Review

American Journal of Rhinology & Allergy
0(0) 1–12

DOI: 10.1177/1945892421995350
journals.sagepub.com/home/ajr
SAGE

The Impact of Maxillary Expansion on Adults' Nasal Breathing: A Systematic Review and Meta-Analysis

Christian Calvo-Henriquez, MD[1], Joaquim Megias-Barrera, MD, PhD[2], Carlos Chiesa-Estomba, MD MS[3,4], Jerome R. Lechien, MD, MS, PhD[3,5], Byron Maldonado Alvarado, MD[1,3], Badr Ibrahim, MD[3,6], David Suarez-Quintanilla, MD, DDS, PhD[7,8], Sandra Kahn, DDS[9], and Robson Capasso, MD, PhD[6]

Abstract

Objective: Nasal surgery fails to restore nasal breathing in some cases. Maxillary constriction is suggested as a major cause of failure. It is thought that maxillary constriction leads to the closure of the internal and external nasal valves. Moreover, it is well established in the literature that maxillary expansion, both in adults and children, increases upper airway volume. However, it is yet unclear whether maxillary expansion may improve nasal function.

Review Methods: Pubmed (Medline), the Cochrane Library, EMBASE and Trip Database were checked by two authors from the Rhinology Study Group of the Young Otolaryngologists section of the International Federation of Otorhinolaryngological Societies. Two authors extracted the data. The main outcome was expressed as the value (in variable units) prior to treatment (T0), after expansion procedures (T1), after the retention period (T2), and after a follow-up period (T3).

Results: A total of 10 studies (257 patients) met the inclusion criteria. The data pooled in the meta-analysis reveals a statistically significant reduction of 0.27 Pa/cm^3/s (CI 95% 0.15, 0.39) in nasal resistance after palatal expansion As far as subjective changes are concerned, the pooled data for the change in the NOSE score shows a statistically significant mean reduction after maxillary expansion of 40.08 points (CI 95% 36.28, 43.89).

Conclusion: The initial available evidence is too limited to suggest maxillary expansion as a primary treatment option to target nasal breathing. However the data is encouraging with regards to the effect of maxillary expansion on nasal function. Further higher quality studies are needed in order to define clearer patient selection criteria, distinguish optimal techniques, and demonstrate long-term efficacy in long term follow up studies.

Keywords

palatal expansion, maxillary expansion, rhinomanometry, RPE, RME, SARPE, MARPE

[1]Service of Otolaryngology, Hospital Complex of Santiago de Compostela, Santiago, Spain
[2]Service of Maxillofacial Surgery, Hospital Complex of Santiago de Compostela, Santiago, Spain
[3]Rhinology Study Group of the Young-Otolaryngologists of the International Federations of Oto-rhino-laryngological Societies (YO-IFOS), Paris, France
[4]Service of Otolaryngology, Donostia University Hospital, San Sebastian, Spain
[5]Foch Hospital, University of Paris Saclay, Paris, France
[6]Department of Otolaryngology—Head and Neck Surgery, Sleep Surgery Division, Stanford University Medical Center, Stanford, California
[7]Orthodontic Private Practice, Santiago de Compostela, Santiago, Spain
[8]Department of Orthodontics, University of Santiago de Compostela, Santiago, Spain
[9]Orthodontic Private Practice, San Francisco, California

Corresponding Author:
Christian Calvo-Henriquez, Service of Otolaryngology, Hospital Complex of Santiago de Compostela, Travesía de Choupana, s/n. 15706 Santiago de Compostela, Spain.
Email: christian.calvo.henriquez@gmail.com

Introduction

Adequate nasal breathing is of paramount importance to healthy living. It is associated to improved quality of life,[1] is an essential prevention and treatment target in comprehensive sleep apnea management,[2] and promotes a healthy body posture,[3] among many other important functions. Unfortunately, impaired nasal breathing is highly prevalent. As a consequence, procedures aiming to improve nasal patency are the most commonly performed in otolaryngology.

Despite vast improvements in surgical techniques and devices, nasal surgery still fails to restore nasal breathing in some cases. Maxillary constriction has been suggested as a major cause[4] explaining these failures. It is thought that maxillary constriction leads to the closure of the internal and external nasal valves.[4]

Maxillary constriction is defined as the reduced transverse dimension of the upper jaw. It frequently leads to posterior crossbite, dental crowding, and high and narrow palatal vault leading to elevation of the nasal floor. It is one of the most frequent craniofacial skeletal deformity. Its prevalence has been estimated from 2.7 to 23.3%.[5,6]

Maxillary expansion (ME) is a common procedure to correct transverse maxillary deficiency. It is a distraction procedure whereby bone growth is induced along the mid-palatal suture. In adults, several methods have been described. Some involve exclusively orthopedic oral devices with an expansion screw welded to molar bands. Others are considered non-orthopedic. The latter are divided between surgical and non-surgical procedures. However, given the increased interdigitation at the midpalatal suture with advancing age,[7] exclusively orthopedic rapid expansion in adults produces predominantly dentoalveolar effects that can damage the periodontum[8] without increasing the size of the bony segments on either sides of the mid-palatal suture. Consequently, adults often require surgically assisted expansion. These involve the creation of a LeFort I osteotomy and a mid-palatal to free both maxillary halves and allow their movement. Several surgical techniques have been described and are commonly known by the acronym SARPE (Surgically Assisted Rapid Palatal Expansion). An intermediate treatment is based on microimplants anchored on the hard palate to optimize the application of mechanical forces to circummaxillary sutures and minimize unwanted tooth movements. These procedures are known as MARPE (Microimplant-Assisted Rapid Palatal Expansion).

It has been well established by previous reviews that maxillary expansion, both in adults and children, increases upper airway volume.[9] However, it remains yet unclear whether maxillary expansion may influence nasal ventilation.

Some authors argue that when the maxillary dental arch is expanded, the lateral nasal walls are shifted outward with a small increase of trans-alar width. This might positively influence nasal breathing.

In this systematic review and meta-analysis, we aim to evaluate the current available evidence on the effect of maxillary expansion in adult's nasal breathing.

Methods

This review was performed in accordance with PRISMA guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses), and a formal PROSPERO protocol was published according to the NHS International Prospective Register of Systematic Review (N° 176848) prior to conducting the review. Also, we followed the recommendations of the AMSTAR-2 guidelines.[10]

Literature Search: Inclusion and Exclusion Criteria

The criteria for considering studies for the systematic review were based on the population, intervention, comparison, and outcome (PICOTS) framework.[11]

Participants: Subjects over fifteen-years-old, as it is well described that the intermaxillary suture initiates its ossification and closure after puberty.[12]

Intervention: maxillary expansion and all its variants (MARPE, SARPE, distraction osteogenesis maxillary expansion, segmented LeFort I, orthopedic).

Comparison: pre- and posttreatment data (case series), or treatment and no treatment cohorts (case-control, cohorts and clinical trials).

Outcomes: Any evaluation of nasal breathing. This evaluation includes either subjective or objective measurements. Subjective measurements include visual analogue scales, questionnaires assessing sinonasal symptoms or any other quantitative way to express patient's nasal patency. Objective measurements of nasal patency include rhinomanometry, rhinohigrometry, fluid dynamics simulation, or Peak nasal flow, among others. Rhinomanometry is an objective test that evaluates transnasal pressure and nasal airflow volume to calculate nasal airway resistance during inspiration. Data extracted from rhinomanometry includes bilateral inspiratory nasal resistance and nasal airflow. Rhinohigrometry assess the area of the expiratory steam from both nostrils. Fluid dynamics simulation is a computational simulation of the nasal breathing from sinonasal CT scans. Finally, peak nasal flow, measured with a peak flow meter, measures the maximum speed of nasal inspiratory and expiratory airflow.

Timing and Setting: without limitations.

Types of studies: Clinical trials, cohort studies, and case series with more than 5 patients published in

peer-reviewed journals. We did not include case reports with less than 5 patients, thesis manuscripts, or meeting abstracts. There were no restrictions of date or publication type. The last update of the search was performed in Apr 2020. We included studies published in English, Spanish, German, French, Italian and Portuguese.

Exclusion criteria: exclusion criteria consisted of: 1) studies where no expansion was performed 2) studies on syndromic patients; 3) dual publications; 4) studies in children without individual analysis of the adults' sample; 5) articles in which another nasal procedure was performed between the first and the second rhinomanometric measurements; 6) studies where nasal breathing was not assessed; 7) studies with another concomitant maxillary surgery (advancement, impaction, or down-grafting).

Search Strategy

We followed the PRISMA statement guidelines to perform a systematic review. The team searched Pubmed (Medline), the Cochrane Library, EMBASE, Scopus, Science direct, SciELO and Trip Database. A predefined search strategy employing a combination of the following keywords (["SARPE" OR "MARPE" OR "Surgically assisted rapid palatal expansion" OR "Surgically Assisted Rapid Maxillary Expansion" OR "Endoscopically-assisted surgical expansion" OR "micro-implant-supported skeletal expander" OR "SARME" OR "EASE" OR "segmental LeFort"] AND ["nasal" OR "nose"]) was employed.

The abstracts retrieved were thoroughly reviewed by two authors from the Rhinology Study Group of the Young Otolaryngologists section of the International Federation of Otorhinolaryngological Societies (CCH, BMA). Based on the abstracts review, all studies that potentially fulfilled inclusion criteria were fully analyzed. Whenever there were disagreements on eligibility, full texts were included for final assessment. The reference list of all selected articles were manually reviewed to identify studies that might have been overlooked in the initial search.

Data Extraction, Categorization, and Analysis

Two authors (CCH, CCE) analyzed independently all articles that met inclusion criteria. Variables assessed included sample size, age, indication for treatment, presence of a control group, methods followed for the expansion process, use of decongestant, follow-up period, and main outcomes. The main outcome was expressed as the value (in variable units) prior to treatment (T0), after expansion procedure (T1), after the retention period (T2), and after a follow-up period (T3). When questionnaires were used, units were converted to base 100 when possible. Nasal resistance (from rhinomanometry and fluid dynamics simulation) was expressed as $Pa/cm^3/s$, while nasal airflow (from rhinomanometry and fluid dynamics simulation) was registered in cm^3/s, and peak nasal inspiratory and expiratory flow in cm^3/min. Rhinohigrometry was recorded in cm^2.

Assessment of Quality

The selected articles were assessed for both the level and quality of evidence. Level of evidence was classified according to the Oxford Centre for Evidence-Based Medicine Levels.[13] The risk of bias was assessed according to the Quality Assessment of case series studies checklist from the National Institute for Health and Clinical Excellence.[14]

For assessing the quality of the design, a score was developed prior to full text reading. It was based on the score employed by Lagravere et al. Each item's score is shown in Table 1. Papers were independently evaluated by two authors from the Rhinology Study Group of the Young Otolaryngologists section of the International Federation of Otorhinolaryngological Societies (CCH, CCE).

Six items were evaluated with a total score range from 0 to 120 points. Final results were reported as percentages. Items considered were: sample size, percentage of lost to follow-up, time to follow-up, presence of a control group, use of decongestant, and adequate control for confounding factors. The item "use of decongestant" was only considered in those studies performing

Table 1. Quality Score. ENT (Otolaryngologist).

Item Assessed	Characteristic	Weight
Sample size	>70	20
	>30–70	10
	0–30	0
Follow-up time (months)	>12	20
	7–12	10
	0–6	0
Control group	Comparable control group	20
	No comparable control group	10
	No control group	0
Decongestant	Yes	20
	No	0
Control of confounding factors	ENT evaluation with sample selection	30
	ENT evaluation without sample selection	10
	No	0
Lost to follow-up (%)	0–10%	10
	>10%	0
Total		

instrumental assessments of nasal ventilation (peak nasal flow, rhinohigrometry and rhinomanometry). The sample size score was decided for nasal resistance based on a sample size calculation, with the following parameters: assuming a bilateral hypothesis, alfa risk 0.05, 80% power, Standard Deviation (SD) 0.10 (according to previous reviews), and minimum effects of 0.05 (the most restrictive) to 0.10 (the laxest scenario).

The item "control of confounding factors" has the largest weight in the quality score assessment. Several factors can influence nasal breathing such as septal deviation, chronic rhinosinusitis, or presence of enlarged adenoids. The "control of confounding factors" refers to either excluding those patients or performing a stratified analysis.

Statistical Analysis

All statistical data were analyzed with STATA software for Macintosh v.15.1 (StataCorp®). Significance was considered with a p value <0.05.

We used Cochrane Collaboration's Review Manager Software (REVMAN) version 5.3 (Nordic Cochrane Centre, Cochrane Collaboration, 2014, Copenhagen, Denmark) to conduct the meta-analysis. Heterogeneity was checked using the Q-test and I2 test. A fixed effects model was used when the I2 value was $<50\%$ and a random effects model when it was $\geq 50\%$. Finally, publication bias was assessed by funnel plot and Egger regression.

Results

Search Results

A flowchart of the search process is shown in Figure 1. The initial search retrieved 566 publications. After reading all titles and abstracts, 26 studies were selected for full reading. A total of 10 studies (257 patients) met the inclusion criteria.[15–24] A total of three authors were contacted twice to provide additional data.[17,21,22] However none of them replied.

Of the selected papers, 16 publications were excluded for the following reasons: no expansion was performed,[25–29] syndromic patients were included,[30] nasal breathing was not evaluated,[31,32] case reports,[33,34] children were included without a subgroup analysis of adult's sample,[35–38] and concomitant maxillofacial surgery (advancement or impaction) was performed.[39,40]

Results of the Included Studies

Results are summarized in Table 2.

General results. The overall mean age was 25.44 year-old. When adjusting for sample size, the weighted mean was

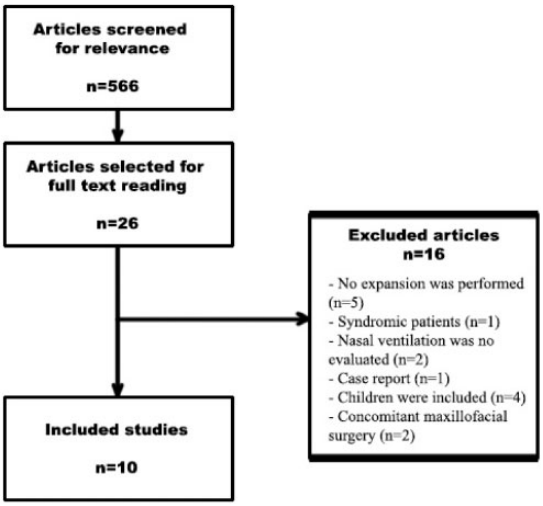

Figure 1. Flow chart.

26.50. The lowest mean age was reported by Storto et al. (17.1 years old)[17] and the highest by Yoon et al. (30.5 years old).[34] The standard deviation of all the included studies was 4.98 years.

The mean sample size was 25.7 (SD 20.18). The largest sample was reported by Yoon et al. (75 patients)[34] and the smallest by Timms (7 patients).[24]

Method of expansion. In the non-surgical approaches, one author used orthopedic expansion[24] and another microimplant assisted rapid palatal expansion (MARPE).[17] Those are also the studies with the lowest sample sizes.

The remaining eight studies used different variations of surgically assisted maxillary expansion (SAME)[15,16,18–23] including: endoscopic assisted surgical expansion (EASE),[18] distraction osteogenesis maxillary expansion (DOME),[15,16] and traditional procedures using a rapid expansion protocol (SARPE) or other protocols for SAME.[19–23] In these surgically assisted protocols, three studies performed disjunction of the pterygomaxillary suture.[18,19,23]

Nasal airway resistance. Four studies evaluated nasal resistance after expansion.[16,21,22,24] Two used anterior active rhinomanometry.[21,22] A third favored posterior rhinomanometry.[24] Finally, Iwasaki et al. employed computer fluid dynamic simulation using a combination of rhinomanometry and cone beam computed tomography.[16] All selected articles found a positive impact after palatal expansion.

Three of the four chosen papers could be merged in a meta-analysis.[16,21,24] Magnusson et al. had to be excluded from the meta-analysis since they did not provide mean and standard deviation data, and they calculated nasal resistance at 75 Pa pressure reference instead of

Table 2. Description of the Included Studies: Bold and Asterisk If There Were a Statistically Significant Difference Compared With T0.

Author (Ref)	Q Score (%)	Design/ Level of Evidence	Sample Size and Sex	Age. Mean (SD) (range)	Indication	Technique	Main Outcome (Mean, SD)					Decongestion	Follow-up (Months)
							Variable	T0	T1	T2	T3		
Yoon et al.[15]	30	Case series/ Level 4	75 (57 M, 18 F)	30.5 (8.5) (UK)	OSA, narrow hard palatal roof, Mallampati 3 or 4.	DOME 2 segments. (no pterygoid disjunction) Device: bone-tooth-borne device Activation: 0.25 mm/day Retention: 6–8 months Amount: 8–12 mm	NOSE scale (over 100)	54.5 (27.5)	**16.5 (14.5)***	NA	NA	NA	3–6
Iwasak et al.[16]	10	Case series/ Level 4	20 (15 M, 5 F)	29.6 (8.3) (UK)	OSA. Narrow hard palatal roof.	DOME expansion (no pterygoid disjunction) Device: microimplant assisted expander Activation: UK Retention: UK Amount: 7.56 mm	Computational fluid dynamics simulation. Resistance ($Pa/cm^3/s$) at 150 Pa	0.53 (0.38)	**0.16 (0.10)***	NA	NA	NA	UK
Storto et al.[17]	8.33	Case series/ Level 4	20 (7 M, 13 F)	17.1 (UK) (UK)	Maxillary transverse deficiency; mouth breather	MARPE Device: bone-tooth anchored Activation: 0.5 mm/day Retention: 5 months Amount: UK	Peak nasal inspiratory flow	UK	**30.45% increase***	**30.28% increase***	NA	No	5
Li et al.[18]	20	Case series/ Level 4	33 (18 M, 15 F)	29.4 (14.6) (15–61)	OSA	EASE 2 segments. (pterygoid disjunction) Device: transpalatal distractor bone anchored. Activation: 0.3mm/day Retention: 2 months Amount: UK	NOSE scale (over 100)	57.8 (12.9)	NA	**15.6 (5.7)***	NA	NA	3–4
Menegat et al.[19]	40	Case series/ Level 4	16 (6 M, 10 F)	31 (7.7) (21–41)	Transverse maxillary deficiency	SARPE 2 segments. (with pterygoid disjunction) Device: Hyrax tooth-borne Activation: 0.75 mm/day Retention: 4 months Amount: 7.3 mm (SD 3.2)	NOSE scale (over 100)	41.6 (35.2)	NA	**10 (15.7)***	NA	NA	6
Catunda et al.[20]	33.33	Case series/ Level 4	10 (5 M, 5 F)	24.5 (UK) (16–44)	Transverse maxillary discrepancy	SAME 2 segments. (no pterygoid disjunction) Device: UK Activation: UK Retention: UK Amount: UK	Glatzel mirror area (cm^2)	21.09 (8.156)	**27.00 (3.357)***	NA	NA	No	2.92

(continued)

Table 2. Continued.

Author (Ref)	Q Score (%)	Design/ Level of Evidence	Sample Size and Sex	Age. Mean (SD) (range)	Indication	Technique	Main Outcome (Mean, SD)					Decongestion	Follow-up (Months)
							Variable	T0	T1	T2	T3		
Zambon et al.[21]	50	Case series/ level 4	27 (M 11, F 16)	25.33 (UK) (7–44)	Orthodontic referral Maxillary constriction	SARPE (no pterygoid disjunction) Device: Hyrax expander. Activation: 2 turns/day Retention: 4 months Amount: UK	AAR. Inspiratory Flow (cm^3/s)	353.41 (135.43)	**421.62 (133.77)***	**425.06 (142.77)***	NA	Yes	4
							AAR. Resistance ($Pa/cm^3/s$) at 150 Pa	1.07 (0.54)	1.27 (1.60)	0.89 (0.41)	NA		
							VAS (UK reference values)	12.35 (4.05)	**17.94 (2.03)***	**19.31 (1.44)***	NA		
Magnuss et al.[22]	58.33	Case series/ Level 4	39 (16 M, 23 F)	19.9 (UK) (15.9–43.9)	Maxillary discrepancy 5 mm	SARPE 2 segments (no pterygoid disjunction) Device: hyrax Activation: 0.5 mm/day Retention: 90 days hyrax. Transapalatal arch. Amount: UK	AAR. Resistance ($Pa/cm^3/s$) at 75 Pa	Median: 0.19. p10: 0.14 p90: 0.36	**Median: 0.15. p10: 0.11 p90: 0.20***	NA	Median: 0.18. p10: 0.12 p90: 0.25	Yes	18
							Petruson et al. questionnaire (over 10)	Median: 2. p10: 0 p90: 8.2	**Median: 0.9. p10: 0 p90: 6.2***	NA	Median: 1.5. p10: 0 p90: 6.2		
Ribeiro et al.[23]	10	Case series/ Level 4	10 (2 M, 8 F)	29.17 (17.33–41.92)	Maxillary constriction	SAME 2 segments. (with pterygoid disjunction) Device: hyrax Activation: 0.5 mm/day/1 week; then individualized. Retention: 138 days (78–198) Amount: 8.65 mm (SD 3.39)(6–11)	Subjective nasal function improvement (yes/no)	UK	60% of patients improved. No SA	NA	NA	NA	UK
Timms[24]	25	Case series/ Level 4	7 (2 M, 5 F)	17.92 (1.14) (16–19.5)	Orthodontic and/or respiratory indication.	Orthopedic RPE Device: silver cap splints type Activation: 2 turns/day Retention: 3 months Amount: 8.65 mm (SD 3.39)(6–11)	PAR. Resistance ($Pa/cm^3/s$) at 150 Pa. % Difference after treatment	UK	0.20 (0.11). No SA 35.04% (14.67)	NA	NA	Yes	0

Abbreviation: UK (unknown). MCA (minimal cross sectional area). OSA (obstructive sleep apnea). DOME (Distraction osteogenesis maxillary expansion). EASE (endoscopically assisted surgical expansion). SD (standard deviation). SSD (statistically significant difference). SARPE (surgical assisted rapid palatal expansion). MARPE (microimplant assisted rapid palatal expansion). CBCT (cone beam computed tomography). RPE (rapid palatal expansion). SAME (surgically assisted maxillary expansion). NA (not applicable). AAR (anterior active rhinomanometry). PAR (posterior active rhinomanometry).

150 Pa like other studies. The pooled data for meta-analysis under a fixed effects model shows a statistically significant mean reduction after maxillary expansion of 0.27 (Pa/cm^3/s) (CI 95% 0.15, 0.39) (Figure 2).

Other objective methods. Zambon et al. evaluated nasal airflow.[21] Catunda et al. used rhinohygrometry with the Glatzel mirror.[20] Storto et al. used peak nasal inspiratory flow.[17] All of them found statistically significant differences after expansion.

Patient-reported changes. Six studies assessed subjective patient reported changes in nasal breathing.[15,18,19,21–23] All found a positive effect of palatal expansion with the exception of Magnuson et al. The latter found an initial improvement that was not maintained after an 18 months follow-up period.[22]

Three studies used the NOSE score.[15,18,19] The results were converted on a basis of 100 (maximum). The pooled data in the meta-analysis under a fixed effects model shows a statistically significant mean reduction after maxillary expansion of 40.08 points (CI 95% 36.28, 43.89) (Figure 3).

Other subjective methods, for which data cannot be merged in a meta-analysis, were the visual analogue scale[21] and the Petruson et al. questionnaire (a 10 item questionnaire designed to assess nasal ventilation[22]). Both studies demonstrated statistically significant differences after palatal expansion. Finally, Ribeiro Junior et al. observed that 60% of patients improved their nasal breathing. However, they did not perform a statistical analysis.[23]

Long term effects. Time points were classified as immediately before surgery (T0), immediately after active expansion (T1), at completion of retention (T2), and follow-up after the retention period (T3). The mean overall follow-up was 5.12 months (SD 5.52), and 5.84 after adjusting for sample size. The lowest follow up was reported by Timms (0 months)[24] and the longest by Magnusson et al. (18 months).[22]

Level of Evidence and Quality of the Included Studies

According to the Oxford Center for Evidence Based Medicine classification[13] all studies are Level 4.

As far as the quality score is concerned, individual data for each study is summarized in Table 3. The mean score was 28.5%. Magnusson et al. achieved the maximum score with a total of 58.33%.[22]

Publication Bias

Both the funnel plot (Figure 4) and Egger regression (coefficient −2.62, p = 0.123 for NOSE score; coefficient 2.14, p = 0.249 for nasal resistance) do not suggest a publication bias.

Discussion

To the best of our knowledge, this is the first comprehensive systematic review of the available literature and meta-analysis on this topic.[41–43]

Ten papers were included. All found a positive effect on nasal breathing. This suggests an important role for maxillary expansion in patients with impaired nasal breathing. Despite the increasing evidence that maxillary

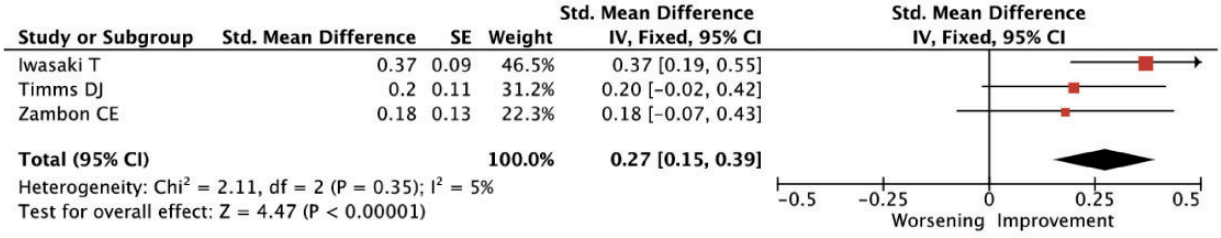

Figure 2. Forest plot. Difference in nasal resistance after maxillary expansion.

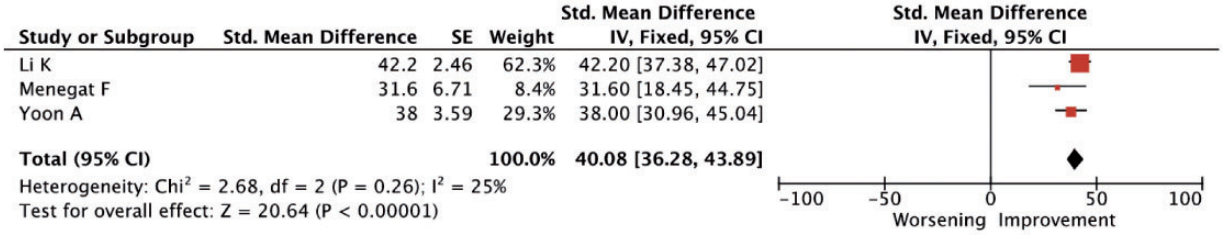

Figure 3. Forest plot. Mean difference in NOSE score after maxillary expansion.

Table 3. Design Quality.

Author (Year)	Sample Size	Follow-up	Control Group	Decongestant	Control of Confounding Factors	Lost to Follow-up	Final (%)
Yoon et al.[15]	20	0	0	NA	0	10	30%
Iwasak et al.[16]	0	0	0	NA	0	10	10%
Storto et al.[17]	0	0	0	0	0	10	8.33%
Li et al.[18]	10	0	0	NA	0	10	20%
Menegat et al.[19]	0	10	0	NA	30	10	40%
Catunda et al.[20]	0	0	0	0	30	10	33.33%
Zambon et al.[21]	0	0	0	20	30	10	50%
Magnuss et al.[22]	10	20	0	20	10	10	58.33%
Ribeiro et al.[23]	0	0	0	NA	0	10	10%
Timms[24]	0	0	0	20	0	10	25%

NA (not applicable).

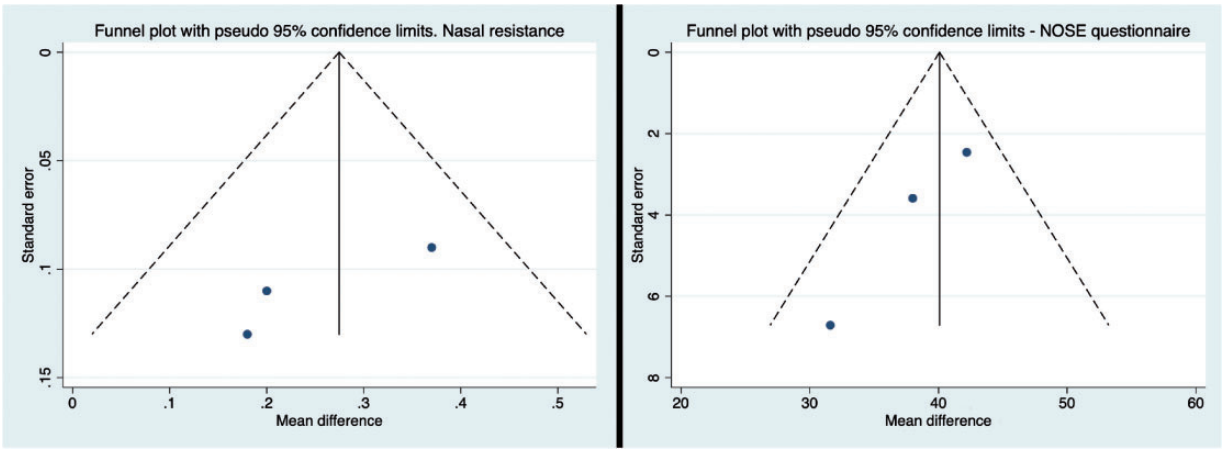

Figure 4. Funnel plot. Left: nasal resistance. Right: NOSE questionnaire.

constriction is a major cause for impaired nasal breathing, the understanding of the role of adult maxillary expansion remains under study.[4] The available evidence is focused on the classical orthodontic indications rather than nasal breathing. The Stanford group has published its initial work on patients with obstructive sleep apnea without traditional orthodontic indications.[15,16,18] This innovative indication of maxillary expansion opens the door to defining alternative for this procedure.

There is certainly an anatomic and physiologic rationale to support the hypothesis that maxillary expansion improves nasal ventilation. The nasal cavity is responsible for almost two thirds of airway resistance due to the upper airway dimensions.[44] According to the Hagen–Poiseuille law, assimilating the nose to a tube, nasal airway resistance is inversely related to the radius of the nose raised to the fourth power. Therefore, small millimetric changes in the radius can drastically decrease or increase nasal resistance.

Data summarized in previous reviews revealed that ME increases nasal volume.[9] This data is also in accordance with a previous systematic review assessing the role of maxillary expansion on nasal breathing in children. That systematic review demonstrated significant decrease in nasal resistance following ME in children.[41]

Nasal Airway Resistance

Four authors have assessed nasal resistance. Only three of them could be included in the meta-analysis. Overall, this meta-analysis found a mean reduction in nasal resistance after ME of 0.27 Pa s/cm^3. This data is clinically relevant since normal values for an adult are thought to be 0.30 (0.80 considered severe nasal obstruction). Therefore, the magnitude of this mean decrease of 0.27 Pa s/cm^3 in nasal resistance is of great importance in the control of nasal obstruction.

These merged data should be interpreted carefully as the methods used for expansion were different. Timms used orthopedic expansion,[24] while Iwasaki et al.[16] and Zambon et al.[21] used SAME procedures. Mean age also

differs among groups, ranging from 17.92 (Timms) to 29.6 (Iwasaki). This might influence the observed results since age is closely related to resistance to expansion. Furthermore, the methods used to evaluate nasal resistance was different. Iwasaki et al. used computational fluid dynamics simulation assisted with rhinomanometry, while Timms and Zambom et al. used rhinomanometry alone.

Rhinomanometry is the gold-standard test to assess nasal airway patency. It estimates nasal resistance through a variance of Ohm's law based on airflow and pressure differences.

Timms found a weak correlation between the amount of orthopedic expansion and the decrease in nasal resistance ($r = 0.32$). This suggests that the length of expansion required to reduce nasal resistance cannot be accurately predicted.[24]

Patient Reported Nasal Obstruction

Six studies assessed patient reported nasal obstruction after maxillary expansion.[15,18,19,21–23] However, only three of them could be assessed in a meta-analysis.[15,18,19] In this case, the three authors had reported a very similar method (surgically assisted expansion) and similar mean age.

All included papers found improvement in subjective nasal breathing perception after maxillary expansion. The three papers included in the meta-analysis used the NOSE scale for assessment. A mean reduction of 40.08 $\pm$1.94 points was found. This is clinically relevant as the maximum value is 100 points.

Techniques

There are several described methods to perform expansion. Most of them can be categorized as orthopedic, microimplant assisted (MARPE) or surgically assisted. Furthermore, each procedure can be accompanied by different types of expanders, different protocols for speed of expansion, and length of retention period.

In this review we assumed that all expansion procedures are the same. Furthermore, we assumed that the amount of expansion and retention type have no effect on outcome in order to combine data. However, this is not true clinically and those differences between studies affect our capacity to combine results. Of note, there is no previous research in adults to support this statement. Instead, there is a previous clinical trial in children comparing orthopedic and microimplant assisted expansion on nose breathing. They found four times more reduction in nasal resistance in the MARPE group than in the orthopedic expansion group.[45]

However, not a single author compared different techniques in adults. There is a great need for observational studies comparing methods and surgical techniques.

With the existing maxillary expansion procedures, total expansion is divided between midpalate opening (desired effect), alveolar bone widening, and undesired dental tilting. Some techniques might need to overexpand the maxillary arch to induce secondary widening of the nasal floor. This might result in an undesired significant malocclusion. It is also noteworthy that the extent of nasal floor widening is inconsistent, inadequate, and often nonexistent, in the posterior nasal region. Skeletal expansion has proven to be higher for SARPE and microimplants reaching 46.3%. In comparison, these methods achieved 33.3% alveolar expansion, and 20.4% dental expansion.[46]

Another important difference among methods is the pterygomaxillary articulation disjunction in surgically assisted methods. According to the review of Buck et al.,[9] the inclusion of pterygomaxillary disjunction as part of surgery did not appear to increase the magnitude of volume change in the nasal cavity. However, it may reduce the relapse or the anterior over expansion. Indeed, pterygomaxillary disjunction allows for the midpalate suture to be opened in a straight parallel way as opposed to a fan shaped opening if the junction remains intact. Li et al., who are the only ones to perform an endoscopic assisted procedure through the nose, extol the benefits of the pterygomaxillary disjunction.[18] It must be highlighted that they performed this procedure for OSA patients rather than for orthodontic reasons. Therefore, they aimed at obtaining mostly an expansion at the midpalatal suture rather than a dental expansion.

Finally, retention time after the expansion procedure is different among selected studies (ranging between 2 to 8 months). It must be noted that complete bone formation is not achieved even after 180 days.[47] Therefore, short retention periods may be related to a certain amount of relapse.

Follow-up Length

The mean follow-up was short at 5.12 months (SD 5.52), and 5.84 when adjusted by sample size.

The longest follow-up period was 18 months. In this study, Magnusson et al. found initial improvement in nasal resistance assessed with rhinomanometry. However, relapse to initial values of nasal airway resistance after the follow-up period was observed. It must be noted that the initial nasal resistance was considered in the normal range (0.19 Pa s/cm3). This is an important caveat. Indeed, it was shown that patients with previously increased nasal resistance benefit the most from ME.[35]

Confounding Factors

Our team would like to emphasize the challenges faced when performing this meta-analysis due to the significant heterogeneity in the use of decongestants (in the pre and post-intervention measurements), subject selection, and expansion methodology.

The use of nasal decongestant was justified by some investigators to decrease the influence of nasal mucosal swelling when assessing the isolated effects of skeletal expansion. However, only three studies used decongestants. This may influence the final analysis.[21,22,24]

Another important factor is subject selection. It is not always clear whether other nasal ailments (such as hypertrophic adenoids, nasal polys, and hypertrophic turbinates) had been addressed prior to the studies being carried out. These conditions will not be improved after maxillary expansion. Therefore, selecting patients affected by them will bias the final results.

Hartgerink et al.[35] Turvey et al.[39] and Timms.[24] found that patients with previously increased nasal resistance benefitted the most from palatal expansion. Menegat et al. report that only one patient who presented high scores for nasal obstruction before surgery had unaltered symptoms after the ME.[19] However, a detailed analysis for other possible causes for this obstruction was not described in their study.

We hypothesize that patients with impaired nasal breathing, without any other clear etiology other than maxillary constriction, would be the ideal candidate for ME. However, seven out of the ten selected studies had performed ME for orthodontic reasons.[15,16,18] They selected patients suffering from OSA, without a primary orthodontic indication. This likely underestimates the potential role of ME in the treatment of nasal obstruction in this population.

Limitations

The conclusions reached by this systematic review and meta-analysis were limited by the quality of the evidence analyzed. Hence, no definitive conclusive result can be generated for the time being. Final results can be influenced by differences in sample size, patient selection criteria, surgical technique, and evaluation methodology that differ among the selected studies.

Conclusions

The initial available evidence is too limited in order to suggest maxillary expansion as a treatment option to target nasal breathing. However, this initial analysis seems to support a positive role of ME for improving nasal breathing in adults. Further higher quality studies are needed in order to refine indications, patient selection criteria, technique, and provide longer follow up periods to demonstrate long-term efficacy.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

ORCID iD

Christian Calvo-Henriquez https://orcid.org/0000-0003-3580-0967

References

1. Gałązka A, Migacz E, Kukwa A, Czarnecka A, Krzeski A, Kukwa W. Association of breathing patterns and quality of life in patients with nasal obstruction. *Otolaryngol Pol Pol Otolaryngol*. 2018;72(1):11–5.
2. Cai Y, Goldberg AN, Chang JL. The nose and nasal breathing in sleep apnea. *Otolaryngol Clin North Am*. 2020;53(3):385–395.
3. Vig PS, Showfety KJ, Phillips C. Experimental manipulation of head posture. *Am J Orthod*. 1980;77(3):258–268.
4. Williams R, Patel V, Chen Y-F, et al. The Upper airway nasal complex: structural contribution to persistent nasal obstruction. *Otolaryngol–Head Neck Surg Off J Am Acad Otolaryngol-Head Neck Surg*. 2019;161(1):171–177.
5. Thilander B, Pena L, Infante C, Parada SS, de Mayorga C. Prevalence of malocclusion and orthodontic treatment need in children and adolescents in Bogota, Colombia. An epidemiological study related to different stages of dental development. *Eur J Orthod*. 2001;23(2):153–167.
6. Laptook T. Conductive hearing loss and rapid maxillary expansion. Report of a case. *Am J Orthod*. 1981;80(3):325–331.
7. Melsen B. Palatal growth studied on human autopsy material. A histologic microradiographic study. *Am J Orthod*. 1975;68(1):42–54.
8. Wertz RA. Skeletal and dental changes accompanying rapid midpalatal suture opening. *Am J Orthod*. 1970;58(1):41–66.
9. Buck LM, Dalci O, Darendeliler MA, Papadopoulou AK. Effect of surgically assisted rapid maxillary expansion on upper airway volume: a systematic review. *J Oral Maxillofac Surg Off J Am Assoc Oral Maxillofac Surg*. 2016;74(5):1025–1043.
10. Shea BJ, Reeves BC, Wells G, et al. AMSTAR 2: a critical appraisal tool for systematic reviews that include randomised or non-randomised studies of healthcare interventions, or both. *Br Med J*. 2017;358:j4008.
11. O'Sullivan D, Wilk S, Michalowski W, Farion K. Using PICO to align medical evidence with MDs decision making models. *Stud Health Technol Inform*. 2013;192:1057.

12. Persson M, Thilander B. Palatal suture closure in man from 15 to 35 years of age. *Am J Orthod*. 1977;72(1):42–52.
13. OCEBM Levels of Evidence [Internet]. CEBM. https://www.cebm.net/2016/05/ocebm-levels-of-evidence/. Published 2016. Accessed February 3, 2021.
14. National Institute for Health and Care Excellence. *Methods for the Development of NICE Public Health Guidance*. London: National Institute for Health and Care Excellence (NICE); 2012 (NICE Process and Methods Guides).
15. Yoon A, Guilleminault C, Zaghi S, Liu SY-C. Distraction osteogenesis maxillary expansion (DOME) for adult obstructive sleep apnea patients with narrow maxilla and nasal floor. *Sleep Med*. 2020;65:172–176.
16. Iwasaki T, Yoon A, Guilleminault C, Yamasaki Y, Liu SY. How does distraction osteogenesis maxillary expansion (DOME) reduce severity of obstructive sleep apnea? *Sleep Breath Schlaf Atm*. 2019;24(1):287–296.
17. Storto CJ, Garcez AS, Suzuki H, et al. Assessment of respiratory muscle strength and airflow before and after microimplant-assisted rapid palatal expansion. *Angle Orthod*. 2019;89(5):713–720.
18. Li K, Quo S, Guilleminault C. Endoscopically-assisted surgical expansion (EASE) for the treatment of obstructive sleep apnea. *Sleep Med*. 2019;60:53–59.
19. Menegat F, Monnazzi MS, Silva BN, de Moraes M, Gabrielli MaC, Pereira-Filho VA. Assessment of nasal obstruction symptoms using the NOSE scale after surgically assisted rapid maxillary expansion. *Int J Oral Maxillofac Surg*. 2015;44(11):1346–1350.
20. Catunda IS, Vasconcelos BC do E, Caubi AF, do Amaral MF, Moreno EFC, Melo AR. Evaluation of changes in nasal airway in patients having undergone surgically assisted maxillary expansion. *J Craniofac Surg*. 2013;24(4):1336–1340.
21. Zambon CE, Ceccheti MM, Utumi ER, et al. Orthodontic measurements and nasal respiratory function after surgically assisted rapid maxillary expansion: an acoustic rhinometry and rhinomanometry study. *Int J Oral Maxillofac Surg*. 2012;41(9):1120–1126.
22. Magnusson A, Bjerklin K, Nilsson P, Jönsson F, Marcusson A. Nasal cavity size, airway resistance, and subjective sensation after surgically assisted rapid maxillary expansion: a prospective longitudinal study. *Am J Orthod Dentofac Orthop Off Publ Am Assoc Orthod Its Const Soc Am Board Orthod*. 2011;140(5):641–651.
23. Ribeiro PD, Jr, Gonçales ES, Souza PCU de, Nary Filho H, Luz JGC. Avaliação clínica dos procedimentos de expansão cirurgicamente assistida da maxila (ECAM). *Rev Dent Press Ortod E Ortop Facial*. 2006;11(1):44–59.
24. Timms DJ. The effect of rapid maxillary expansion on nasal airway resistance. *Br J Orthod*. 1986;13(4):221–228.
25. Erbe M, Lehotay M, Göde U, Wigand ME, Neukam FW. Nasal airway changes after Le Fort I–impaction and advancement: anatomical and functional findings. *Int J Oral Maxillofac Surg*. 2001;30(2):123–129.
26. de Mol van Otterloo JJ, Leezenberg JA, Tuinzing DB, van der Kwast WA. The influence of the Le Fort I osteotomy on nasal airway resistance. *Rhinology*. 1990;28(2):107–112.
27. Guenthner TA, Sather AH, Kern EB. The effect of Le Fort I maxillary impaction on nasal airway resistance. *Am J Orthod*. 1984;85(4):308–315.
28. Götzfried HF, Masing H. On the improvement of nasal breathing following mid-face osteotomies, and possible reasons for the phenomenon. *J Maxillofac Surg*. 1984;12(1):29–32.
29. Haarmann S, Budihardja AS, Wolff K-D, Wangerin K. Changes in acoustic airway profiles and nasal airway resistance after Le Fort I osteotomy and functional rhinosurgery: a prospective study. *Int J Oral Maxillofac Surg*. 2009;38(4):321–325.
30. Saito K, Ono T, Mochida M, Ohyama K. Changes in nasorespiratory function in association with maxillary distraction osteogenesis in subjects with cleft lip and palate. *Cleft Palate-Craniofacial J Off Publ Am Cleft Palate-Craniofacial Assoc*. 2006;43(1):75–83.
31. Basciftci FA, Mutlu N, Karaman AI, Malkoc S, Küçükkolbasi H. Does the timing and method of rapid maxillary expansion have an effect on the changes in nasal dimensions? *Angle Orthod*. 2002;72(2):118–123.
32. Kunkel M, Ekert O, Wagner W. [Changes in the nasal airway by transverse distraction of the maxilla]. *Mund-Kiefer-Gesichtschirurgie MKG*. 1999;3(1):12–16.
33. Brunetto DP, Sant'Anna EF, Machado AW, Moon W. Non-surgical treatment of transverse deficiency in adults using Microimplant-assisted Rapid Palatal Expansion (MARPE). *Dent Press J Orthod*. 2017;22(1):110–125.
34. Zhao T, Zhang X, Ngan P, et al. Effects of maxillary skeletal expansion on upper airway airflow: a computational fluid dynamics analysis. *J Craniofac Surg*. 2020;31(1):e6–e10.
35. Hartgerink DV, Vig PS, Abbott DW. The effect of rapid maxillary expansion on nasal airway resistance. *Am J Orthod Dentofac Orthop Off Publ Am Assoc Orthod Its Const Soc Am Board Orthod*. 1987;92(5):381–389.
36. White BC, Woodside DG, Cole P. The effect of rapid maxillary expansion on nasal airway resistance. *J Otolaryngol*. 1989;18(4):137–143.
37. Hershey HG, Stewart BL, Warren DW. Changes in nasal airway resistance associated with rapid maxillary expansion. *Am J Orthod*. 1976;69(3):274–284.
38. Wertz RA. Changes in nasal airflow incident to rapid maxillary expansion. *Angle Orthod*. 1968;38(1):1–11.
39. Turvey TA, Hall DJ, Warren DW. Alterations in nasal airway resistance following superior repositioning of the maxilla. *Am J Orthod*. 1984;85(2):109–114.
40. Galbiati G, Maspero C, Giannini L, Guenza GC, Zanoni F, Farronato G. Orthodontic–surgical treatment and respiratory function: rhinomanometric assessment. *Minerva Stomatol*. 2017;66(3):91–97.
41. Neeley WW, Edgin WA, Gonzales DA. A review of the effects of expansion of the nasal base on nasal airflow and resistance. *J Oral Maxillofac Surg Off J Am Assoc Oral Maxillofac Surg*. 2007;65(6):1174–1179.
42. Ramires T, Maia RA, Barone JR. Nasal cavity changes and the respiratory standard after maxillary expansion. *Braz J Otorhinolaryngol*. 2008;74(5):763–769.

43. Liu K, Wei H, Dai J, Wang X. Does nasal cavity enlargement associated with respiratory function improvement after surgically assisted rapid maxillary expansion? *J Craniofac Surg*. 2020;31(3):829–831.
44. Jalowayski AA, Yuh YS, Koziol JA, Davidson TM. Surgery for nasal obstruction–evaluation by rhinomanometry. *Laryngoscope*. 1983;93(3):341–345.
45. Bazargani F, Magnuson A, Ludwig B. Effects on nasal airflow and resistance using two different RME appliances: a randomized controlled trial. *Eur J Orthod*. 2018;40(3):281–284.
46. Asscherickx K, Govaerts E, Aerts J, Vande Vannet B. Maxillary changes with bone-borne surgically assisted rapid palatal expansion: a prospective study. *Am J Orthod Dentofac Orthop Off Publ Am Assoc Orthod Its Const Soc Am Board Orthod*. 2016;149(3):374–383.
47. Salgueiro DG, Rodrigues VHL de O, Tieghi Neto V, Menezes CC de, Gonçales ES, Ferreira Júnior O. Evaluation of opening pattern and bone neoformation at median palatal suture area in patients submitted to surgically assisted rapid maxillary expansion (SARME) through cone beam computed tomography. *J Appl Oral Sci Rev FOB*. 2015;23(4):397–404.