ORIGINAL ARTICLE

Relationship between rapid maxillary expansion and nasal cavity size and airway resistance: Short- and long-term effects

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Introduction: The availability of new, reliable, objective, and 3-dimensional techniques to assess the effects of rapid maxillary expansion on the morphology of the maxillary dental arch, nasal cavity dimensions, and nasal airway resistance led to the development of this research. **Methods:** Thirty-eight subjects participated in this study (mean age, 13 years). Data were collected before expansion, when the expander was stabilized, when the expander was removed, and 9 to 12 months after the expander was removed. Subjective assessment of improvement in nasal respiration was obtained when the expander was stabilized. Three-dimensional imaging and acoustic rhinometry were used to assess the virtual cast and the nasal cavity, respectively. **Results and Conclusions:** The statistically significant short-term effects of RME were (1) mean increases in palatal area, volume, and intermolar distance; (2) a mean reduction of nasal airway resistance; and (3) mean increases in total nasal volume and nasal valve area. Our long-term findings were the following: (1) mean palatal area and intermolar distance were reduced, while palatal volume was stable, and (2) nasal airway resistance was stable, whereas mean nasal cavity volume and minimal cross-sectional area increased. Additionally, 61.3% of our subjects reported subjective improvement in nasal respiration. Weak correlations were found between all variables analyzed. (Am J Orthod Dentofacial Orthop 2008;134:370-82)

Nasal respiration is of extreme importance for those who are predominantly nasal breathers. The nasal cavity is specifically designed to prepare the air before reaching the lungs by humidification, adjusting its temperature, and removing infectious and impure particles. In addition, nasal respiration contributes to the ideal development of the nasomaxillary complex.

Rapid maxillary expansion (RME) is a recognized and recommended therapy to treat constricted maxillary arches, preferably in growing patients. Because the maxillary bones form half of the nasal cavity's anatomic structure, it has been hypothesized that midpalatal disjunction would affect the anatomy and the physiology of the nasal cavity.[1-9]

The nasal valves are the minimal cross-sectional areas (MCA) of the nose[6,9] and, therefore, the site of greatest resistance to nasal airflow.[1-5,7,8] RME promotes the separation of the maxillary bones in a pyramidal shape in which maximum expansion is at the level of the incisors, just below the nasal valves. Palatal disjunction can also cause a total increase in the nasal cavity's volume, since its lateral walls are displaced apart. Ultimately, a combination of these phenomena could result in improvement in the patient's ability to breathe through the nose.

Uncertainties about the long-term stability of RME and the availability of new, reliable, objective, and 3-dimensional (3D) techniques to assess the effects of RME on the morphologic changes of the maxillary arch, nasal cavity dimensions, and nasal airway resistance (NAR) led to the development of this study. The following hypotheses were tested: (1) RME changes the anatomy of the maxillary dental arch and affects the anatomy and function of the nasal cavity; (2) these changes result in a subjective impression of

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Original master thesis (N.L.O.) at ProQuest Digital Dissertations, #AAT 1425058, ISBN 0-496-92609-8.
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Submitted, June 2006; revised and accepted, October 2006.
0889-5406/$34.00

doi:10.1016/j.ajodo.2006.10.034

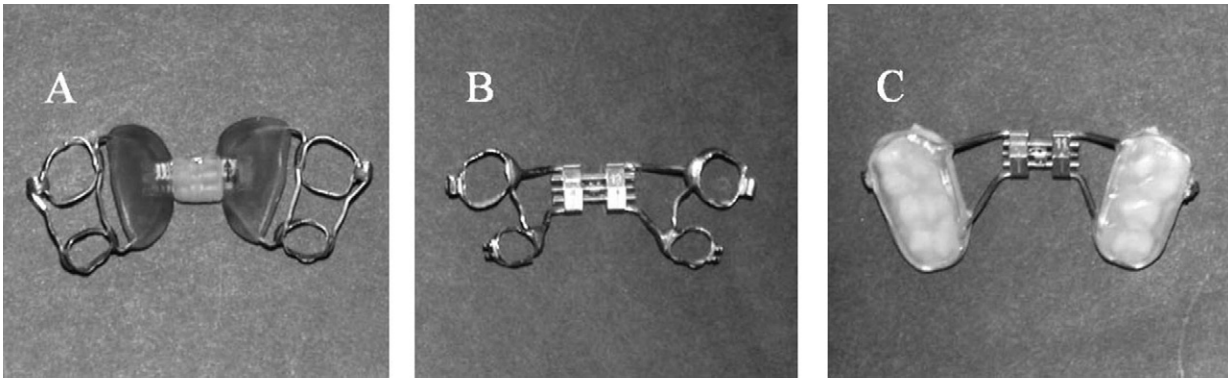

Fig 1. A, Haas expander with buccal and lingual bars; **B,** Hyrax expander with lingual bars only; **C,** bonded expander.

improved nasal breathing; and (3) these changes are stable up to 12 months after removal of the expander.

The specific aims of this investigation included (1) assessment of morphometric changes before and after RME in the maxillary dental arch, (2) assessment of changes before and after RME in nasal cavity geometry, (3) objective assessment of changes before and after RME in NAR, (4) subjective assessment of improvement in nasal respiration and its correlation to the anatomic findings, and (5) evaluation of long-term stability of the RME outcomes on the nasal cavity and the maxillary dental arch.

We generated 3D long-term data on the effects of RME on the nasal cavity not previously reported in the literature. Our ultimate goal was to use objective and subjective data to determine whether RME is an efficient tool to modify the anatomy and the physiology of the nasal cavity. Whether these changes are the foundation for a posterior change in the predominant mode of breathing was not investigated and cannot be inferred from our results.

MATERIAL AND METHODS

A total of 38 subjects participated in this study (19 boys, 19 girls; mean age, 13 years [boys, 8-16 years; girls, 9-15 years]). The subjects were recruited from the Department of Orthodontics at the College of Dentistry and the Craniofacial Center at the University of Illinois at Chicago. Its institutional review board approved this research and the involvement of human subjects. Among others, the inclusion criteria were growing patients who were to receive RME with no history for upper respiratory diseases or anomalies. We decided not to add subjects with a previous history of compromised upper airways, even though one might assume that they would benefit the most from RME therapy. The rationale was that the pretreatment condition should be similar in every subject, and the enrollment of subjects with respiratory problems would increase uncontrolled variables. In addition, we were not involved in the diagnosis, appliance design, and treatment plan of the subjects. Skeletal maturation for each patient was determined by the treating doctor with hand-wrist and cervical vertebrae analyses. We recruited only those with potential growth forecasted.

Three types of expanders (Fig 1) were used in this study: Haas (n = 21); Hyrax (n = 14), and bonded (n = 3). The rates of activation varied from 2 turns per day (50% of the sample), to 1 turn per day (42% of the sample), and to 1 turn every other day (8% of the sample). The termination point was clinical observation of 2 to 3 mm of overexpansion determined by the clinician and the assigned faculty. According to Sari et al,[10] expansion was considered adequate when the occlusal aspect of the lingual cusp of the maxillary first molars contacted the occlusal aspect of the facial cusp of the mandibular first molars. The 2 to 3 mm of overexpansion was designed to compensate for relapse after expansion. Ideally, a frontal cephalogram or a cone-beam computed tomography scan would be necessary to objectively identify optimal expansion for every subject. However, due to limitations in our imaging resources, we used clinical judgment.

The midline diastema was assessed by visually comparing the maxillary incisal area before and after RME and by asking the patient whether he or she had noticed a gap between the front teeth or an enlargement of existing spaces. The types of subsequent orthodontic treatment were either full bonded edgewise technique (95%), no treatment (placement of an acrylic plate with checkup recalls only), or maxillary protraction with an extraoral device. Table I gives details of sample distribution.

Casts of the maxillary arch were made at pretreat-

Table I. Sample distribution according to palatal expander

	Haas (n = 21)	*Hyrax (n = 14)*	*Bonded (n = 3)*
Appliance configuration			
Lingual bars only	9	12	0
Buccal and lingual bars	9	2	0
Unknown	3	0	0
Rate of activation			
1 turn per day	6	7	3
2 turns per day	14	5	0
1 turn every other day	1	2	0
Postretention therapy			
Maxillary protraction	4	0	0
Edgewise appliance	20	14	2
No treatment	1	0	1
Presence of midline diastema	19	10	3
Average screw opening (mm)	10	7	5
Average treatment length (d)	43	56	21
Average retention length (d)	120	128	117
Average postretention length (d)	333	328	403

ment (T1), at expander removal (T3), and after a long observational period (T4). The day in which the expander was stabilized was called T2. At T2, an alginate impression was not taken because the appliance was still cemented to the teeth. Subjective impressions of improvement in nasal respiration were obtained at T2. All subjects had their maxillary dental arch impression taken with alginate (Kromopan Idrocoloide 100 hours, Lascod S.P.A., Firenze, Italy) and poured with orthodontic white stone (GAC Orthoworks Orthostone Super White, Bohemia, NY) (mixing ratio of water to powder, 30 mL per 100 mg). Before the casts were digitized, we carefully removed any bubbles and placed pencil landmarks on the palatal dento-gingival margins of the canines and posterior teeth (Fig 2).

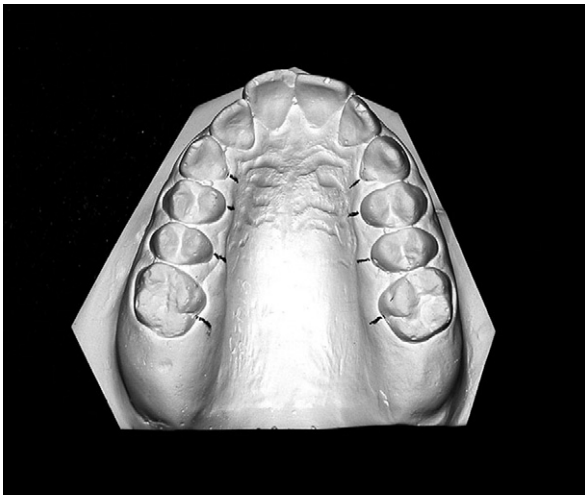

Fig 2. Pencil landmarks.

The plaster casts were digitized with a 3D imaging system that consisted of (1) a surface laser scanner (Vivid700 3D, Minolta, Wayne, NJ) in a fixed position at 61 cm from the turntable center, (2) a side tungsten light source (60W 120V, Westinghouse, Lake Bluff, Ill), and (3) a computerized turntable with a special cast holder to allow for precise positioning of the cast at a standardized distance from the camera lens (Fig 3).

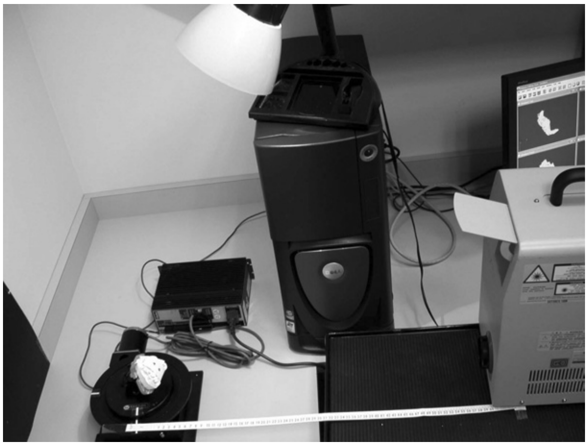

Fig 3. Three-dimensional setup.

Polygon editing software (version 1.20, Minolta) was used to capture the 3D images. Three images were scanned at 0°, 45° and 315° and automatically registered by using a calibrated chart on the turntable. Later, the 3-piece image was merged into 1 complete 3D file (Fig 4). Qualify 6 software (Raindrop Geomagic, Durham, NC) was used to obtain the morphometric analysis of the virtual casts according to the methodology of Oliveira et al.[11] Means, standard deviations, and ranges for palatal surface area and volume (Fig 5), intermolar distance (IMd), intercanine distance, interfirst premolar distance, intersecond premolar distance, interpalatal distance, palatal shelves inclination, and right and left molar crown tipping (RMCT and LMCT) were calculated (Fig 6). Palatal flattening was assessed by comparing the absolute values of palatal depth at T1, T3, and T4. A value of 1 for flattening or 0 for no flattening was assigned, generating a binomial that was statistically tested. Palatal flattening is understood as loss of palatal depth from the gingival margin to the deepest point at the raphe.[11] This objective technique excludes molar extrusion, which could generate an unrealistic depth of the palate. Palatal inclination, on the other hand, is an angular assessment measured

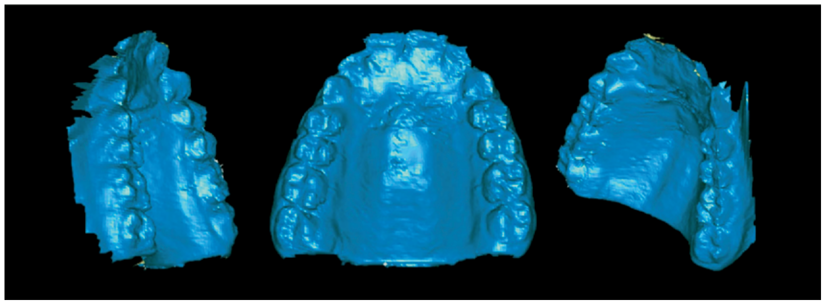

Fig 4. Virtual cast.

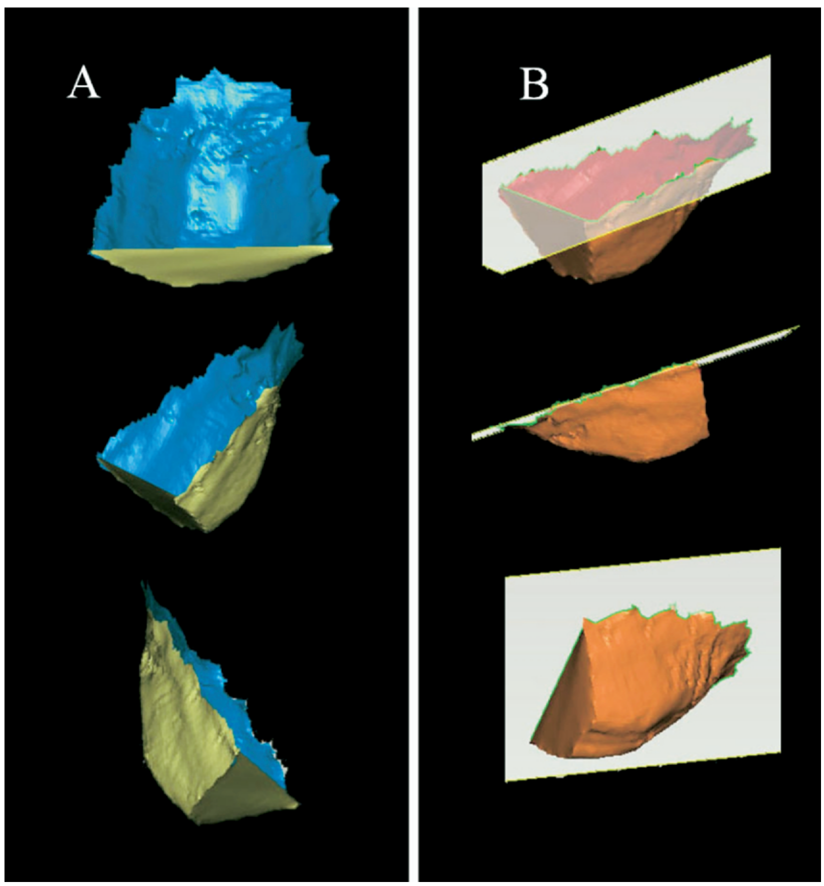

Fig 5. Working virtual cast: **A,** measurement of surface; **B,** measurement of volume.

between 2 tangent lines touching the most palatal point in each palatal shelf (right and left).[11] An increase of this angle after treatment represented tipping of the palatal shelves. If the angle was unchanged or reduced, parallel expansion was noted.

Acoustic rhinometry (AR) with the Eccovision system (Hood Laboratories, Pembroke, Mass) was used to assess the geometry and the function of the nasal cavity at T1, T2, T3, and T4. The measurements were taken 4 consecutive times in each nostril under basal conditions (no nasal decongestant) according to the methods of Roithman et al[12] and Parvez et al,[13] who stated that basal condition is more realistic when estimating anatomic-functional variability. This equipment automatically generates NAR by calculating the resistance of an equivalent duct segment with the same area function and circular cross-section, with a low Reynolds number flow. Nasal volume is calculated as

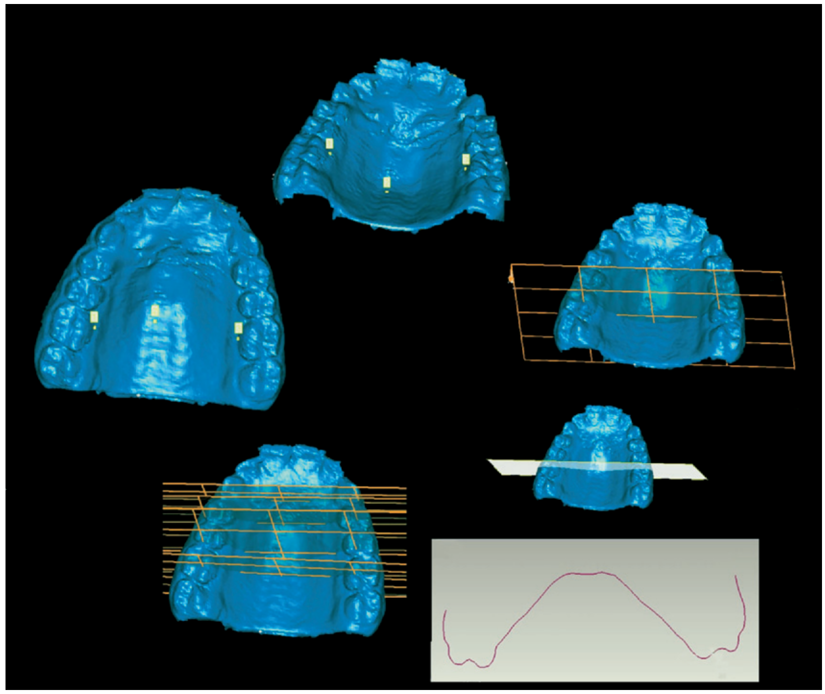

Fig 6. Linear and angular measurements: palatal shelves inclination, interpalatal distance, palatal depth, palatal height, RMCT, LMCT, and IMd.

an integral of the area-distance function over the segment being tested (5 cm). The area at the nasal valve is equivalent to the first dip in the rhinograph (Fig 7) of the segment being tested. Means, standard deviations, and ranges for NAR, volume, and MCA were computed separately for each nostril. The total NAR was determined by using Ohm's law equation for parallel resistors (1/NARt = 1/NARr + 1/NARl), where *NARt* is the total nasal resistance, *NARr* is the airway resistance for the right side, and *NARl* is the airway resistance for the left side.[14] The total volume and the total MCA of the nasal cavity were calculated by simple sums: Vt = Vr + Vl and MCAt = MCAr + MCAl (*V*, volume; *t*, total; *r*, right; *l*, left).[15-17] Special attention was given to subject acclimatization to the room temperature (20 minutes before the test), reduction of ambient noise levels below 60dB,[16,17] controlled sitting position of the subject, and ideal wave tube placement according to the European Rhinological Society's guidelines.[17] Figure 7 shows the AR equipment.

To determine whether short- and long-term changes were related to a subject's impression of improved nasal breathing immediately after the active phase of expansion, a structured questionnaire was used.[14] It consisted of 1 yes or no question: "Did you feel that, after opening the screw, breathing through the nose became easier?" If the subject did not understand the question, more clarification and additional explanations were given. Two groups of subjects—those who felt improvement in nasal breathing and those who felt no difference—were created for comparison. Our major uncertainty was whether the subjects who responded positively would be those who had began RME therapy with a more constricted maxillary dental arch or a smaller nasal cavity with greater values for NAR.

The data were analyzed with Student *t* tests and correlation analysis. The mean differences between all 4 time points were evaluated by using paired *t* tests, and the mean difference between subjects who reported improvement on nasal respiration and those who did not notice a change, in all time points, was assessed with independent *t* tests. Correlation analysis was used to relate nasal and maxillary findings. All statistical analyses were performed with a software package (SPSS for Windows, version 11.5, SPSS, Chicago, Ill).

RESULTS

The average treatment length (ie, expansion time) was 40 days (range, 14-173 days). This wide range of time in some cases was due to either the inability to activate the expander according to the rate prescribed by the treating doctor, sometimes because its activation key was lost, or simply failure to keep the scheduled

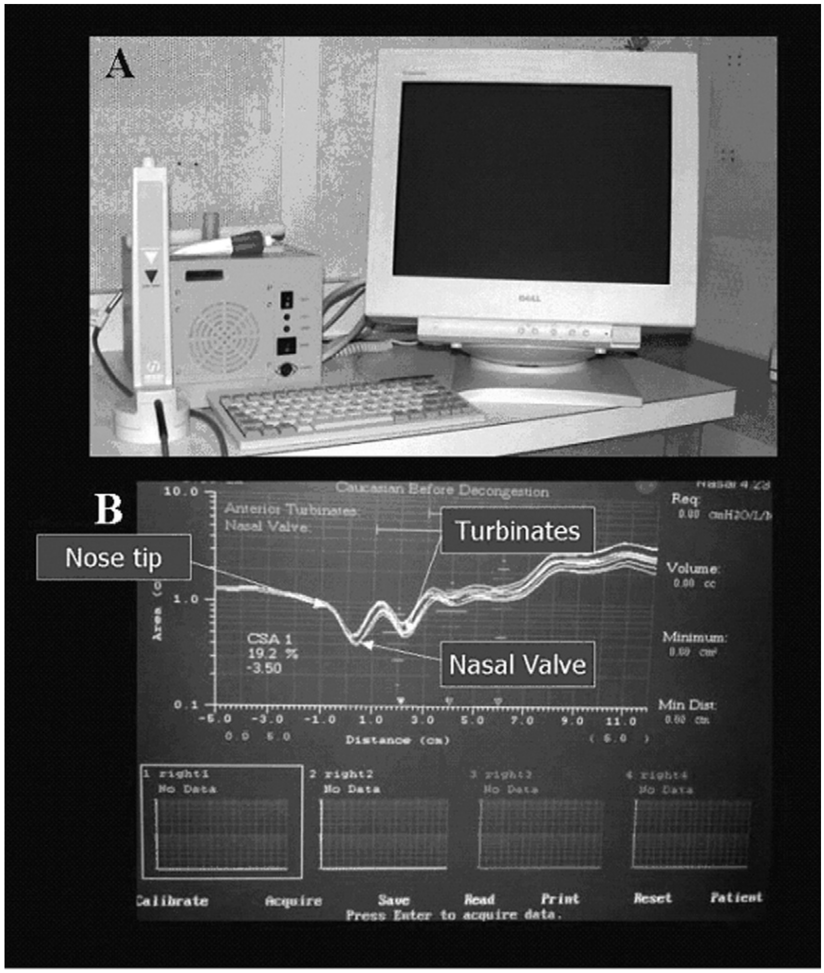

Fig 7. AR: **A,** sound wave tube, computer hardware and software, water-based gel, silicone nose tip, keyboard, and monitor; **B,** Rhinograph, the graphic representation of the geometry of the nasal cavity; note that the change in NAR starts at the nose tip and has its first dip (point of greater resistance) at the nasal valve, and the second dip is at the inferior head of the first turbinate.

appointments. The average retention period (T2-T3) was 121 days (range, 94-183 days) (Table I). The long-term observational time average was 355 days (11.8 months; range, 274-403 days).

Repeatability of the methodology was obtained by reassessing the same variables after a short time. Five randomly selected subjects had their AR tests at T1 retaken after 11 days, and 11 randomly selected casts (at T1, T3, and T4) were reevaluated 3 days after the first set of measurements. The paired *t* test demonstrated, for all variables, no statistical significance ($P > 0.005$) between the first and second sets of measurements.

Since some linear measurements on the virtual casts were not obtained because of teeth absent by extraction, transitional dentition, or agenesis. We reported only measurements of palatal surface area, palatal volume, IMd, palatal inclination, and palatal flattening. Table II gives the descriptive statistics for the 3D morphometric assessment and the AR tests; Figures 8 and 9 represent graphically these data. Table III summarizes the comparison among all variables and their mean differences between all time points.

Before treatment, the mean values were 1198.44 mm^2 for area and 5100.01 mm^3 for volume. After the active phase of expansion, the mean value for area increased by 35.1% to 1619.47 mm^2 (statistically significant at $P = 0.000$), and the mean value for volume increased by 40.6% to 7169.47 mm^3 (statistically significant at $P = 0.000$). The long-term evaluation showed that the total palatal area decreased by 7.9% to 1491.32 mm^2 at T4, with statistical significance ($P =$

Table II. Descriptive statistics

Time point	*Variable*	*n*	*Mean*	*SD (±)*	*Range*	
					Minimum	*Maximum*
T1	Palatal area		1198.44	162.74	876.21	1601.26
	Palatal volume		5100.01	1324.91	1814.50	7991.64
	IMd		29.75	3.63	23.18	37.75
	PI		72.98	38.20	31.52	283.96
	Total	38				
T1	NARr		4.41	2.40	1.02	13.30
	NARl		5.94	5.13	0.90	27.14
	NARt		2.16	1.05	0.62	6.42
	Nasal Vr		3.75	1.28	1.75	8.87
	Nasal Vl		3.83	1.97	1.50	10.32
	Nasal Vt		7.58	2.72	4.06	15.18
	MCAr		0.41	0.13	0.20	0.81
	MCAl		0.38	0.14	0.14	0.86
	MCAt		0.79	0.22	0.38	1.50
	Total	38				
T2	NARr		3.18	1.76	0.76	9.66
	NARl		3.69	2.02	1.63	9.67
	NARt		1.61	0.72	0.52	3.60
	Nasal Vr		4.88	2.02	2.24	10.04
	Nasal Vl		4.37	1.43	2.17	8.82
	Nasal Vt		9.25	2.89	4.78	15.76
	MCAr		0.48	0.14	0.26	0.91
	MCAl		0.48	0.19	0.22	1.22
	MCAt		0.97	0.28	0.57	1.66
	Total	31				
T3	Palatal area		1449.00	553.87	1202.88	2166.63
	Palatal volume		6414.79	3167.49	3363.42	14007.23
	IMd		33.36	12.20	27.66	44.27
	PI		67.11	27.32	29.53	94.85
	Total	34				
T3	NARr		3.43	2.09	1.05	9.43
	NARl		3.36	1.33	1.02	6.24
	NARt		1.57	0.65	0.61	3.38
	Nasal Vr		4.61	1.52	1.93	8.42
	Nasal Vl		4.58	1.38	2.24	7.40
	Nasal Vt		9.19	2.39	4.69	13.36
	MCAr		0.48	0.14	0.26	0.92
	MCAl		0.47	0.17	0.28	1.13
	MCAt		0.96	0.23	0.59	1.69
	Total	38				
T4	Palatal area		1491.32	234.3	1164.9	1949.98
	Palatal volume		6514.49	2093.82	2573.5	10507.9
	IMd		34.38	3.94	27.14	41.82
	PI		73.31	16.17	46.13	141.2
	Total	38				
T4	NARr		3.33	3.11	0.92	16.13
	NARl		3.92	4.87	1.02	25.39
	NARt		1.41	0.62	0.59	2.91
	Nasal Vr		5.38	1.78	2.15	10.89
	Nasal Vl		5.27	1.72	2.06	9.61
	Nasal Vt		10.65	3.06	6.18	19.92
	MCAr		0.53	0.18	0.21	0.99
	MCAl		0.51	0.16	0.15	0.83
	MCAt		1.04	0.27	0.55	1.54
	Total	38				

Palatal area, mm^2; palatal volume, mm^3; IMd, mm; PI, °; NARr, NARl, and NARt, cmH2O/l/sec; Vr, Vl, and Vt, cm^3; MCAr, MCAl, and MCAt, cm^2.
PI, Palatal shelves inclination; *V*, volume; *r*, right; *l*, left, *t*, total.

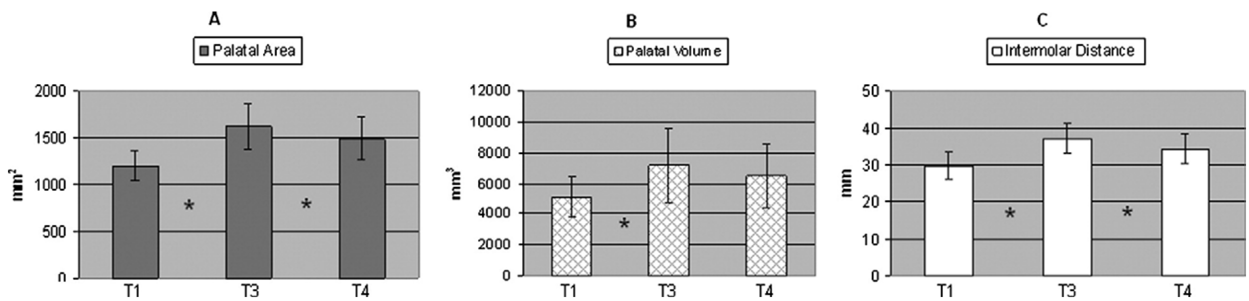

Fig 8. Graphic representation of the 3D descriptive data: **A,** palatal area before and after RME; **B,** palatal volume before and after RME; **C,** IMd before and after RME. *Significant at $P \leq 0.005$.

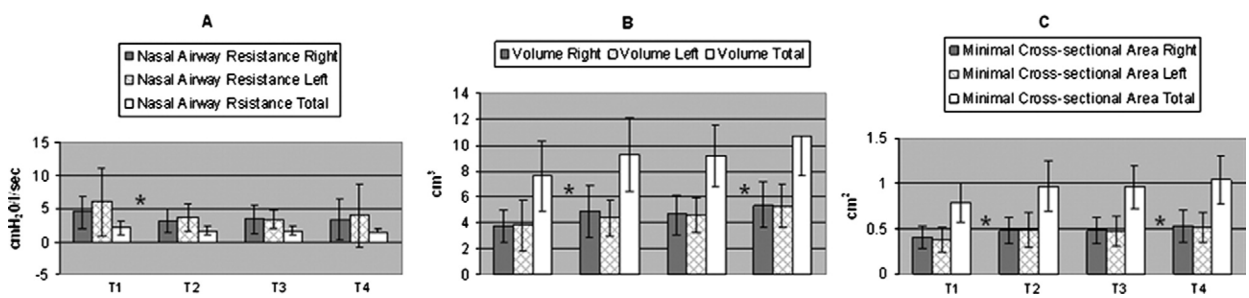

Fig 9. Graphic representation of the AR descriptive data: **A,** NAR before and after RME; **B,** volume before and after RME; **C,** MCA before and after RME. *Significant at $P \leq 0.005$.

Table III. Comparison before and after treatment (paired *t* test, $\alpha = 0.05$)

		Significance (2-tailed)			
Pairs	*n*	*Palatal area*	*Palatal volume*	*IMd*	*PI*
T1/T3	34	.000*	.000*	.000*	.016*
T1/T4	38	.000*	.001*	.000*	.958
T3/T4	34	.008*	.282	.000*	.306

Pairs	*n*	*NARr*	*NARl*	*NARt*	*Nasal Vr*	*Nasal Vl*	*Nasal Vt*	*MCAr*	*MCAl*	*MCAt*
T1/T2	31	.028*	.014*	.002*	.010*	.268	.007*	.005*	.009*	.000*
T1/T3	38	.027*	.002*	.000*	.003*	.011*	.000*	.001*	.003*	.000*
T1/T4	38	.071	.078	.000*	.000*	.001*	.000*	.000*	.000*	.000*
T2/T3	31	.962	.196	.206	.904	.090	.265	.449	.828	.645
T2/T4	31	.744	.633	.150	.114	.048*	.030*	.032*	.660	.170
T3/T4	38	.825	.458	.074	.004*	.026*	.002*	.020*	.275	.042*

*Significant at $P \leq 0.005$.
PI, Palatal shelves inclination; *V*, volume; *r*, right; *l*, left; *t*, total.

0.008), although there was no statistically significant change in total palatal volume ($P = 0.282$).

Mean IMd increased from 29.75 mm at T1 to 37.28 mm at T3. This 25.3% gain in IMd was statistically significant ($P = 0.000$) and also clinically significant with an average increment of 6.89 mm. Between T3 and T4, the IMd relapsed from 37.28 to 34.38 mm, with statistical significance ($P = 0.000$).

Palatal inclination decreased, with statistical significance ($P = 0.016$), by 9% from T1 to T3; no statistically significant change ($P = 0.306$) was found between T3 and T4.

To date, the methodology for assessing palatal flattening after RME has been questionable, because only a few studies have obtained cross-sectional views of the maxillary arch. Rather, qualitative assessments based on the investigators' visual perception have been reported. We measured palatal depth as a linear distance from the deepest point on the palatal vault to a line connecting the 2 gingival margins around the molars, eliminating any dental component such as extrusion at different times and compared them. Only 2 subjects (5.88%) had palatal flattening between T1 and T3, and 3 subjects (8.82%) had it between T3 and T4.

The average NARt values at T1 and T2 were 2.16 $cmH_2O/L/sec$ and 1.61 $cmH_2O/L/sec$, respectively. At T3, it was 1.57 $cmH_2O/L/sec$, and, at T4, it was 1.41 $cmH_2O/L/sec$. A statistically significant ($P = 0.002$) reduction in NARt of 25.5% was observed during the active phase of the treatment. However, the reductions during the retention period and the long-term evaluation were not statistically significant ($P = 0.206$ and $P = 0.074$, respectively) indicating that NARt stabilized between T2 and T4.

The mean total volumes of the nasal cavity were 7.58 cm^3 at T1, 9.25 cm^3 at T2, 9.19 cm^3 at T3, and 10.65 cm^3 at T4. There were statistically significant increases in the total volume of 18% between T1 and T2, 17.5% between T1 and T3, and 13.7% between T3 and T4. The *P* values were 0.007, 0.000, and 0.002, respectively. No statistically significant ($P = 0.265$) difference was found between T2 and T3, indicating that, during the retention period, nasal cavity volume remained stable.

The average values for MCAt were 0.79 cm^2 at T1, 0.97 cm^2 at T2, 0.96 cm^2 at T3, and 1.04 cm^2 at T4. It increased by 22.8% from T1 to T2 (with statistical significance, $P = 0.000$), stabilized from T2 to T3 (no statistical significance, $P = 0.645$), and increased by 7.7% from T3 to T4 (with statistical significance, $P = 0.042$).

The subjective evaluation showed that 61.3% of the subjects felt improvement in nasal respiration after the active phase of expansion. Table IV illustrates the mean differences between those who responded positively and negatively to the question about subjective improvement in nasal respiration. No statistical difference was observed between the groups ($P > 0.05$). Pearson correlation analysis was used to determine whether there was a constant relationship between subjective improvement in nasal respiration and variables such as diastema, time of treatment, rate of activation, NARt, MCAt, and total volume. Correlation analysis was also computed to confirm whether IMd and NARt had an association (Table V). The results showed no statistical significance ($P > 0.05$) between subjective improvement of nasal respiration and any variables studied, and poor correlation between NARt and IMd.

DISCUSSION

Our long-term findings should be interpreted as a combination of the outcomes from RME, fixed appliance therapy, and growth. The only way to truly elucidate the outcomes of RME, excluding growth and the effects of edgewise therapy, would be with a matched control sample without orthodontic or orthopedic therapy. However, that was not our primary intention, which was to investigate the RME outcomes on the nasal cavity; therefore, our subjects served as their own controls. Moreover, the findings about the nasal cavity are limited to assumptions based on 2 major concerns: we compared our numerical findings only after matching the age of our subjects to the sample from the cited study, and we did not compare our measurements with those from pressure-flow rhinomanometry studies. In spite of having the same trends from the AR, they are completely different because pressure-flow rhinomanometry reproduces the entire morphology and the function across the nasal cavity in a dynamic test, whereas AR reflects the morphology and the function of the nasal cavity in a predetermined segment—in our case 5 cm—in a static mode.

Maxillary dental arch

When analyzing total palatal area (Fig 8, *A*), we noticed a substantial increase from T1 to T4 because of the active phase of RME with a relapse between T3 and T4 after expander removal. This statistically significant relapse might have been due to edgewise mechanotherapy, depending on the arch form chosen by the treating orthodontist. In addition, it is possible that relapse occurred due to the criterion for termination of expansion being a slight overexpansion. Nevertheless, the overexpansion amount might have been functionally unstable. Another possible explanation for the long-term reduction in total palatal area could be an insufficient retention period (T2-T3), since our average retention time was 4 months.

Until the appliance was removed, between T1 and T3, we noticed an increase in palatal volume that remained stable for approximately 11 months (Fig 8, *B*). This statistically significant increase during the active phase of expansion can be explained by a drastic change in the architecture of the palate caused by RME. After the retention period, palatal volume remained stable, most likely because fixed appliances and normal growth modifications maintained the shape of the palate and, therefore, its volume. Both findings for total palatal area and volume agree

Table IV. Comparison between positive and negative subjective improvement in nasal respiration (independent *t* test, α = 0.05)

	Yes			No				
Time point	*n*	*Mean*	*SD (±)*	*n*	*Mean*	*SD (±)*	*t*	*Significance (2-tailed)*
T1								
NARr		4.60	2.97		3.57	0.96	1.153	.258
NARl		6.32	5.81		5.10	4.33	0.622	.539
NARt		2.23	1.31		1.87	0.69	0.873	.390
Vr		3.97	1.57		3.99	0.71	−0.054	.958
Vl		3.86	1.91		4.48	2.32	−0.814	.422
Vt		7.83	2.83		8.47	2.72	−0.630	.534
MCAr		0.42	0.16		0.43	0.08	−0.105	.917
MCAl		0.38	0.17		0.40	0.13	−0.268	.791
MCAt		0.81	0.25		0.83	0.19	−0.229	.821
Total	19			12				
T2								
NARr		3.22	1.93		3.12	1.52	0.158	.880
NARl		3.85	1.87		3.45	2.30	0.523	.605
NARt		1.62	0.64		1.57	0.86	0.189	.851
Vr		4.93	2.18		4.81	1.83	0.156	.877
Vl		4.07	1.20		4.86	1.69	−1.523	.139
Vt		8.99	2.90		9.66	2.96	−0.621	.539
MCAr		0.48	0.14		0.49	0.16	−0.036	.971
MCAl		0.48	0.22		0.48	0.13	−0.010	.992
MCAt		0.97	0.29		0.97	0.25	−0.010	.992
Total	19			12				
T3								
NARr		3.31	1.88		3.00	2.14	0.415	.681
NARl		3.30	1.31		3.09	1.31	0.427	.673
NARt		1.53	0.56		1.37	0.66	0.701	.489
Vr		4.88	1.51		5.01	1.40	−0.235	.816
Vl		4.70	1.20		5.13	1.50	−0.876	.388
Vt		9.58	2.10		10.14	2.13	−0.711	.482
MCAr		0.49	0.15		0.52	0.13	−0.491	.627
MCAl		0.51	0.21		0.47	0.12	0.642	.526
MCAt		1.00	0.27		0.98	0.15	0.190	.850
Total	19			12				
T4								
NARr		3.76	4.10		2.68	1.60	0.871	.391
NARl		4.98	6.70		2.98	1.30	1.015	.318
NARt		1.50	0.75		1.29	0.41	0.890	.381
Vr		5.40	2.19		5.52	1.18	−0.176	.861
Vl		5.06	1.78		5.43	1.48	−0.613	.545
Vt		10.45	3.46		10.95	2.23	−0.443	.661
MCAr		0.54	0.20		0.56	0.17	−0.328	.745
MCAl		0.50	0.17		0.50	0.13	0.009	.993
MCAt		1.04	0.31		1.06	0.20	−0.210	.835
Total	19			12				

V, Volume; *r*, right; *l*, left; *t*, total.

with those reported by Oliveira et al,[11] who used a similar 3D methodology.

The IMd increased by 25.3% between T1 and T3 as shown in Figure 8, *C*. This agrees with the studies of Mew[18] and Memikoglu and Iseri,[19] even though the latter authors used different landmarks (cusp tips) in their analysis. However, Sari et al[10] reported a greater increase of 15% in the IMd after a similar time. Between T3 and T4, a statistically significant decrease of 2.9% was found (Fig 8, *C*). Clinically, this relapse might not be significant because the mean values varied from 37.28 to 34.38 mm, with an average decline of 2.81 mm. Mew[18] reported a relapse in intermolar width of 0.2% in his sample (n = 25) after 2.4 years.

Palatal inclination decreased with statistical significance between T1 and T3, suggesting that RME

Table V. Correlation analysis (Pearson correlation analysis, α = 0.05)

	Subjective improvement	*NARt/IMd*
Diastema at T2	r = 0.093	
Treatment length at T2	r = 0.167	
Rate of activation at T2	r = −0.228	
NARt at T2	r = 0.045	
MCAt at T2	r = 0.026	
Vt at T2	r = −0.033	
At T1		r = −0.102
At T3		r = −0.230
At T4		r = 0.828

V, Volume; *t*, total.

might have expanded the base of the maxilla more than the alveolar process. A true separation at the base of the maxilla results in a more parallel configuration of the palatal shelves after treatment. Dentoalveolar expansion, on the other hand, increases palatal inclination, since it bends the alveolar processes buccally. Starnbach et al,[20] studying the effects of RME in the maxillary arch of rhesus monkeys, also noticed parallelism of the palatal tangents. From T3 to T4, palatal inclination increased without statistical significance, suggesting stability.

Palatal flattening was not statistically significant between T1 and T3 and between T3 and T4, suggesting that this phenomenon was not consistently observed in our sample.

Nasal cavity

We observed a reduction in NARt after the active phase of expansion (25.5% reduction between T1 and T2) (Fig 9, *A*). Our findings differ from those of Doruk et al,[14] who also used AR. Our smaller percentage in NAR reduction than in the study of Doruk et al (35%) might be explained by our larger sample size or different starting values for NARt. Our subjects might have had lower resistance values before treatment than theirs. When analyzing our retention phase (T2-T3), we observed a reduction, which was not statistically significant, indicating that NARt stabilized between T2 and T3 (Fig 9, *A*). Stabilization of NARt during the retention phase was also noticed by Doruk et al.[14] We found that the values for total NAR did not change significantly between T3 and T4 (Fig 9, *A*); this agrees with Doruk et al,[14] who observed NAR for 8 months after T3.

In this study, we noticed statistically significant increases in the total volume of 18% between T1 and T2 and 17.5% between T1 and T3 (Fig 9, *B*). Our percentages for total nasal cavity volume were greater than those reported by Hahn et al[15] (12.15% between T1 and T2 and 10.13% between T1 and T3). A smaller sample and different assessment periods were used in their study. No statistically significant difference was found between T2 and T3, indicating that, during the retention period, nasal cavity volume was stable. Our long-term evaluation of total nasal volume indicated a statistically significant increase after approximately 11 months (Fig 9, *B*), probably because of growth. Unfortunately, no long-term study could be used to compare with our results.

We found that the MCAt increased by 22.8% from T1 to T2 and by 21.5% from T1 until T3. It then stabilized from T2 to T3 and increased by 7.7% from T3 to T4 (Fig 9, *C*). This is in contrast with the study of Bicakci et al,[21] who reported an increase of 8.7% between T1 and T3 and a decrease of 6.3% between T2 and T3. Their modest increment in MCAt during treatment and the lack of stabilization during the retention phase might be related to their smaller sample size, even though our group's average age was a year younger than theirs. We believe that the long-term small increment at the nasal valve in our sample is the result of remaining stresses that gently restricted the appropriate growth on that region.

In our study, 61.3% of the subjects responded positively for the subjective impression of improvement in nasal respiration after RME. Both groups had similar values for NAR, volume, and MCA, and the comparison between the 2 groups at all times was not statistically significant for any variable. This contrasts with the findings of Hershey et al,[22] who suggested that subjects who had greater NAR, smaller MCA, and smaller volume at T1 would have inadequate nasal function and experience a more dramatic change in those nasal parameters after RME.

It is most likely that RME promotes changes in the anatomy and the physiology of the nasal cavity. However, these changes do not consistently and predictably relate to changes in the mode of breathing. Mouth breathing is an extremely complex phenomenon and must not be addressed in a simplistic manner. Unfortunately, our study lacks an objective assessment of the predominant respiratory mode, usually assessed with the SNORT[23] technique or plethysmography.[24] Moreover, subjective studies of breathing require tight control of all variables to express clinical validity. We followed the research design of Doruk et al,[14] and, likewise, our results might be in line with subjective guessing when asked.

We observed weak correlations with no statistical significance between the subjective perception of improvement in nasal respiration and the presence of diastema (r = 0.093), treatment length (r = 0.167), rate of activation (r = −0.228), total NAR (r = 0.045), total volume (r = −0.033), and total MCA (r = 0.026). Lack of strong relationships among these variables indicates that they are not closely related to the subjects' impression of improvement in nasal respiration. Moreover, our results show that it is difficult to predict whether the subject will feel improvement in nasal respiration after enlargement of the nasal cavity.

When analyzing the correlation between NARt and IMd, we agreed with the findings of Timms[3] (r = 0.32) and Hershey et al[22] (r = 0.42), even though our correlation was lower (r = 0.23). The reason for weak correlations might be because of the great intersubject variability in this sample.

CONCLUSIONS

RME proved to be an efficient therapy to change the anatomy of the maxillary dental arch, the anatomy and the function of the nasal cavity. Our findings for the sample analyzed are as follows.

1. Total palatal area increased significantly by 35.1% between T1 and T3 and relapsed by 7.9% between T3 and T4.
2. Total palatal volume increased significantly by 40.6% and stabilized until T4.
3. IMd increased significantly by 25.3% between T1 and T3 and by 7.8% between T3 and T4. Clinically, the T1-T3 increment can be considered significant (6.89 mm); nevertheless, the decrease between T3 and T4 might have no clinical significance.
4. Palatal inclination decreased significantly by 2.8% between T1 and T3 and stabilized until T4.
5. Palatal flattening was present in only 5.88% of our subjects between T1 and T3. In addition, only 8.82% had flattening of the palate between T3 and T4. These frequencies were not considered clinically meaningful.
6. NAR had a statistically significant reduction between T1 and T2 (25.5%) and stabilized until T4.
7. Nasal volume increased significantly by 18% between T1 and T2, stabilized until T3, and increased significantly by 13.7% until T4.
8. MCA increased significantly between T1 and T2 by 22.8%, stabilized until T3, and increased significantly by 7.7% until T4.
9. Subjective impression of improved nasal breathing was reported by 61.3% of our subjects after RME. There was no statistical difference between those who responded positively and those who responded negatively to subjective improvement in nasal respiration at all times and for all nasal variables.
10. Correlation analysis showed that the subjective impression is not closely related to diastema, treatment length, rate of activation, and NARt, Vt, and MCA at T2. NARt is not associated with IMd at every time point. Overall, there is poor predictability between nasal and maxillary findings in relation to the subjective impression of improvement in nasal respiration.

We thank Yunqing Pan for assistance with the 3D images and analysis, Louis Portugal for the AR training, and Cyril Sadowsky for manuscript review.

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