

Review Article

Rapid Palatal Expansion Effects on Nasal Airway Dimensions as Measured by Acoustic Rhinometry

A Systematic Review

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ABSTRACT

Objective: To evaluate available information on the effects of rapid maxillary expansion on nasal airway minimal cross-sectional area and volume, as measured by acoustic rhinometry.

Materials and Methods: An electronic database search was conducted. Based on abstracts/titles, articles were initially selected; then full articles were retrieved and were further sorted according to secondary, more stringent criteria. References from selected articles were hand-searched for potential missed publications. Clinical trials using acoustic rhinometry on subjects undergoing rapid maxillary expansion therapy were included. Syndromic or medically compromised patients and absence of an untreated control group were reasons for exclusion. Selected studies thereafter were evaluated methodologically.

Results: Only four articles reached final selection, and their overall methodology scores were low, limiting the applicability of results. After rapid maxillary expansion, three of four studies found statistically significant increases in minimal cross-sectional area, and two of three studies reported statistically significant increases in nasal cavity volume as compared with control groups. It appears that any increase is less stable if a traditional technique is used on patients who have passed their peak growth spurt.

Conclusions: Although some increases in nasal dimensions have been reported, the changes in nasal volume were small and should not be presented to patients as a clinically significant indication for therapeutic maxillary expansion. (*Angle Orthod.* 2009;79:1000–1007.)

KEY WORDS: Systematic review; Rapid maxillary expansion; Acoustic rhinometry; Nasal airway dimensions

INTRODUCTION

During rapid maxillary expansion (RME), the great-

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est changes occur in the maxillary dentition, especially in the transverse dimension. Although some immediate changes in vertical and transverse dimensions have been reported, no long-term changes have been found.^{1–3} In addition, on a long-term basis, the transverse skeletal maxillary increase ranges from approximately 25% of the total appliance adjustment in prepubertal adolescents to a not significant change in postpubertal adolescents when traditional RME was evaluated.^{2,3} However, the RME effect on the nasal cavity and respiratory function has been disputed.^{4,5}

Differing methods of measurement of nasal airway dimensions and function have been proposed and utilized; each technique has its strengths and limitations.⁶ Radiographic techniques expose patients to excessive dosages of radiation; patient positioning error and structural superimposition limit posteroanterior cephalograph validity, and traditional computed tomography has associated high cost.⁶ Cone-beam computed tomography shows promising possibilities, and equipment is becoming increasingly available to orthodontists.⁶ Nasal endoscopy provides exceptional visualization of the area of interest, but it cannot provide di-

dimensional estimates.⁶ Rhinostereometry is a direct optical technique that is performed to measure nasal mucosal swelling with the use of a surgical microscope. This method poses practical clinical limitations⁷ such as the requirement for an individual tooth splint per subject, as well as provides only limited information of specific structures and not of the larger part of the nasal airway. Rhinomanometry can help identify whether an obstruction to nasal airflow is absent or present, however it cannot localize the level and sites of obstruction. Finally, acoustic rhinometry (AR)⁶⁻¹⁰ determines minimum cross-sectional area (MCA) as a function of distance in the nasal airways by emitting a sound impulse and then processing the resultant reflection and comparing it with the original; the size of the reflections may reflect changes in airway size, and the return time may provide the distance between the changes.

Thus, AR has the advantage of providing objective area and volume measurements, along with ease of use and minimal invasiveness. AR has been validated for evaluation of nasal cavity dimensions compared with other techniques.^{6,8-10} It has demonstrated reasonable correlation with both computed tomography and magnetic resonance imaging for the anterior 6 centimeters of the nasal cavity.^{8,10-12}

Multiple studies have used AR for assessment of changes to airway dimensions after RME intervention. The purpose of this systematic review is to evaluate the effects of RME on nasal airway dimension measured by AR, while addressing the quality of evidence and the methodology of those reports. Knowledge of scientific evidence on the nasal airway would facilitate orthodontists' decisions as to whether RME could be a treatment alternative that not only produces dentoalveolar changes, but also has implications in the nasal complex. This information would also be important for otolaryngologists.

MATERIALS AND METHODS

An electronic database search was conducted in several databases. The computerized search was accomplished with the assistance of a senior Health Sciences Librarian. Databases searched, along with terms used as keywords/subject headings within each database are listed in Table 1. No language limitation was set.

In selecting articles from the search results, initial inclusion criteria applied to the title/abstract were as follows:

- Use of a rapid palatal/maxillary expansion device
- Use of an instrument to measure nasal area/volume

Independent article selection was accomplished by

two researchers. If the abstract was judged to contain insufficient information for a decision of inclusion or exclusion, the full article was obtained and reviewed before a final decision was made.

Full articles from the abstract/titles previously selected were retrieved. Retrieved articles were ultimately selected if they also satisfied the following secondary inclusion criteria:

- Human clinical trials with a nontreated control group (no case reports or series of cases)
- Nonsyndromic nor medically compromised subjects
- Use of AR as a method to measure nasal airway differences (minimal cross sections volume evaluated)

Any discrepancies in inclusion of articles between researchers were addressed through discussion and consensus. Reference lists from selected articles were hand-searched for additional publications that may not have appeared in the electronic database searches.

Articles that satisfied the final inclusion criteria were evaluated using the methodologic criteria listed in Table 2. Methodologic scores are summarized in Table 3. A meta-analysis was planned if the quality of information retrieved warranted a meaningful statistical combination.

RESULTS

The details for each search, as well as the number of abstracts retrieved from each database, are listed in Table 1, but only four articles¹³⁻¹⁶ met all inclusion criteria. Attempts to retrieve two abstracts/articles of possible use from the hand-search of the reference lists were unsuccessful. One publication of interest from the Lilacs search was also unobtainable.

Methodologic assessment of finally selected publications resulted in scores approximating 50% of the possible total maximum; score summaries can be seen in Table 3. Appendix 1 provides the list of excluded articles and the reasons for their exclusion. Common reasons for exclusion were case series, or the fact that the study did not use AR for nasal airway status assessment.

Table 4 provides a study summary of the main methodologic characteristics and obtained results from the publications included in the final selection.

DISCUSSION

The principle of AR is based on the reflection of sound waves inside the nasal cavity. Its use is very diverse in the field of rhinology and has been validated with results showing reasonable correlation to computed tomography (CT) and magnetic resonance imaging (MRI) for the first 6 centimeters of the nasal cav-

Table 1. Search Results From Databases

Database	Search Strategy	Results	Abstracts Obtained	Articles Selected for the Systematic Review	% of Total Selected Articles (3) Found by Database
Old MEDLINE (1950–1965)	Exp palatal expansion technique, palatal expansion.mp, maxillary expansion.mp, rapid palatal expansion.mp, rapid maxillary expansion.mp, air\$.mp, nas\$.mp 1 OR 2 OR 3 OR 4 OR 5, 7 OR 8, 6 AND 9	0	0	0	0
MEDLINE + In-Process & Other Non-Indexed Citations (1950–August week 2 of 2008)	Exp palatal expansion technique, palatal expansion.mp, maxillary expansion.mp, rapid palatal expansion.mp, rapid maxillary expansion.mp, air\$.mp, nas\$.mp 1 OR 2 OR 3 OR 4 OR 5, 7 OR 8, 6 AND 9	188	32	3	75
PubMed (up to August 18, 2008)	Palatal expansion technique, palatal expansion, maxillary expansion, rapid palatal expansion, rapid maxillary expansion, air*, nas* 1 OR 2 OR 3 OR 4 OR 5, 6 OR 7, 8 AND 9	221	35	4	100
EMBASE (1988–week 33 of 2008)	Exp palatal expansion technique, palatal expansion.mp, maxillary expansion.mp, rapid palatal expansion.mp, rapid maxillary expansion.mp, air\$.mp, nas\$.mp 1 OR 2 OR 3 OR 4 OR 5, 7 OR 8, 6 AND 9	153	9	1	25
All EBM Reviews: Cochrane DSR, ACP Journal Club, DARE, and CCTR (up to August 18, 2008)	Exp palatal expansion technique, palatal expansion.mp, maxillary expansion.mp, rapid palatal expansion.mp, rapid maxillary expansion.mp, air\$.mp, nas\$.mp 1 OR 2 OR 3 OR 4 OR 5, 7 OR 8, 6 AND 9	14	3	1	25
Lilacs (up to August 18, 2008)	Palatal expansion technique, maxillary expansion, nas\$, air\$ 1 OR 2, AND 3 OR 4	29	0	0	0
Scopus (up to August 18, 2008)	Palatal expansion technique, palatal expansion, maxillary expansion, rapid palatal expansion, rapid maxillary expansion, air*, nas* 1 OR 2 OR 3 OR 4 OR 5, 6 OR 7, 8 AND 9	284	33	3	75
Thomson's ISI Web of Science (from 1900–1914 up to August 18, 2008)	Palatal expansion technique, palatal expansion, maxillary expansion, rapid palatal expansion, rapid maxillary expansion, air*, nas* 1 OR 2 OR 3 OR 4 OR 5, 7 OR 8, 6 AND 9	156	22	3	75
Hand-search			0	0	0

ity.^{8,10–12} These latter imaging techniques provide useful information with respect to local and surrounding structural anatomy, but they are costly and time-consuming to interpret. AR is a noninvasive, relatively inexpensive technique that requires minimal time and patient cooperation. The equipment also is relatively inexpensive and requires very little space to operate, making it suitable in a clinical situation. Geometry of the nasal cavity is provided in two dimensions on the AR output. The cross-sectional area, as a function of distance from the nostril into the nasal cavity visually, displays the location and size of the MCAs. The resultant reflected waves are shown over a large depth, but the machine is programmed to measure over a

certain distance anteroposteriorly. Standardizations of operation have been recommended,^{17,18} and adherence to these recommendations should produce highly accurate and repeatable measures.

Because of the influence of the nasal cycle on the nasal mucosa, it has been recommended that topical decongestants be given when AR is used to assess the nasal cavity.¹⁹ Decongestants reduce the possibility of the confounding effect of differing levels of congestion on the nasal mucosa, thus allowing measures of an individual's nasal anatomy as opposed to their variable physiologic or pathologic states. Inflammatory conditions, exercise, head posture, emotional and hormonal states, and medications can influence the nasal

Table 2. Methodologic Score for Clinical Trials (modified from Lagravère et al, 2005²)

I. Study design (7 ✓)
A. Objective—objective clearly formulated (✓)
B. Sample size—considered adequate (✓)
C. Sample size—estimated before collection of data (✓)
D. Selection criteria—clearly described (✓)
E. Baseline characteristics—similar baseline characteristics (✓)
F. Timing—prospective (✓)
G. Randomization—stated (✓)
II. Study measurements (3 ✓)
H. Measurement method—appropriate to the objective (✓)
I. Blind measurement—blinding (✓)
J. Reliability—adequate level of agreement (✓)
III. Statistical analysis (5 ✓)
K. Dropouts—dropouts included in data analysis (✓)
L. Statistical analysis—appropriate for data (✓)
M. Confounders—confounders included in analysis (✓)
N. Statistical significance level— <i>P</i> value stated (✓)
O. Confidence intervals provided (✓)
Maximum number of ✓s = 15

mucosa. This has clinical implications, in that it is important to assess all individuals in their most decongested state so results can be compared over time or after intervention.

Because each of the selected investigations differed in approach, it was difficult to directly compare the results. Methodologic assessment resulted in all studies scoring similarly. Measurement reliability was not discussed, nor was blinding or randomization. These limitations weaken the overall strength of the results in that biases may have been introduced.

The presence of a malocclusion requiring RME was similar between all studies. However, in the study by Baraldi et al,¹³ patients who required surgically assisted rapid maxillary expansion (SARME) included non-growing adults, whereas Cappellette et al¹⁶ investigated an adolescent subject group who presented with a mouth-breathing habit. Bicakci et al¹⁵ required that adolescent subjects have no history of nasal disease, whereas Baraldi et al¹³ required no use of medications for nasal obstruction and a negative history of labial/palatal fissures or presence of craniofacial anomalies or chronic systemic disease. These are important factors when baseline differences between subjects are considered. Compadretti et al¹⁴ assessed children and

adolescents with varying histories of ENT surgery, tonsillitis, snoring/sleep apnea, mouth breathing posture, allergies, and septal deformity or hypertrophy of inferior turbinates. Statistical analysis showed that these variables, along with gender and unilateral or bilateral crossbites, did not influence measurements or response to treatment.

An investigation by Babacan et al²⁰ compared subjects with differing levels of maturity. Investigators evaluated RME in an adolescent subject group and SARME therapy in an adult subject group and showed a significant increase in nasal volume measured using AR but no differences between groups.

Changes in breathing pattern were discussed by Compadretti et al,¹⁴ who reported that 42.8% of patients switched from an oral to a nasal breathing mode after RME, which was consistent with findings from other studies.^{4,21,22} This may have occurred as the result of increased flow capacity of the nasal cavity caused by an increase in MCA after RME.

Because of the anatomic proximity of the nasal cavity to the oral cavity, maxillary complex, and teeth, changes in the nasal cavity as a result of expansion of the maxillary palatal suture are not unexpected. It is important to note that although theoretically changes in the nasal cavity can occur with changes in maxillary arch width, a multitude of factors exist that can influence nasal airway geometry and resultant patient perception of airflow. Our results did report trends (some statistically significant) of an increase in MCA after RME.

Bicakci et al¹⁵ compared nasal airway changes in 29 subjects treated with RME either before or after the pubertal growth spurt vs 29 untreated control subjects. Treatment and control subjects were divided into two groups according to their skeletal maturity, which was assessed using the cervical vertebral maturation method on lateral cephalograms taken before treatment. Early-treated subjects and early-control subjects had not yet reached the pubertal peak in skeletal growth velocity and presented with a cervical vertebral stage from one to three. Late-treated subjects and late-control subjects were at a stage during or after the pubertal peak in skeletal growth velocity with cervical stage from four to six. The study reported a significant

Table 3. Methodologic Score of Selected Articles

Articles	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	Total (÷15)
Bicakci et al ¹⁵	✓	/	×	/	×	✓	×	✓	×	×	×	✓	✓	✓	✓	8
Compadretti et al ¹⁴	✓	/	×	/	×	✓	×	✓	×	×	×	✓	✓	✓	×	7
Baraldi et al ¹³	✓	/	×	✓	×	✓	×	✓	×	×	×	✓	✓	/	×	7
Cappellette et al ¹⁶	✓	/	×	✓	×	✓	×	✓	×	×	×	✓	✓	✓	×	7.5

✓ Fulfilled satisfactorily the methodologic criteria (1 check point); / fulfilled partially the methodologic criteria (0.5 check point); × did not fulfill the methodologic criteria (0 check point).

Table 4. Description of Studies Included in Final Selection^a

Author (Year)	Size	Age	Male	Female	Treatment/ Appliance	Evaluation Method [measurement (units)]	Mean Measurement Differences Using AR				Estimated Mean Percent Increase Using AR			
							Cross-Sectional Area		Volume		Cross-Sectional Area		Volume	
Bicakci et al (2005) ¹⁵	58	11–8	8	8	bonded RME	acoustic rhinometry [MCA (mm ²)]	0.34*	N/A			16.92	N/A		
		12–6	8	8	control		0.08				Information unavailable			
		14–1	5	8	bonded RME		0.19*				8.76			
		13–4	5	8	control		0.02				Information unavailable			
Compadretti et al (2006) ¹⁴	51	9.5 ± 2.1	13	14	Hyrax	rhinomanometry, acoustic rhinometry [TMCA (cm ²) & TNV (cm ³)] & cephalometry	0.15*	0.17*	0.65*	1.44*	Information unavailable			
		10.2 ± 1.5	16	8	control		0.03	0.01	0.06	0.03				
Baraldi et al (2007) ¹³	23	25.15 ± 6.93	4	9	SARME/ Haas or Hyrax	acoustic rhinometry [MCA (cm ²) & Volume] & frontal cephalograms	0.02	0.32	0.18	1.16	1.94	25.81	4.97	8.61
		26.10 ± 4.68	4	6	control		1.17	1.61	4.05	15.19	N/A			
Cappellette et al (2008) ¹⁶	50	4–14 (range)	27	23	modified Biederman	acoustic rhinometry (posttreatment–pretreatment)	MCA1		MCA2		Vol 1		Vol 2	
		4–11 (range)	11	9	control		L	R	L	R	L	R	L	R

* Statistically significant.

^a *Italics*, Control group measures taken only once, thus absolute measures are given as opposed to changes.

RME: Rapid Maxillary Expansion

SARME: Surgical Assisted Rapid Maxillary Expansion

MCA: Minimal Cross-sectional Area

TMCA: Total Minimal Cross-sectional Area

TNV: Total Nasal Volume

Vol: Volume

increase in MCA in subjects before and after their pubertal growth spurt compared with untreated controls, but no significant difference in MCA change was noted between treatment groups until after the retention phase, when a significant decrease in MCA was reported in the group assessed to be past their skeletal growth spurt. This could possibly be explained by the increasing rigidity of the facial skeleton with age.^{23,24} Compadretti et al¹⁴ reported rhinometric results of a significant increase in total MCA and total nasal volume (NV) in both basal and decongested conditions between control and treatment groups (see Table 4). Baraldi et al¹³ did not observe significant increases in MCA or NV after SARME, but a not significant increase in posterior MCA was observed post SARME.

Of interest is a patient-reported improvement in air-

flow through the nose after RME therapy. With normal anatomy, inspired air passes at high velocities anteriorly up to the nasal valve area, after which velocity drops substantially because of increased volume in the nasal cavity. Airflow deviates from laminar to turbulent once inside the nasal cavity, thereby promoting the resultant cleaning and conditioning of inspired air. Air through the nose has been thought of as passing through a series of pipes of varying cross-sections, but nasal anatomy is complex, resulting in limitations of this postulation. Although a physically compressible medium, air is said to be incompressible at velocities below 0.3 Mach—a condition that is largely satisfied by the current situation.²⁵ Air traveling through the nasal passage can be accurately modeled by Bernoulli's equation,²⁶ with consideration of flow across the nasal

valve region as a result of pressure differences, with constant density and negligible viscosity. Bernoulli's principle, which was developed from the momentum equations with assumptions of conservation, states that for a fluid, an increase in speed of the fluid occurs simultaneously with a decrease in pressure. Flow in the nose is analogous to a subsonic diffuser; therefore, from the continuity equation, the volumetric flow rate must be maintained, which leads to slower air velocity. The nasal valve was defined by Cole²⁷ as a short resistor of a few millimeters in length with a base at the floor of the nose, the lateral walls as the ala, and a bony caval entrance anterior to the inferior turbinate and within a few millimeters of the bony pyriform aperture. Because the nasal valve is contributed to in part by the lateral walls of the nasal cavity, widening of these walls by RME may result in an increase in the nasal valve (increasing MCA), thereby decreasing resistance to nasal airflow. In laminar flow, Ohm's law states that resistance equals the change in pressure divided by volumetric flow rate ($R = \Delta P/Q$), and in conditions of turbulent flow, the formula changes to the square of the volumetric flow rate ($R = \Delta P/Q^2$). When theory is applied to clinical findings, it can be seen that as a result of RME, both nasal volume and MCA increase, thereby decreasing resistance to airflow and allowing increased movement of air through the nasal passage with decreased nasal respiratory effort.

Recent reports that used CT images to quantify nasal change after RME have been published. A study by Palaisa et al²⁸ used conventional tomography to evaluate nasal cavity changes after RME treatment in 19 subjects aged 8 to 15 years at three time points (before, immediately after, and 3 months after RME therapy). Investigators found overall that the area and volume increased significantly in each region of the nasal cavity measured (anterior, middle, or posterior) between time points, with the exception of the right middle time point from before to after RME, and reported an overall increase in volume of 10.7% from before to after RME. They did not detect any relapse in measurements during a 3 month retention phase after expansion. However, it may have been useful to extend this interval to ensure adequate time for any changes. Investigators also concluded that no significant correlations were found between the amount of expansion and the increase in nasal cavity area or volume for any region of the nasal cavity.

In summary, each of these four studies reported changes consistent with an increased MCA and/or NV, but none of the changes is likely to be considered clinically significant. The finally selected articles included no report of percent increase in MCA or volume (an estimate was calculated where possible in Table 4); these data may be an important practical consider-

ation for clinicians in distinguishing between clinical and statistical significance. In addition, although it is probable that RME has an effect on the nasal airway, clinical and patient-perceived improvements are yet to be reliably established. Quality of life effects of RME beyond the orthodontic advantages have been reported,^{4,21,29,30} including change from a mouth-breathing dependence to a nasal respiratory pattern, as well as improved overall health and sleep. Most reports, however, have described investigations of limited quality, such as from case series. Individuals who present with maxillary transverse constriction and reduced nasal respiration should be considered possible candidates for treatment with expansion therapy. Treatment of this type is minimally invasive and can address a dental disharmony requiring correction. One must consider conceivably greater effects in those individuals who have nasal constrictions in the areas most affected by RME as opposed to those with causes for reduced airflow in other areas of the nasal airway passage (eg, enlarged tonsils and/or adenoids). Long-term randomized controlled trials are needed to facilitate further evaluation of the effects of RME on the nasal airway, as well as investigation using patient perception and feedback as to their nasal airway status before and after RME.

CONCLUSIONS

- RME should not be encouraged as a treatment option for individuals with reduced MCA without an orthodontic indication. In cases with an orthodontic treatment need, nasal cavity changes are expected; however, their clinical significance is questionable.
- Variability has been noted; therefore, for a given individual patient, the change may be significant.
- Given the current limited quality of evidence, it is encouraged that future studies overcome the identified limitations in an effort to support related conclusions with stronger methodologic quality.

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APPENDIX 1 Articles Not Selected From the Initial Abstract Selection List and Reasons for Exclusion

Reason for Exclusion	Article
No control group	Babacan ¹
Syndromic subjects	de Moura ² Pirelli ³
Did not use AR	Bascifitci ⁴ Dogru ⁵ Hartergerink ⁶ Loreille ⁷ Timms ⁸ Warren ⁹ Wollens ¹⁰
Summary of treated cases, did not use AR	Gray ¹¹
Case series, did not use AR	Berretin-Felix ¹² Cistulli ¹³ De Mol Van Otterloo ¹⁴ Garrett ¹⁵ Hershey ¹⁶ Malkoc ¹⁷ Palaisa ¹⁸ Pirelli ¹⁹ Timms ²⁰ Timms ²¹ Wertz ²² White ²³
Case series	Ceroni Compadretti ²⁴ Doruk ²⁵ Doruk ²⁶ Enok ²⁷ Kunkel ²⁸ Picchi ²⁹ Piccini ³⁰ Wriedt ³¹
Discussion paper	Bonk ³² Brogan ³³ Timms ³⁴

AR, acoustic rhinometry.

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