pre-RME AHI	Post-RME AHI	AHI % Change	Pre-RME LSAT	Post-RME LSAT
>3 year F/U									
Pirelli et al. 2015	23	8.6	22.7 ± 1.3	12.3 ± 1.5 yr	12.2 ± 2.6	0.4 ± 1.6	−96.7%	78.9 ± 8.6	95.1 ± 1.9
Guilleminault et al. 2013	29	7.6	15.8 ± 2.0	6.5 ± 1.0 yr	3 ± 4	2.3 ± 1.5	−23.3%	94 ± 3	93.9 ± 2.5
Total	52	8.2	—	—	7.07 ± 5.74	1.46 ± 1.80	−79.3%	87.32 ± 9.71	94.43 ± 2.31
≤3 year F/U									
Fatsuca et al. 2015	22	8.3 ± 0.9	NR	1 yr	5.0 ± 1.5	1.5 ± 0.6	−71.1%	90.2 ± 1.3*	95.9 ± 1.5*
Taddei et al. 2015	30	8.9 ± 0.8	NR	1.9 yr	5.2 ± 1.0	4.8 ± 1.0	−7.7%	NR	NR
Villa et al. 2015	21	6.2 ± 1.7	19.9 ± 2.2	1 yr 5 mo	5.7 ± 3.5	2.8 ± 3.0	−51.2%	97.3 ± 1.5	97.6 ± 0.9
Kim 2014	1	11	22.4	2 yr 5 mo	18.9	1.0	−94.7%	60	94
Villa et al. 2014	22	6.6 ± 1.8	18.8 ± 3.4	1 yr	5.8 ± 6.1	2.6 ± 1.5	−55.2%	96.6 ± 1.5*	97.4 ± 1.8*
Guilleminault et al. 2013	29	7.8 ± 1.8	NR	10 mo	3 ± 4	0.4 ± 0.4	−86.7%	94 ± 3	98 ± 1.5
Goncalves et al. 2012	9	6 (4−10)	NR	6 mo	6.9 ± 4.8	2.2 ± 1.5	−68.3%	NR	NR
Marino et al. 2012	15	5.9 ± 1.6	NR	1.6 ± 0.6 yr	4.5 ± 3.8	3.4 ± 4.3	−24.8%	NR	NR
Pirelli et al. 2012	40	7.1 ± 0.8	<24	4 mo	12.1 ± 4.9	5.4 ± 5.4	−55.4%	84.6 ± 2.7	95.2 ± 3.5
Guilleminault et al. 2011	31	6.5 ± 1.1	NR	3 mo	7.9 ± 3.2	3.1 ± 2.3	−60.8%	93.9 ± 1.4	97.0 ± 1.1
Villa et al. 2011†	10	6.6 ± 2.1	16.7 ± 3.6	2 yr 11 mo	6.3 ± 4.7	2.3 ± 1.7	−63.5%	95.8 ± 1.8*	97.7 ± 1.0*
Pirelli et al. 2010	60	8.7	<24	11–17 mo	16.3 ± 2.5	0.8 ± 1.3	−95.1%	77.9 ± 8.4	95.4 ± 1.4
Hosselet et al 2009	10	12 ± 5	NR	NR	9 ± 7.6	4 ± 2.9	−55.6%	NR	NR
Miano et al. 2009	9	6.4 ± 2.0	18.0 ± 3.5	1 yr	17.4 ± 21.0	5.4 ± 6.3	−69.0%	91.3 ± 3.5	90.5 ± 2.9
Villa et al. 2007	14	6.9 ± 2.2	16.7 ± 3.6	12 mo	5.8 ± 6.8	1.5 ± 1.6	−74.1%	96.0 ± 1.8*	96.7 ± 2.4*
Rose & Schessl 2006	1	8	NR	2 mo	NR	NR	NR	68	88
Total	314	7.6 ± 2.0	18.6 ± 3.3	≤3 yr	8.9 ± 7.0	2.7 ± 3.3	−70%	87.0 ± 9.1	96.0 ± 2.7

*Mean oxygen saturation.
†Unique data at 2 years 11 months, however, excluded from total calculations as this is a subset from Villa et al. 2007.
AHI = apnea–hypopnea index; BMI = body mass index; F/U = follow-up; LSAT = lowest oxygen saturation; NR = not reported; RME = rapid maxillary expansion.

the remaining studies provided a cure rate (<1/hr) of 25.6% (23 of 90 children).

Lowest oxygen saturation. For follow-up of ≤3 years, the lowest oxygen saturations improved from 87.0 ± 9.1% to 96.0 ± 2.7%, a 9.0% improvement in 191 patients. Random effects modeling (190 patients) demonstrated an LSAT MD of 5.78 (95% CI = 1.99-9.58, overall effect z = 2.99, P = .003). The Q statistic is P < .00001 (significant heterogeneity) and I^2 = 99% (high inconsistency; see Fig. 2). Random effects modeling (190 patients) for LSAT SMD is 1.74 (large magnitude of effect using Cohen's guidelines; 95% CI = 0.67-2.82, overall effect z = 3.17, P = .002). The Q statistic is P < .00001 (significant heterogeneity) and I^2 = 94% (high inconsistency; see Fig. 2). For >3-year follow-up, one study reported outcomes (12-year follow-up); compared to baseline, the LSAT improved from 87.3 ± 9.7% to 94.4 ± 2.3% (P < .0001).

Variables affecting outcomes. COMORBIDITIES. Most studies specifically excluded patients with comorbidities or syndromes. One study (by Taddei et al.[27]) specified the comorbidity of Marfan syndrome in 30 children who had minimal AHI improvement as a group, from 5.2 ± 1.0/hr to 4.8 ± 1.0/hr (7.7% reduction).

QUALITY OF THE STUDY. For the four studies[26,30,35,37] with higher quality (≥6 NICE criteria met), the ≤3-year outcomes include: 1) the AHI MD is −4.07/hr (95% CI = −5.07 to −3.07), 2) the AHI SMD is −1.12 (95% CI = −1.60 to −0.64; large effect), 3) the LSAT MD is 1.71 (95% CI = −1.04 to 4.45), and 4) the LSAT SMD is 1.33 (95% CI = −0.82 to 3.48; large effect). For the nine studies [9,27,29,32–34,38–40] meeting ≤5 NICE quality assessment tool criteria, the ≤3-year outcomes include: 1) the AHI MD is −5.32/hr (95% CI = −10.11 to −0.53), 2) the AHI SMD is −1.74 (95% CI = −2.85 to 0.63; large effect), 3) the LSAT MD is 7.87 (95% CI = 1.51-14.24), and 4) the LSAT SMD is 1.95 (95% CI = 0.65-3.26). Note that the above calculations exclude the case reports[31,41]; the Villa et al. 2011 study,[36] as it is a subset of the Villa et al. 2007 study[40]; and the Pirelli et al. 2015 study,[28] because the data are long term (10-year follow-up).

Previous adenotonsillectomy versus no previous adenotonsillectomy. A subanalysis was performed based on the studies reporting: 1) a) previous adenotonsillectomy or b) mixed previous adenotonsillectomy with small tonsils; or 2) no surgery: a) small tonsils, b) large tonsils, or c) mixed small and large tonsils. Villa 2015,[26] Taddei et al.,[27] Fatsuca et al.,[29] Marino et al.,[34] and Hosselet et al.[39] did not report either tonsil sizes or whether there was any prior surgery, and therefore were excluded from this subanalysis.

Previous adenotonsillectomy. The subject of Kim's case report[31] had been previously treated with adenotonsillectomy. Guilleminault et al.'s 2013 study[32]

Study or Subgroup	Post-Rapid Maxillary Exp Mean	SD	Total	Pre-Rapid Maxillary Exp Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI	Year
Villa 2015	2.8	3	21	5.7	3.5	21	8.2%	-2.90 [-4.87, -0.93]	2015
Taddei 2015	4.8	1	30	5.2	1	30	8.3%	-0.40 [-0.91, 0.11]	2015
Fatsuca 2015	1.5	0.6	22	5	1.5	22	8.3%	-3.50 [-4.18, -2.82]	2015
Villa 2014	2.6	1.5	22	5.8	6.1	22	8.0%	-3.20 [-5.82, -0.58]	2014
Guilleminault 2013	0.4	0.4	29	3	4	29	8.2%	-2.60 [-4.06, -1.14]	2013
Pirelli 2012	5.4	5.4	40	12.1	4.9	40	8.1%	-6.70 [-8.96, -4.44]	2012
Goncalves 2012	2.2	1.5	9	6.9	4.8	9	7.8%	-4.70 [-7.99, -1.41]	2012
Marino 2012	3.4	4.3	15	4.5	3.8	15	7.9%	-1.10 [-4.00, 1.80]	2012
Guilleminault 2011	3.1	2.4	31	7.9	3.2	31	8.2%	-4.80 [-6.21, -3.39]	2011
Pirelli 2010	0.8	1.3	60	16.3	2.5	60	8.3%	-15.50 [-16.21, -14.79]	2010
Miano 2009	5.4	6.3	9	17.4	21	9	3.6%	-12.00 [-26.32, 2.32]	2009
Hosselet 2009	4	2.9	10	9	7.6	10	7.2%	-5.00 [-10.04, 0.04]	2009
Villa 2007	1.5	1.6	14	5.8	6.8	14	7.7%	-4.30 [-7.96, -0.64]	2007
Total (95% CI)			312			312	100.0%	-4.84 [-8.47, -1.21]	

Heterogeneity: Tau² = 40.99; Chi² = 1193.24, df = 12 (P < 0.00001); I² = 99%
Test for overall effect: Z = 2.62 (P = 0.009)

Mean Difference IV, Random, 95% CI — Favors [Post RME] Favors [Pre RME]

Study or Subgroup	Post-Rapid Maxillary Exp Mean	SD	Total	Pre-Rapid Maxillary Exp Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI	Year
Villa 2015	2.8	3	21	5.7	3.5	21	7.9%	-0.87 [-1.51, -0.24]	2015
Taddei 2015	4.8	1	30	5.2	1	30	8.0%	-0.39 [-0.91, 0.12]	2015
Fatsuca 2015	1.5	0.6	22	5	1.5	22	7.5%	-3.01 [-3.89, -2.12]	2015
Villa 2014	2.6	1.5	22	5.8	6.1	22	7.9%	-0.71 [-1.32, -0.10]	2014
Guilleminault 2013	0.4	0.4	29	3	4	29	8.0%	-0.90 [-1.44, -0.36]	2013
Pirelli 2012	5.4	5.4	40	12.1	4.9	40	8.1%	-1.29 [-1.77, -0.80]	2012
Goncalves 2012	2.2	1.5	9	6.9	4.8	9	7.2%	-1.26 [-2.29, -0.22]	2012
Marino 2012	3.4	4.3	15	4.5	3.8	15	7.8%	-0.26 [-0.98, 0.46]	2012
Guilleminault 2011	3.1	2.4	31	7.9	3.2	31	8.0%	-1.68 [-2.26, -1.09]	2011
Pirelli 2010	0.8	1.3	60	16.3	2.5	60	7.2%	-7.73 [-8.79, -6.67]	2010
Miano 2009	5.4	6.3	9	17.4	21	9	7.4%	-0.74 [-1.70, 0.23]	2009
Hosselet 2009	4	2.9	10	9	7.6	10	7.4%	-0.83 [-1.76, 0.09]	2009
Villa 2007	1.5	1.6	14	5.8	6.8	14	7.7%	-0.85 [-1.62, -0.07]	2007
Total (95% CI)			312			312	100.0%	-1.54 [-2.29, -0.78]	

Heterogeneity: Tau² = 1.78; Chi² = 188.36, df = 12 (P < 0.00001); I² = 94%
Test for overall effect: Z = 3.99 (P < 0.0001)

Std. Mean Difference IV, Random, 95% CI — Favors [Post RME] Favors [Pre RME]
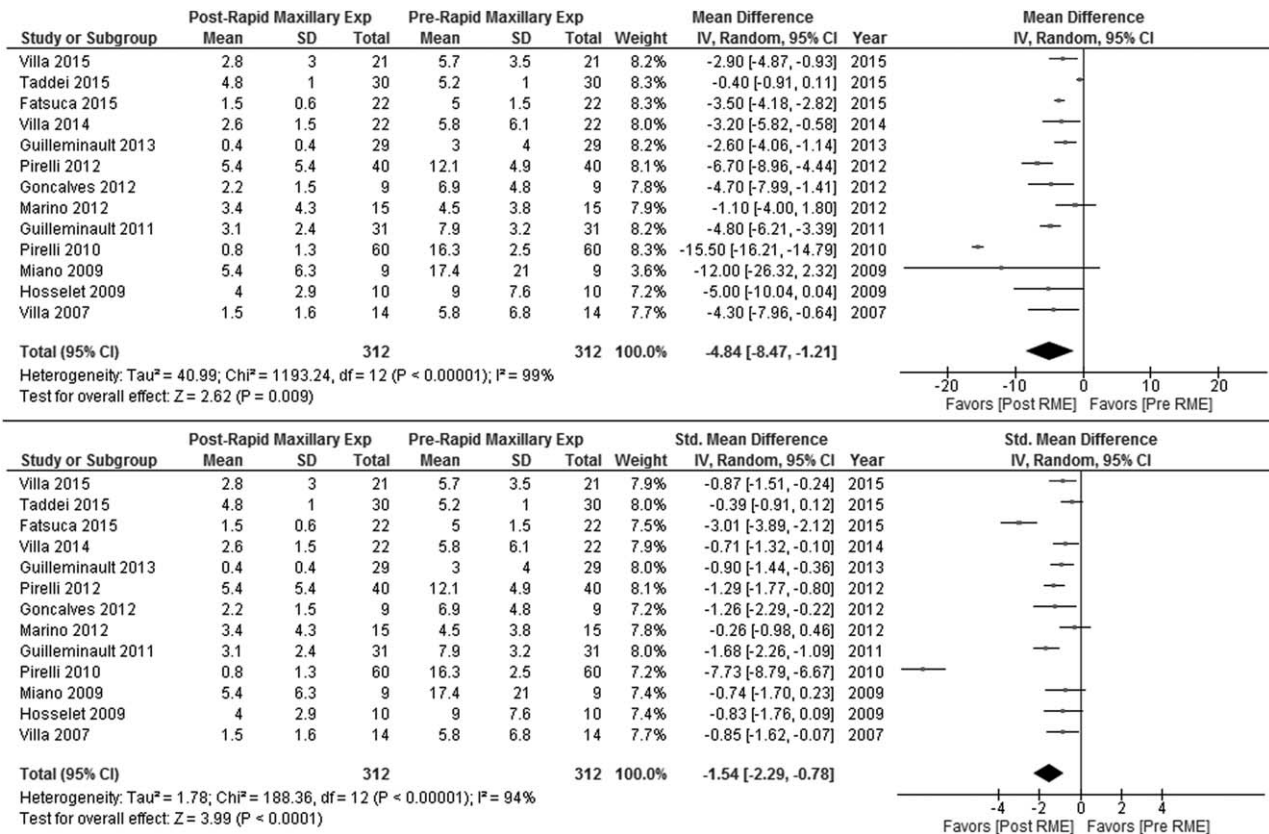
Fig. 1. Apnea–hypopnea index mean difference and standardized mean difference before and after rapid maxillary expansion (RME). CI = confidence interval; IV = inverse variance; SD = standard deviation.

reported outcomes for patients who had all undergone adenotonsillectomy prior to RME, with outcomes at three time intervals, including 6.5 years after RME. Guilleminault et al.' 2011 study[37] evaluated RME (group 1) after adenotonsillectomy in 16 children with narrow maxillas with high and narrow hard palates; AHI improved from 4.9 ± 0.6/hr to 0.9 ± 0.3/hr. Combining all studies, the AHI (46 patients) improved from 4.0 ± 4.0/hr to 0.6 ± 0.4/hr (MD = −3.4/hr, 95% CI = −4.6 to −2.2, P < .0001; 85% reduction).

Mixed previous adenotonsillectomy or small tonsils. Pirelli et al.[9] reported that 42 of 60 patients had previous adenotonsillectomy, and the remaining patients did not have adenotonsillar hypertrophy. The

Study or Subgroup	Post-Rapid Maxillary Exp Mean	SD	Total	Pre-Rapid Maxillary Exp Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI	Year
Villa 2015	97.6	0.9	21	97.3	1.5	21	17.1%	0.30 [-0.45, 1.05]	2015
Guilleminault 2013	98	1.5	29	94	3	29	16.9%	4.00 [2.78, 5.22]	2013
Pirelli 2012	95.2	3.5	40	84.6	2.7	40	16.9%	10.60 [9.23, 11.97]	2012
Guilleminault 2011	97	1.1	31	93.9	1.4	31	17.2%	3.10 [2.47, 3.73]	2011
Pirelli 2010	95.4	1.4	60	77.9	8.4	60	16.3%	17.50 [15.35, 19.65]	2010
Miano 2009	90.5	2.9	9	91.3	3.5	9	15.6%	-0.80 [-3.77, 2.17]	2009
Total (95% CI)			190			190	100.0%	5.78 [1.99, 9.58]	

Heterogeneity: Tau² = 21.75; Chi² = 345.89, df = 5 (P < 0.00001); I² = 99%
Test for overall effect: Z = 2.99 (P = 0.003)

Mean Difference IV, Random, 95% CI — Favors [Pre-RME] Favors [Post-RME]

Study or Subgroup	Post-Rapid Maxillary Exp Mean	SD	Total	Pre-Rapid Maxillary Exp Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI	Year
Villa 2015	97.6	0.9	21	97.3	1.5	21	16.9%	0.24 [-0.37, 0.85]	2015
Guilleminault 2013	98	1.5	29	94	3	29	16.9%	1.66 [1.06, 2.27]	2013
Pirelli 2012	95.2	3.5	40	84.6	2.7	40	16.6%	3.36 [2.67, 4.05]	2012
Guilleminault 2011	97	1.1	31	93.9	1.4	31	16.7%	2.43 [1.77, 3.10]	2011
Pirelli 2010	95.4	1.4	60	77.9	8.4	60	17.1%	2.89 [2.37, 3.40]	2010
Miano 2009	90.5	2.9	9	91.3	3.5	9	15.8%	-0.24 [-1.17, 0.69]	2009
Total (95% CI)			190			190	100.0%	1.74 [0.67, 2.82]	

Heterogeneity: Tau² = 1.70; Chi² = 83.38, df = 5 (P < 0.00001); I² = 94%
Test for overall effect: Z = 3.17 (P = 0.002)

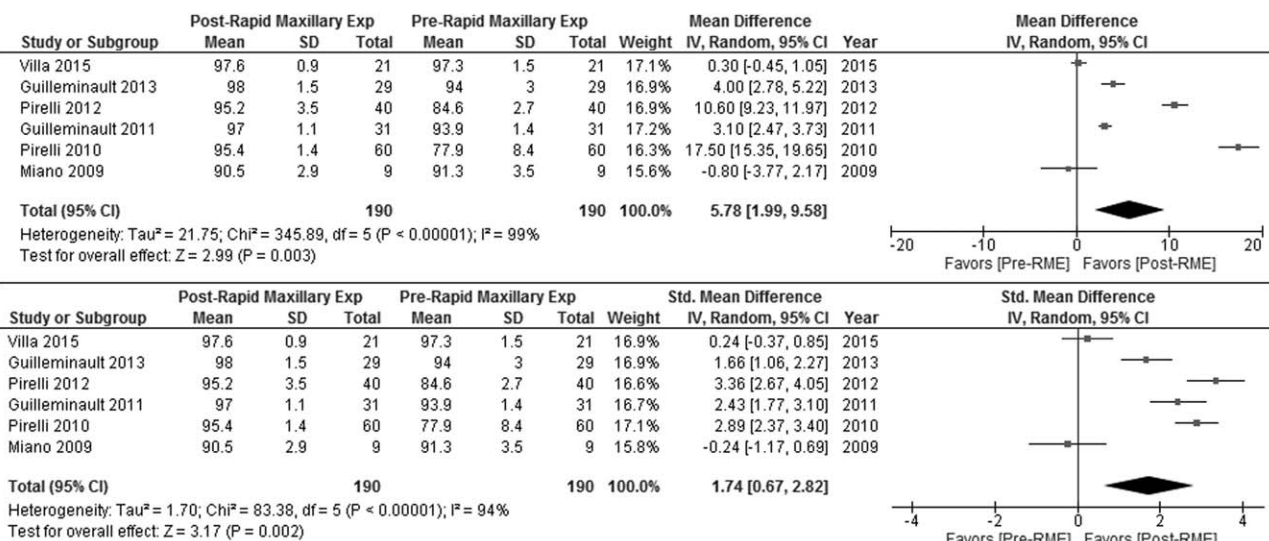Std. Mean Difference IV, Random, 95% CI — Favors [Pre-RME] Favors [Post-RME]

Fig. 2. Lowest oxygen saturation mean difference and standardized mean difference before and after rapid maxillary expansion (RME). CI = confidence interval; IV = inverse variance; SD = standard deviation.

TABLE III.
Pre– and Post–Rapid Maxillary Expansion Outcomes Based on Prior Adenotonsillectomy and Tonsil Size.

Tonsil Status	Pre-RME AHI	Post-RME AHI	AHI % Change	P
No tonsils, n = 46	4.0 ± 4.0	0.6 ± 0.4	−85%	<.0001
Mixed: no or small tonsils, n = 60	16.3 ± 2.5	0.8 ± 1.3	−95%	<.0001
Small tonsils, n = 71	12.1 ± 4.0	3.3 ± 4.8	−73%	<.0001
Large tonsils, n = 33	11.4 ± 11.6	4.5 ± 3.6	−61%	.002
Mixed: small or large tonsils, n = 45	6.0 ± 6.0	2.2 ± 1.6	−63%	<.0001

Small tonsils = grade 1; large tonsils = grades 2–4; Mixed = not substratified in the studies.
AHI = apnea–hypopnea index; RME = rapid maxillary expansion.

AHI in 60 patients improved from 16.3 ± 2.5/hr to 0.8 ± 1.3/hr (MD = −15.5/hr, 95% CI = −16.2 to −14.8, P < .0001; 95% reduction).

No prior surgery. SMALL TONSILS. Pirelli et al.'s 2015 study[28] reported that the patients had no prior adenotonsillectomy and had "absence of enlarged adenotonsils at baseline." Pirelli et al.'s 2012 study[33] performed RME on 40 patients without significant chronic tonsillitis or tonsillar enlargement. Combined outcomes at <2 years for AHI in both groups (71 patients) demonstrated an AHI improvement from 12.1 ± 4.0/hr to 3.3 ± 4.8/hr (MD = −8.8/hr, 95% CI = −10.3 to −7.3, P < .0001; 73% reduction).

LARGE TONSILS (GRADES 2–4). Villa et al.[36] excluded those with prior adenotonsillectomy and reported tonsil sizes as grade 2 (three of 10), grade 3 (five of 10), or grade 4 (two of 10). Miano et al.[38] reported that no patient had a prior adenotonsillectomy (all parents refused), and six of nine patients had grade 2 or 3 tonsils, whereas three of nine patients had grade 4 tonsils. Rose and Schessl[41] reported that the patient had an adenoidectomy; however, in the article's figure, the tonsils were 3+ bilaterally. Guilleminault et al.[37] performed RME in 14 patients (group 2) with grade 2 or larger tonsils and narrow maxillas with high and narrow hard palates, with an improvement in AHI from 11.1 ± 0.7/hr to 5.4 ± 0.6/hr. Combined outcomes (33 patients) demonstrated an AHI improvement from 11.4 ± 11.6/hr to 4.5 ± 3.6/hr (MD = −6.9/hr, 95% CI = −11.1 to −2.7, P = .002; 61% reduction).

MIXED SMALL AND LARGE TONSILS. Villa et al.'s 2014 study[30] excluded those with prior adenotonsillectomy and reported that grade 3 or 4 was present in nine of 22 children undergoing RME. For the nine patients in the study by Goncalves et al.,[35] seven patients had adenoid hypertrophy and six patients had tonsillar hypertrophy; however, the individual patient data were not stratified, so no success can be reported based on the presence or absence of adenoid and tonsillar hypertrophy. Villa et al.'s 2007 study[40] reported that the parents had refused adenotonsillectomy, and tonsil sizes were grade 1 (three of 14), grade 2 (five of 14), grade 3 (five of 14), and grade 4 (one of 14) for children. Combined outcomes (45 patients) demonstrated an AHI improvement from 6.0 ± 6.0/hr to 2.2 ± 1.6/hr (MD = −3.8/hr, 95% CI = −5.6 to −2.0, P < .0001; 63% reduction).

Summary of Outcomes Based on Prior Surgery and Tonsil Size

AHI outcomes based on the tonsil sizes and previous adenotonsillectomy are as follows: 1) previous adenotonsillectomy: 85% reduction, 2) mixed previous adenotonsillectomy or small tonsils: 95% reduction, 3) small tonsils: 73% reduction, 4) large tonsils: 61% reduction, and 5) mixed small and large tonsils: 63% reduction (see Table III).

Risk of Bias

There was a high risk of publication bias when evaluating AHI, because the funnel plots (Fig. 3 and Supporting Fig. 2 in the online version of this article) were skewed toward the center and did not have the appearance of an inverted funnel shape; for example, the funnel plot for SMD was clustered near an SMD of −1.5 and the standard error for SMD was clustered between 0.2 and 0.5 (see Fig. 3). The risk of bias was not assessed for LSAT because there are <10 studies reporting the variable.

DISCUSSION

There are four main findings. First, AHI has improved after RME in children with OSA. AHI decreased (313 patients) from a M ± SD of 8.9 ± 7.0/hr to 2.7 ± 3.3/hr. This is a 70% improvement in the AHI. The effect both was statistically significant and demonstrated a large effect size (SMD = −1.54). The least successful group based on percentage reduction of the AHI
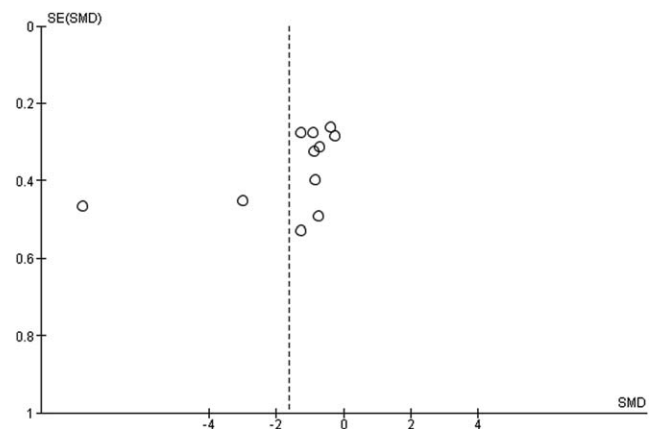

Fig. 3. Funnel plot for the standardized mean difference (SMD) of the apnea–hypopnea index. SE = standard error.

were the 30 patients who had Marfan syndrome (Taddei et al.[27]), with a minimal 7.7% AHI improvement as a group from 5.2 ± 1.0/hr to 4.8 ± 1.0/hr; this may possibly be associated with excessive tissue laxity in Marfan syndrome, which is too severe to overcome the palatal tensing effect afforded by maxillary expansion. The children in the study by Marino et al.[34] had a 24.8% reduction in AHI. Aside from these two studies, RME has been shown to provide at least a 50% reduction in the AHI and has been effective for either primary or secondary OSA treatment in children with transverse maxillary deficiency. RME could be considered as a primary treatment option in patients with small tonsils (grade 1) or as a secondary intervention in patients who have failed adenotonsillectomy and persist with OSA in the setting of high-arched and/or narrow hard palates. In most studies, the mean ages were between 6 and 8 years; however, RME can be performed up until the midpalatal suture fuses, which is typically into the teenage years. For patients who have undergone adenotonsillectomy and RME, with residual OSA, additional sites of obstruction during sleep could be considered, such as epiglottis collapase,[42] supraglottis collapse,[43] or tongue base collapse. The improvement in the obstructions is likely secondary to a combination of post-treatment benefits from RME that include: 1) increased size of the intranasal cavity with improvement in nasal airflow and thereby less mouth breathing, 2) the increased transverse maxillary width also allows for better tongue positioning during wakefulness and sleep, and 3) it is possible that the improved positioning of the maxillary teeth may stimulate the mandible to develop into a more normal position as the mandible grows in the child.

Second, RME has improved both mean oxygen saturation and lowest oxygen saturation after RME. For studies reporting LSAT, there was an improvement from 87.0 ± 9.1% to 96.0 ± 2.7% (9.0% improvement). The SMD was 1.74, which corresponds to a large magnitude of effect using Cohen's guidelines. The mean oxygen saturations in the articles reporting it improved between 0.4% to 5.7% depending on the study. Overall, there were no clear factors predicting which patients would have lesser or greater improvement in oxygenation. For future studies, to determine the true effect of RME on oxygenation, we would encourage authors to report multiple oxygen-related variables such as the mean oxygen saturation, lowest oxygen saturation, percentage of time spent <90% oxygen saturation, and oxygen desaturation index. Most studies report only one or two of these variables and that makes it difficult to make generalizable conclusions, especially without publication of individual patient data.

Third, regarding the variables affecting outcomes, a larger reduction in the AHI was observed among children with small (grade 1) or no tonsils when compared to children with large tonsils (grades 2–4). This is a logical finding given that those with large tonsils can continue to have oropharyngeal obstruction despite improvement at the level of the palate. It is difficult to state whether the improvement in obstructive sleep apnea outcomes persist in the long-term in patients who do not have a recurrence of OSA symptoms (i.e., sleepiness, difficulty

concentrating, etc.). With regard to study quality, the RME intervention had a large effect on the AHI and LSAT independent of the quality of the articles based on the NICE quality assessment tool. However, the one notable difference between the two groups is that the LSAT improved to a greater extent in the studies with low to moderate quality (7.87 oxygen saturation points) when compared to studies with higher quality (1.71 oxygen saturation points). The long-term data are very limited, and there can be relapse in some patients in the long-term, as Guilleminault et al.[32] found in patients with a recurrence of OSA symptoms 6.5 years after RME. In that study, among patients with recurrent symptoms, long-term follow-up sleep studies showed a mean AHI of 3.1 ± 1.0/hr (consistent with recurrent OSA), whereas in teenagers without OSA symptoms, the patients remained cured (AHI = 0.5 ± 0.2/hr). Interestingly, 16 of the 20 children with OSA recurrence had "high and narrow hard palates," and 14 of the 20 children had "an overjet of more than 2.5 mm," suggesting that these patients had skeletal relapse despite prior maxillary expansion.[32]

Fourth, there are many opportunities for future research. Research could be performed to explore whether repeat RME (without surgery) could be performed for patients who have OSA recurrence years after the initial treatment so long as the midpalatal suture has not fused. Currently, most studies are not randomized or controlled; therefore, it is impossible to know whether the children undergoing RME might have improved without any intervention at all and it is possible that some of the improvements seen in the sleep study parameters could be due to growth of the children or spontaneous resolution of OSA. Additional long-term studies, as performed by Dr. Pirelli et al., would help elucidate the lasting effects of RME for AHI and oxygen saturation during sleep. With regard to complications, only one study in this review[33] reported outcomes, and it stated there were no complications. We reviewed the RME literature, and a review article found that the midpalatal suture failed to open in 1.7% of patients; extremely rarely there were significant root resorptions and/or bone dehiscences; however, the study also found that side effects were often temporary and only rarely were there permanent changes.[44] Currently, there is no standardized nomenclature to reproducibly describe the extent of maxillary expansion that is achieved. The published articles vary widely in terms of measurements used to record changes in the width of the maxilla: interpalatal foramen distance, intermolar distance, midpalatal suture expansion, intercanine distance, and interpremolar distance. As such, there is a need for standardizing the terminology used to describe the results of this expansion technique; perhaps it would be useful to have a few different and complementary measurement techniques, each based on a series of anatomical landmarks and validated among raters. Typically, articles describe that the midpalatal suture is widened at a rate of about 0.5 mm daily over 10 to 14 days, and subsequently a retainer is kept in for 6 to 12 months.[9] Additionally, it can be difficult at times to determine whether a child has a high-arched and/or narrow hard palate. A

few signs include occlusal anomalies, dental crowding, and crossbite. Patients being considered for RME should be referred to a pediatric dentist or orthodontist, or a multidisciplinary sleep surgery and medicine center that includes a dental specialist.

Limitations

First, all of the included studies are level 5 (case reports) or level 4 (case series), with the exception of one randomized trial. Therefore, the studies report outcomes for different patient populations with different inclusion/exclusion criteria, and with inconsistent ascertainment of outcome measures. Because of these limitations, it is difficult to draw firm conclusions, other than that there did appear to be significant improvements in polysomnography parameters from baseline to follow-up (but with highly variable length of follow-up). Additionally, it is possible that despite the reporting of RME as the sole intervention between sleep studies, there may be patients who underwent additional interventions between sleep studies, especially when followed over long periods of time. Quality of life and snoring after RME were not reviewed, and therefore remain open to investigation by future researchers.

CONCLUSION

Improvement in AHI and lowest oxygen saturation has consistently been seen in children undergoing RME, especially in the short term (<3 years of follow-up). Randomized trials and more studies reporting long-term data (≥3 years of follow-up) would help determine the effect of growth and spontaneous resolution of OSA.

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