

Upper airway assessment using four different maxillary expanders in cleft patients:

A cone-beam computed tomography study

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ABSTRACT

Objective: To evaluate the anterior and posterior maxillary width, the nasal passage volume, the oropharyngeal minimum axial area, and volume changes in unilateral cleft lip and palate patients treated with one of the following four expanders: Hyrax, Fan-Type, inverted mini-hyrax supported on the first permanent molars (iMini-M), or inverted mini-hyrax supported on the first premolars (iMini-B).

Materials and Methods: A total of 40 patients with transverse maxillary deficiency who were submitted for rapid maxillary expansion were divided in four groups according to type of expander used. Cone-beam computed tomography images were taken before and 3 months after expansion. One-way analysis of variance was used to analyze the differences among the groups, and paired *t*-tests were used to evaluate the changes in each group.

Results: All groups showed a significant increase in the anterior maxillary width, with no intergroup differences. The iMini-B was the only group that did not show a significant increase in the posterior maxillary width. The intergroup comparison demonstrated differences among all groups except between Hyrax and iMini-M, which showed the greatest posterior expansions. The intragroup analysis showed a significant increase in the nasal passage volume in hyrax and inverted mini-hyrax on the molar groups, but the intergroup comparison revealed a significant difference only between Fan-Type and inverted mini-hyrax on the molars. None of the expanders caused significant changes in the oropharyngeal measurements.

Conclusions: Only the Hyrax and inverted mini-hyrax on the molar expanders effectively increased the nasal passage volume, and none of the expanders evaluated in this study modified the oropharyngeal airway. (*Angle Orthod.* 2016;86:617–624.)

KEY WORDS: Maxillary expansion; Cleft lip; Cleft palate; Upper airway; Computed tomography

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INTRODUCTION

Cleft lip and palate (CLP) has a significant impact on the nasomaxillary complex and frequently leads to nasal deformities, such as septum deviation, nostril atresia, and turbinates' hypertrophy, which reduces the internal dimensions of the nose, increases resistance to respiratory airflow, and produces mouth breathing.^{1,2} Moreover, the growth and development of the maxillary segments are further compromised by the scar tissues originating from the primary surgeries, thus aggravating the maxillary constriction, particularly in the anterior region.³

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Table 1. Age (in Years), Gender, and Cleft Side Distribution and Comparison Among All Groups

Group	Age			Gender			Cleft Side		
	Mean	SD	<i>P</i> Value*	M	F	<i>P</i> Value**	RS	LS	<i>P</i> Value**
Hyrax	11.1	2.4	ns	7	3	ns	4	6	ns
Fan-type	10.5	1.8		6	4		2	8	
iMini-M	10.5	2.4		7	3		3	7	
iMini-B	12.5	2.3		3	7		4	6	

SD indicates standard deviation; M, male; F, female; RS, right side; LS, left side; ns, not significant ($P > .05$).

* *P* value obtained by one-way analysis of variance; ** *P* value obtained by chi-square test.

Rapid maxillary expansion (RME) is commonly used to correct this transverse deficiency,^{3,4} and its effect over the maxilla and as a treatment for respiratory disturbances have been described in the literature, especially for noncleft patients.^{5,6} RME has an important impact on the upper airway dimensions because of the transverse movement of the nasal lateral walls.⁴ Furthermore, RME may also affect the position of the mandible, which may change the size and volume of the oropharyngeal airway.⁷

Previous cone beam computed tomography (CBCT) studies have confirmed that it is possible to visualize and measure the upper airway as a solid structure, allowing volumetric measurements with minimal margin of error.^{8,9} Lower costs, shorter scanning time, and consequently lower radiation doses have made CBCT technology the preferred method to assess the airways.⁹ However, there is a lack of CBCT studies assessing the volumetric changes in the nasal and oropharyngeal airways postorthodontic treatment of CLP patients. Clinically, it is important to know how RME, performed with different kinds of expanders, might affect the upper airway dimensions. Therefore, the objectives of this retrospective cleft study were to evaluate the changes on maxillary width, the volume of oropharynx (OP) and nasal passage (NP), and the OP minimum axial area after RME with four different types of expanders.

MATERIALS AND METHODS

This study was approved by the Institutional Review Board of the Pontifical Catholic University of Minas Gerais (PUC Minas). All subjects signed an informed consent prior to the start of treatment. The sample comprised 40 unilateral cleft lip and palate (UCLP) children (23 boys and 17 girls ranging in age from 8 years to 14 years) with a mean age of 11.1 years $\pm$ 2.2, who sought orthodontic treatment at the cleft center of our university. All CBCT scans were obtained from the existing patient database. The scans were acquired with an iCat machine (Imaging Sciences International, LLC, Hatfield, Pa) by the same radiology technician and with a 40-second scan, a 23 $\times$ 17-cm field of view (FOV), and a voxel size of 0.3 mm. The selection criteria included the presence of UCLP repaired by Millard's¹⁰

and Veau's methods,¹¹ RME as an initial part of the orthodontic treatment, and absence of previous orthodontic treatment. The exclusion criteria were any additional craniofacial syndrome and the absence of erupted maxillary permanent first molars. All subjects were in prepubertal or pubertal stage of maturation based on the cervical vertebrae maturation¹² assessed on reconstructed lateral cephalograms generated from CBCT.

The patients were distributed into four groups (10 patients each) according to the extension of the maxillary deficiency. The patients with anterior and posterior maxillary deficiency received the Hyrax or inverted mini-hyrax supported on the first permanent molars (iMini-M). Those with only anterior maxillary deficiency were treated with Fan-Type or inverted mini-hyrax supported on the first premolars (iMini-B) (Table 1). Because of the characteristics of the iMini-B, only patients with fully erupted first premolars were included in this group. The Hyrax is a tooth-borne appliance with a jackscrew (Leone Orthodontics and Implantology, Firenze, Italy) located in the deciduous molars or premolar region (Figure 1A). The Fan-Type expander is a tooth and tissue-borne appliance with a jackscrew and a posterior hinge (Morelli Ortodontia, Sorocaba, Brazil) located in the first permanent molars region (Figure 1B). The iMini-M is a tooth-borne appliance constructed with a mini-hyrax screw (Dyna-flex, Saint Ann, Mo) positioned at the anterior region, with its arms bent posteriorly and bilaterally soldered to first permanent molar bands (Figure 1C).¹³ The iMini-B was constructed similarly to the iMini-M, but its arms are bilaterally soldered to first premolar bands. It was used in association with a transpalatal arch (TPA) inserted to the first permanent molars (Figure 1D). The same lab technician fabricated all expanders.

The CBCT images were taken before (T0) and 3 months after expansion (T1) for adequate secondary bone graft surgical planning. The activation regimen was established at two turns per day until the tip of the lingual cusps of the maxillary teeth touched the tips of the buccal cusps of the mandibular teeth.

All CBCT images were oriented and standardized using Dolphin Imaging 11.5 software (Dolphin Imaging & Management Solutions, Chatsworth, Calif). The images

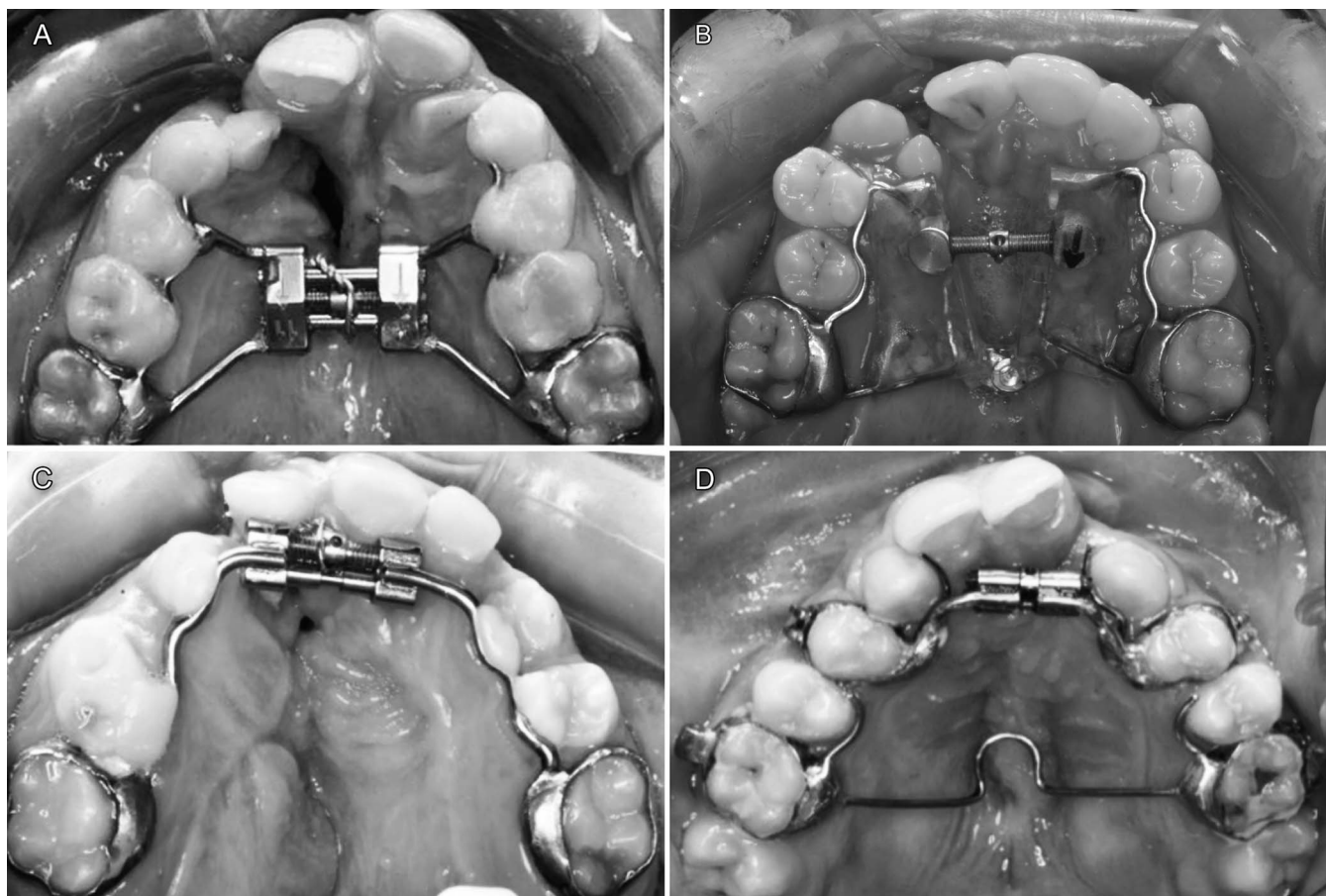


Figure 1. Rapid maxillary expanders. (A) Hyrax. (B) Fan-type. (C) iMini-M. (D) iMini-B.

of each patient's head were oriented in all three planes of space for frontal, right lateral, and top (facing down) views, as previously described.¹⁴ The RME effects were examined comparing measurements made at T0 and T1 in all patient groups. The same operator who was properly calibrated and blinded to the group status performed all exams.

The two-dimensional topographic assessments of the anterior maxillary width (AMW) and posterior maxillary width (PMW) were performed in the coronal slice. For AMW, the best slice that showed the crown of first deciduous molar, or first premolar, was selected. The axial plane that passes through the cement-enamel junction on the palatal surface of each tooth was identified. The distance between the median point of the palatal surface of the dental crown and a median line was measured on this slice. The values for right and left sides were summed and represented the AMW (Figure 2A,B). For the PMW, the first permanent molars were used as references (Figure 2C,D). A line perpendicular to the ground that intersected the frontal crypt, seen on axial slices, determined the midline. The methodology for the three-dimensional volumetric assessment of OP and NP was previously described¹⁵

(Figures 3 and 4). In addition to the OP volume, the software automatically calculated the minimum axial area of this structure, which represents the most constricted cross-sectional area of OP.

Statistical Analysis

Statistical analysis was performed with GraphPad Prism 5.01 software (GraphPad Software, San Diego, Calif). The significance level was set at 5%. Chi-square tests were used to assess differences in patients' gender and cleft sides among the groups. Parametric tests were used to evaluate the other variables because the D'Agostino-Pearson test showed that the data were normally distributed. Intragroup differences between T1 and T0 were tested for statistical significance using paired *t*-tests. Moreover, one-way analysis of variance followed by Bonferroni's post hoc test were performed to compare a variable's change (T1 minus T0) among the four expanders. Intraexaminer repeatability and interexaminer reproducibility were assessed with the measurement of 20 CBCT scans randomly selected after a 2-week interval. The intra-class correlation coefficient (ICC) showed that inter-examiner agreement was greater than 0.91, whereas

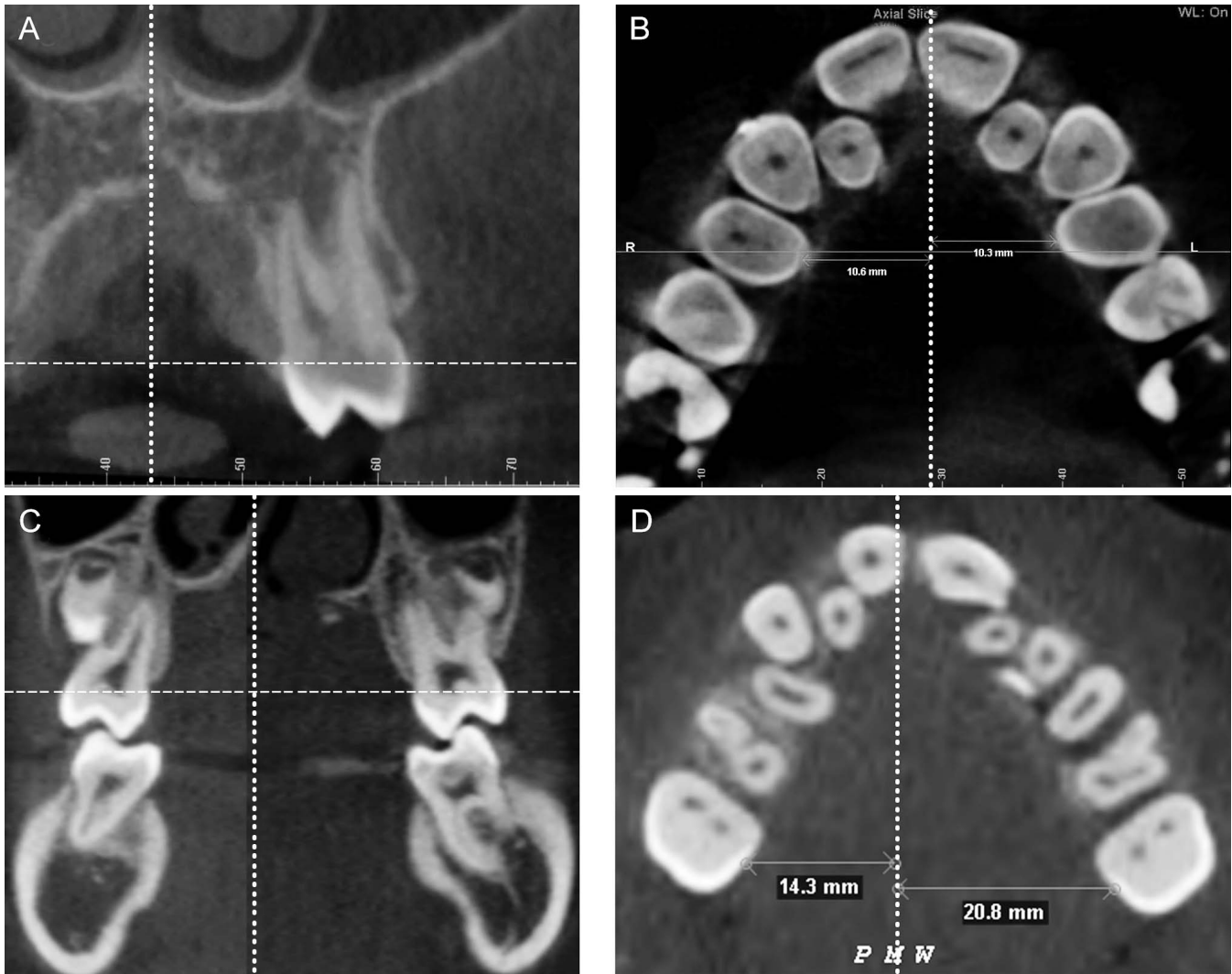


Figure 2. (A) Anterior maxillary width (AMW) with a coronal slice that best shows the crown of each anterior tooth. The dashed line intersects the cemento-enamel junction (CEJ) on the palatal surface of the teeth. (B) AMW with axial cut determined by the line on the coronal slice where the distance of the median point of the palatal surface of the dental crown and a median line was measured. The values for right and left sides were summed and represent the AMW. (C) Posterior maxillary width (PMW) with a coronal slice that best shows the crown of each posterior tooth. The dashed line intersects the CEJ on the palatal surface of the teeth. (D) PMW with axial cut determined by the dashed line on the coronal slice where the distance of the median point of the palatal surface of the dental crown and a median line was measured. The values for right and left sides were summed and represent the PMW.

Table 2. Comparison of Variables Before (T0) and 3 Months After Expansion (T1) in the Hyrax Group

Variables	T0		T1		Mean of Differences	P Value*
	Mean	SD	Mean	SD	T1–T0	
Anterior maxillary width (mm)	22.02	3.15	26.69	3.36	4.67	<.05
Posterior maxillary width (mm)	31.71	2.46	36.39	2.50	4.68	<.05
Nasal passage volume (mm ³)	6,738	1,798	7,588	1,970	850	<.05
Oropharynx volume (mm ³)	11,127	3,622	12,290	5,593	1,163	ns
Oropharynx minimum area (mm ²)	187.2	83.67	211.4	99.48	24.2	ns

SD indicates standard deviation; ns, not significant ($P > .05$).
* P value obtained by paired t-test: T0 vs T1.



Figure 3. Limits of the oropharynx. (A) The upper limit is the palatal plane extended to the pharyngeal posterior wall, and the lower limit is the plane parallel to the palatal plane intersecting the lower and most anterior point in the second cervical vertebra. The horizontal white line represents the most constricted axial area in the oropharyngeal (minimum axial area). (B) Three-dimensional view of the oropharynx. The gray plane represents its minimum axial area.

intraexaminer ICC varied from 0.97 to 0.99 for all measurements except NP volume, which was 0.87.

RESULTS

All Groups Were Matched on Age, Gender, and Cleft Side

As shown in Table 1, no significant differences ($P > .05$) were found in patient age, gender, or cleft side among the groups.

The AMW Significantly Increased in All Groups

All groups showed a significant increase ($P < .05$) in the AMW (Tables 2 to 5), with no intergroup differences (Table 6).

The PMW Significantly Increased in All Groups Except iMini-B

The iMini-B was the only group that did not show a significant increase in the PMW ($P > .05$) (Table 5). The

intergroup comparison demonstrated differences among all groups except between Hyrax and iMini-M, which showed the greatest posterior expansions (Table 6).

Hyrax and iMini-M Significantly Increased NP Volume

Hyrax and iMini-M groups were the only groups to show a significant increase ($P < .05$) in NP volume, as shown in Tables 2 and 4. The intergroup comparison demonstrated that the greatest increase was found in the iMini-M group (1423 mm³), followed by Hyrax (850 mm³), iMini-B (553 mm³), and the Fan-Type group (112 mm³), with significant differences found only between the iMini-M and the Fan-Type groups, as shown in Table 6.

There Were No Significant Changes in the OP Volume and Minimum Axial Area in Any of the Groups

The OP volume and minimum axial area increased in the hyrax and iMini-M groups and decreased in

Table 3. Comparison of Variables Before (T0) and 3 Months After Expansion (T1) in the Fan-Type Group

Variables	T0		T1		Mean of Differences	P Value*
	Mean	SD	Mean	SD	T1–T0	
Anterior maxillary width (mm)	21.57	3.12	27.27	3.54	5.70	<.05
Posterior maxillary width (mm)	33.13	3.24	35.23	2.57	2.10	<.05
Nasal passage volume (mm ³)	7,331	3,318	7,443	3,041	112	ns
Oropharynx volume (mm ³)	12,273	2,167	11,627	4,018	–646	ns
Oropharynx minimum area (mm ²)	211.2	108.3	186.9	65.60	–24.3	ns

SD indicates standard deviation; ns, not significant ($P > .05$).

* P value obtained by paired t-test: T0 vs T1.

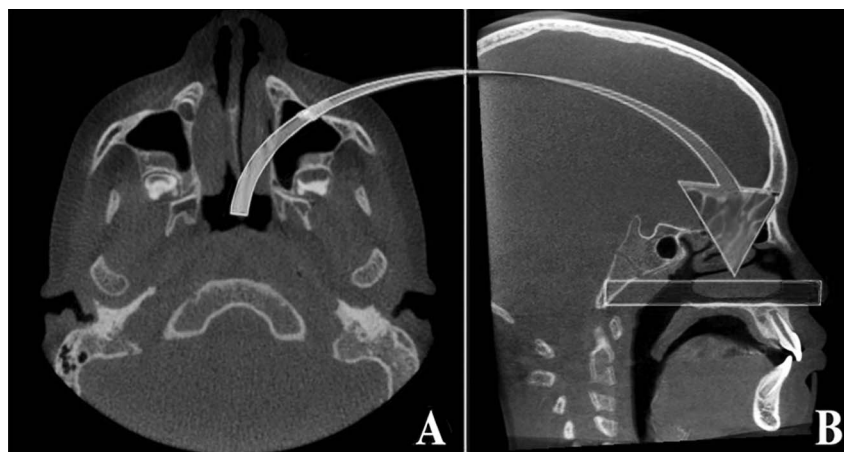


Figure 4. Limits of the nasal passage. (A) Determination of the last axial slice before the fusion of the nasal septum with the pharyngeal posterior wall. (B) The reflection of that slice in the sagittal plane defines the upper limit, and the palatal plane determines the lower limit.

the Fan-Type and iMini-B groups, but these changes were not statistically significant ($P > .05$), as shown in Tables 2 to 5. Moreover, there was no significant intergroup difference (Table 6).

DISCUSSION

CLP has a major impact on the nasomaxillary complex and may affect craniofacial development and compromise airway function.¹⁻³ The transverse skeletal and morphological effects of RME have been investigated in noncleft and cleft patients using different diagnostic methods.^{4-7,14,16-18} However, there is a lack of CBCT studies in CLP patients that quantify and compare the volumetric changes in the upper airway post RME, especially evaluating the efficacy of different types of expanders.

The maxillary arch of cleft patients often presents a transverse deficiency limited to the anterior region.³ Therefore, these patients would benefit from the use of an expander that favors intercanine and interpremolar expansion while restricting intermolar transverse changes. With this in mind, the iMini-B, the Fan-Type, and the iMini-M expanders were designed to be compared with the Hyrax expander, which is the most

commonly used maxillary expander worldwide. The results of the present study revealed that all four expanders provided significant anterior maxillary expansion. The iMini-B was the only expander to significantly restrict the posterior maxillary expansion, and the Fan-Type only partially restricted the posterior expansion, compared to the Hyrax. Despite the significant increase in the anterior maxillary transverse dimension, the anterior location of the screw in the iMini-M did not limit the posterior expansion.

The maxilla forms most of the nasal cavity lateral walls. Therefore, an increase in nasal cavity volume after RME would be expected.^{6,15} The series of events that cause this expansion is mainly a triangular¹⁶ or parallel¹⁹ opening of the median palatal suture, which increases the nasal floor width and the nasal cavity volume in both noncleft and cleft patients. This study showed a significant increase in the NP volume in the hyrax and iMini-M groups, which is consistent with the results of a previous study that used acoustic rhinometry to assess the nasal cavity volume changes in CLP patients with the Hyrax expander and found a significant increase post RME.⁴ In the present study, the NP volume increased

Table 4. Comparison of Variables Before (T0) and 3 Months After Expansion (T1) in the iMini-M Group

Variables	T0		T1		Mean of Differences	P Value*
	Mean	SD	Mean	SD	T1-T0	
Anterior maxillary width (mm)	21.77	2.90	26.45	3.48	4.68	<.05
Posterior maxillary width (mm)	33.17	2.29	38.35	2.83	5.18	<.05
Nasal passage volume (mm ³)	5,440	2,246	6,863	3,182	1,423	<.05
Oropharynx volume (mm ³)	8,947	4,146	11,901	10,638	2,954	ns
Oropharynx minimum area (mm ²)	127.2	45.82	190.5	127.1	63.3	ns

SD indicates standard deviation; ns, not significant ($P > .05$).

* P value obtained by paired *t*-test: T0 vs T1.

Table 5. Comparison of Variables Before (T0) and 3 Months After Expansion (T1) in the iMini-B Group

Variables	T0		T1		Mean of Differences	P Value*
	Mean	SD	Mean	SD	T1-T0	
Anterior maxillary width (mm)	22.93	1.99	26.79	2.50	3.86	<.05
Posterior maxillary width (mm)	36.00	2.94	35.93	2.78	-0.07	ns
Nasal passage volume (mm ³)	8,743	2,325	9,296	2,897	553	ns
Oropharynx volume (mm ³)	12,200	4,505	12,068	5,973	-132	ns
Oropharynx minimum area (mm ²)	174.4	132.4	146.0	93.35	-28.4	ns

SD indicates standard deviation; ns, not significant ($P > .05$).

* P value obtained by paired *t*-test: T0 vs T1.

approximately 12.6% in the Hyrax group, 26.1% in the iMini-M group, 6.3% in the iMini-B group, and 1.5% in the Fan-Type group.

These findings suggest that RME might improve the breathing pattern in CLP patients by reducing nasal resistance when the expansion of the posterior part of the maxilla is not restricted, such as when Hyrax and iMini-M expanders are used. Further studies are necessary to verify the long-term stability of this effect and to confirm the relationship between the increase in NP volume and the RME's beneficial effects in respiratory function.

A previous RME study⁷ in noncleft patients reported that the mandibular position changes in different directions, which may affect the OP airway size, shape, and volume. However, our results indicated no significant changes in the OP volume and area in any of the study groups. These findings are consistent with other RME studies that evaluated OP airways in noncleft patients and concluded that this procedure did not significantly affect the oropharyngeal dimensions.^{20,21} Moreover, the transverse maxillary deficiency might also play a role in the pathophysiology of obstructive sleep apnea syndrome (OSA) because maxillary constriction is associated with a lower posture of the tongue that could result in narrowing of the oropharynx airway, which is an important risk factor for developing OSA. RME has been proposed as a treatment modality for OSA based on the hypothesis that the airway volume increases after maxillary expansion

because the tongue would reposition more anteriorly in the oral cavity.²² However, the present study cannot support this hypothesis because no significant increase in the OP dimensions were registered in any group, at least during the evaluation period.

One limitation of this retrospective study is the lack of homogeneity of the sample in T0. However, all patients presented a complete UCLP and were operated on by the same surgeon with the same techniques. Moreover, the individual patient's response to surgeries and other intrinsic and extrinsic factors might have affected the growth and development of the maxillae, which is variable and unpredictable. Therefore, some patients presented greater anterior maxillary constriction and others showed more posterior transverse deficiency. The other limitation is the lack of control over tongue position when the CBCT images were obtained. The position of the tongue and soft tissues are important anatomic factors that affect the shape and size of the oropharynx airway volume.²³ As all individuals in this study were matched by age and gender and scanned with a standardized imaging protocol (scans taken during the same period of time by the same operator with the same instructions to the patients), possible confounding effects of tongue-position changes (changes in tongue length and height) might be minimized. Further studies should be performed to assess those changes. Taken together, the RME treatment was not an effective method to increase

Table 6. Comparison^a of Changes in Variables Before and 3 Months After Expansion Among All Expanders

Variables ^b	Hyrax (1)		Fan-Type (2)		iMini-M (3)		iMini-B (4)		P	1 vs 2	1 vs 3	1 vs 4	2 vs 3	2 vs 4	3 vs 4
	Mean	SD	Mean	SD	Mean	SD	Mean	SD							
AMW (mm)	4.67	0.87	5.70	2.89	4.68	1.60	3.86	1.42	.194	ns	ns	ns	ns	ns	ns
PMW (mm)	4.68	1.05	2.10	1.25	5.18	1.78	-0.07	0.21	.000	*	ns	*	*	*	*
NP volume (mm ³)	850	937.9	112	681.2	1,423	1,261	553	1,091	.046	ns	ns	ns	*	ns	ns
OP volume (mm ³)	1,163	4,272	-646	3,603	2,954	8,684	-132	3,144	.458	ns	ns	ns	ns	ns	ns
OP minimum area (mm ²)	24.2	94.5	-24.3	109.6	63.3	144.4	-28.4	73.4	.204	ns	ns	ns	ns	ns	ns

^a Comparison by one-way analysis of variance followed by the Bonferroni post hoc test.

^b AMW indicates anterior maxillary width; PMW, posterior maxillary width; NP, nasal passage; OP, oropharynx; SD, standard deviation; ns, not significant ($P > .05$).

* $P < .05$.

the oropharynx airway volume of UCLP patients with maxillary constriction, regardless of expander type.

Clinically, the type of expander to treat CLP patients with maxillary transverse deficiency is determined by an orthodontist's preference and should be based on patients' specific needs. Our results suggested that RME is not an effective method to increase OP airway volume of CLP patients, regardless of the expander used. However, if an increase in NP volume is required, the Hyrax and iMini-M expanders should be the expanders of choice.

CONCLUSIONS

- The Hyrax and iMini-Molar appliances were the only expanders to significantly increase nasal cavity volume.
- RME did not increase the volume of the oropharyngeal airway.

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