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Original Article

Cone beam CT evaluation of skeletal and nasomaxillary complex volume changes after rapid maxillary expansion in OSA children

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ABSTRACT

Objective: The first objective of this study was to evaluate skeletal changes and changes in dimensions and volume of the upper airways before and after rapid maxillary expansion (RME) therapy in children with obstructive sleep apnoea (OSA), by Cone Beam computed tomography (CBCT). The second objective was to evaluate if RME therapy could improve both the patency of the nasal airways and the Obstructive Sleep Apnoea Syndrome (OSAS).

Methods: 19 children with OSA and malocclusion took CBCT scans with a Dentascan and 3D reconstruction program before (T0) and 4 months after (T1) RME. Patients underwent an ENT visit with auditory and respiratory tests, including a daytime sleepiness questionnaire, a 19-channel polysomnography, and an orthognatodontic examination before orthodontic therapy (T0), after 2 months (T1) with the device still on, and 4 months after the end of the orthodontic treatment (T2).

Results: In all cases opening of the mid-palatal suture was demonstrated. Nasal osseous width, volume of the total upper airways, nasal cavity and nasopharynx and oropharynx increased significantly (P, .001). The increased W-ANS, W-mid and WPNS were closed linked to the enlarged midpalatal suture (P, .001). The increased WPNS were closed linked to the enlarged pterygoid processes (P, .001). The increased V-NC and V-NPA was closely linked to the enlarged W-PNS (P, .001) as well as VOPA and consequently to the enlarged midpalatal suture and pterygoid processes.

Conclusion: RME treatment had a positive effect on children affected by chronic snoring and OSA, causing an increase in volume of the nasal cavity and nasopharynx, with expansion of the nasal osseous width and maxillary width. Enlarged nasal width at the PNS plane contributed to the increase in nasopharynx volume. Enlarged maxillary width showed a direct correlation to increased airways volume, bringing a functional improvement. The results show that the RME therapy can restore and improve a normal nasal airflow with disappearance of obstructive sleep breathing disorder.

1. Introduction

The Orthodontists can play a very important role in the early detection of OSAS in children, and dental/orthodontic treatment options have emerged in the past decade for children with OSAS [1–3]. RME can help to increase nasopharyngeal and oropharyngeal space for children with upper jaw restriction. The nasomaxillary complex provides anterior bony support for the upper airways, and orthodontic treatment affects these structures, causing changes in the airways to some extent. This means that orthodontists have the responsibility to understand the physiology of upper airways [4,5]. Katyal et al. [6] showed that children with narrow dentoalveolar transverse width and reduced nasopharyngeal and oropharyngeal sagittal dimensions had a high risk for sleep-disordered breathing. Many studies have reported the influence of RME on the upper airways, though the results were different due to various subjects and expansion methods [7].

Imaging software programs have been extremely useful in assessing the benefits of RME. Three-dimensional method of investigation (3D-CT) has been used to study the effects of RME

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treatment using low dose protocol [8–12]. The CBCT systems are operated at a lower patient dose than the MDCT systems, which are used for wide ranges of exposure protocols in dental clinics [9,13] and have become a standard technique for dentomaxillofacial CT imaging [14–16].

The purpose of this study was to evaluate skeletal changes and changes in dimension and volume of upper airways before and after rapid maxillary expansion (RME) therapy in children with obstructive sleep apnoea (OSA), by Cone Beam computed tomography (CBCT), and to evaluate if RME therapy could improve both the patency of the nasal airways and the Obstructive Sleep Apnoea Syndrome (OSAS).

2. Materials and methods

2.1. Subjects

78 children were selected from a sample of 120 patients presenting malocclusion (45 boys and 33 girls) with the average age of 8.5 years (range: 5–12 years) presenting oral breathing, snoring and OSA symptoms. Patients presenting adeno-tonsillar hypertrophy and body mass index more than 24 kg/m^2 were excluded from this sample. Furthermore, a subsequent selection excluding the younger population was made: in order to reduce the probabilistic effects of ionizing radiation —the stochastic radiation effect— children between 5 and 9 years of age were excluded. Moreover, only patients who have undergone polysomnography were selected, and patients who did not undergo second CB CT control or who had image artifacts in the first or second control were excluded. At the end of the screening the selected sample for the study consisted of 19 patients with mixed dentition, an average age of 10.5 years (range 9 e12 years), an average apnea/hypopnea index (AHI0) of 14.1 (±2.4), and an average minimum oxygen saturation of 75.8 (±8.3)%.

Selection criteria included: malocclusion with upper jaw contraction, oral breathing, snoring and OSA symptoms (documented by polysomnography), no adenotonsillar hypertrophy, body mass index less than 24 kg/m^2.

Patients underwent an ENT visit with auditory and respiratory tests, including a daytime sleepiness questionnaire, a 19-channel polysomnography, an orthognatodontic examination and CB CT scans with a Dentascan and 3D reconstruction program, before (T0) and 4 months after (T1) RME. All the clinical investigations were carried out before orthodontic therapy (T0), after 2 months (T1) with the device still on, and 4 months after the end of the orthodontic treatment (T2).

This study was approved by internal University Ethical Committee (approval number 91/06) and the informed consent was obtained from the parents or guardians of all patients.

Specific evaluations were made regarding the following parameters: maxillary suture width at anterior, middle and posterior level; nasal width; right and left molar angulation and pterygoid processes distance. Vertical and horizontal dimensions and volume of the nasal cavity, nasopharyngeal, oropharyngeal and the total pharyngeal airway volume were compared before and after RME. Correlations between changed volume and dimensions were explored.

2.2. Data collection

CBCT scans examinations (NewTom 5GXL) were performed before expansion (T0) and after 4 months' retention (T1) by the same operator.

The patients were scanned in orthostatic position with the Frankfurt plane perpendicular to the floor, keeping the teeth in centric occlusion and the tongue in the position at the end of swallowing (against the palate), breathing smoothly, and no swallowing. The digital imaging and communications in medicine (DICOM) data were imported into Dolphin Imaging software (Chatsworth, CA, USA) and used for the measurements described. Volumetric measurements were carried out with the aid of Dolphin® Imaging v. 11.7 software, using the "Airways Volume" tool, and density was set at 55 for all patients.

The images were evaluated in three views (sagittal, coronal and axial), thus delimiting the nasomaxillary complex, and then calculating the volume in cubic millimetres.

Numerical evaluation of the various parameters was based on the identification and registration of a group of reference points, identified on the CT images reformatted on different planes.

Before landmark identification, the three-dimensional volumetric images were oriented with the Dolphin imaging software as follows: coronal plane (horizontal line through orbital bilaterally), sagittal plane (Frankfurt horizontal), and axial plane (Crista galli to basion). The Dolphin software allowed automatic volume calculation after segmenting the area of interest by setting the threshold value of 55.

The material was measured twice by the same author, with at least one week interval between T0 and T1.

The following parameters were measured in millimetres:

(1) Suture opening was measured at three levels on the axial plane: anterior edge, middle and posterior nasal spine. At T0 the measurement of the midpalatal suture at three different levels was considered equal to 0 in order to level the different values before RME treatment that were in the range of 0–0.3.
(2) Maxillary base width was calculated on the axial plane between the vestibular border of buccal cortical plate (left and right respectively). The points were joined using a line tangent to the dental root of the first molar.
(3) The distance between the apices of the pterygoid processes (left and right) was calculated on the axial plane.
(4) Right and left molar angulation were measured on the coronal plane, between a line passing through the cusp tips of the mesio-buccal cusp on the maxillary first molar and the apices of the palatal roots of the first molar (left and right respectively), and a line parallel to the sagittal line.
(5) Nasal cross-sectional (ANS) height (H-ANS): The height of nasal cavity at the cross-section passing through ANS on Coronal plane reconstruction.
(6) Nasal cross-sectional (ANS) width (W-ANS): The greatest width of nasal cavity at the cross-section passing through ANS on coronal plane reconstruction.
(7) Nasal cross-sectional height (midpoint) (H-mid): The height of nasal cavity at the cross-section passing though the midpoint between ANS and PNS on coronal plane reconstruction.
(8) Nasal cross-sectional width (midpoint) (W-mid): The greatest width of nasal cavity at the cross-section passing through the midpoint between ANS and PNS on coronal plane reconstruction.
(9) Nasal cross-sectional height (PNS) (H-PNS): The height of nasal cavity at the cross-section passing through PNS on coronal plane reconstruction.
(10) Nasal cross-sectional width (PNS) (W-PNS): The greatest width of nasal cavity at the cross-section passing through ANS on coronal plane reconstruction (Fig. 1).

The cavity volume was measured in mm^3 by 3D images:

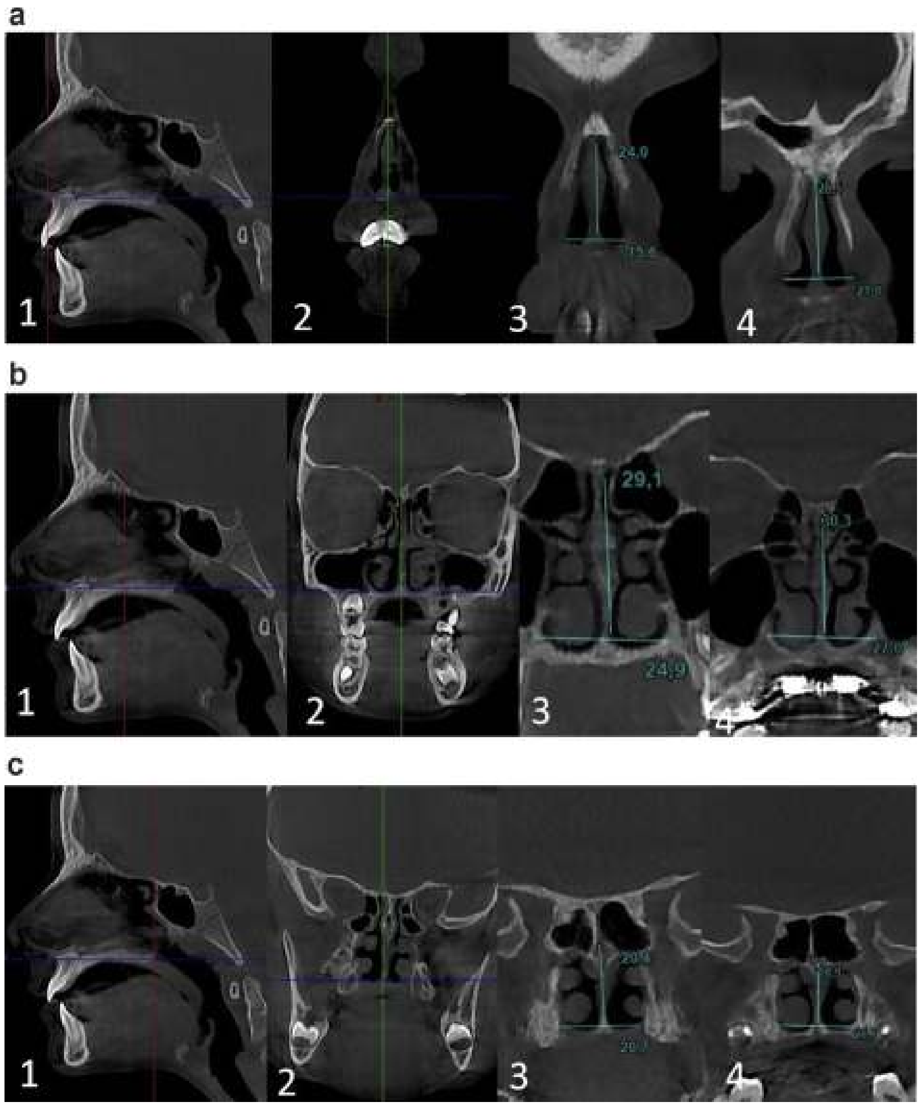

Fig. 1. a,b,c, Landmark on sagittal (1) and coronal plane (2): ANS (a 1,2), midpoint between ANS and PNS (b 1,2) and PNS (c 1,2). Nasal cross-sectional height and width on coronal plane reconstruction before (3) e after RME (4) at the level of the ANS (a), midpoint between ANS and PNS (b) and PNS (c).

(1) Nasal cavity volume (V-NC) bound by lines connecting the anterior nasal spine (ANS) to the tip of the nasal bone, then to nasion (N), then to sella (S), then to posterior nasal spine (PNS) (Fig. 2a).
(2) Nasopharyngeal airways volume (V-NPA): The line passing through PNS and S is its anterior border, the line parallel to the Frankfurt horizontal plane (FHP) passing through PNS point is the inferior border, pharyngeal posterior wall is the posterior border.
(3) Oropharyngeal airways volume (V-OPA): The line parallel to FHP passing through the tip of the uvula (Fig. 2b) is the inferior border pharyngeal anterior wall is the anterior border and pharyngeal posterior wall is the posterior border.
(4) Total upper airway volume (V-TA): The line passing through PNS and S is its anterior border, the top of the epiglottis is its inferior border (Fig. 2c), pharyngeal anterior wall is the anterior border and pharyngeal posterior wall is the posterior border added to nasal cavity volume (V-NC) (Fig. 3).

Rhinomanometric and polysomnography was performed before, after 2 and 4 months from RME.

The following parameters of the polysomnography test were evaluated: Obstructive AHI Range, Nadir SPO_2 (%), Duration of Longest Obstructive Apneas, Duration of Desaturation (S302 < 92%) ass% TST and Sleep Efficiency (%).

2.3. Statistical analysis

The normality of the data was evaluated using the Shapiro–Wilk test. Measurements for each patient before and after treatment were compared with Wilcoxon's paired matched test. Values are

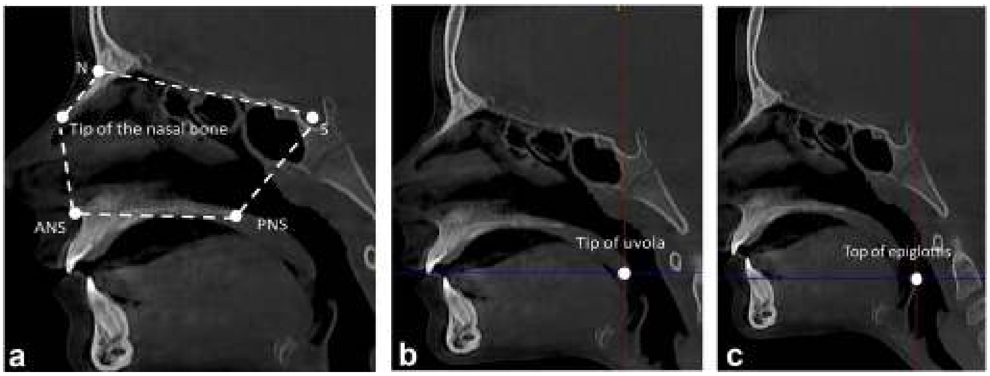

Fig. 2. (a) Nasal cavity volume (V-NC) bound by lines connecting the anterior nasal spine (ANS) to the tip of the nasal bone, then to nasion (N), then to sella (S), then to posterior nasal spine (PNS). (b) Oropharyngeal airways volume (V-OPA): landmark of the inferior border (tip of the uvula). (c)Total upper airway volume (V-TA): landmark of the inferior border (the top of the epiglottis).

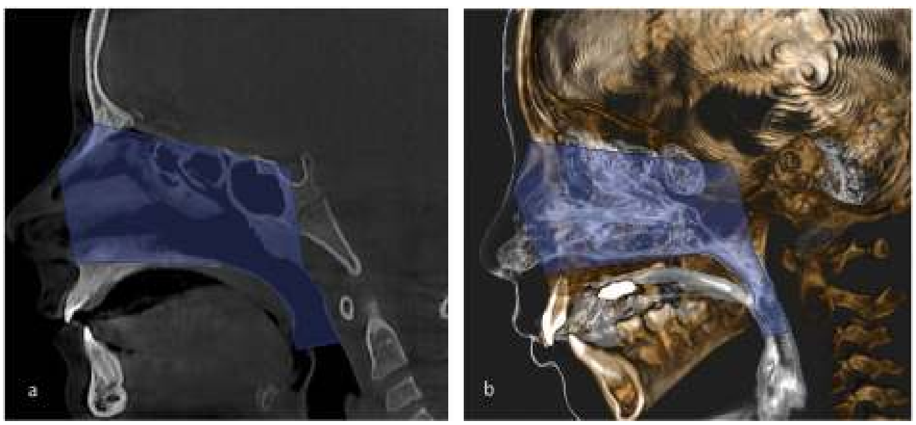

Fig. 3. Sagittal plane (a) and 3D volume CT reconstruction (b): total upper airway volume (V-TA): nasal cavity volume (V-NC) added to pharyngeal airways volume evaluated up to the top of the epiglottis.

expressed as mean ± standard deviation. As a threshold of statistical significance, a value of p _ 0.05 and p_ 0.001 was used.

The statistical treatment of the data was performed with the Statistical Package for the Social Sciences (SPSS), version 22 for Windows.

3. Results

All the results in each patient of the sample are shown in Table 1a–c.

In all the 19 cases, an opening of the midpalatal suture was obtained, with resulting effects at different levels.

3.1. Midpalatal suture

In all cases we obtained the opening of the midpalatal suture. The increase at the anterior level of the suture showed an average opening of 4.1 mm. This increase is evident with the appearance of an interincisive space, the hallmark of the midpalatal suture opening that was always present in all cases; 3.1 mm at the medium level of the suture; 1.95 at the posterior level of the suture (Fig. 4).

3.2. Maxillary width

RME therapy is responsible for the expansion of the maxilla with an average cross-sectional increase of 3.5 mm. There were individual variations, although all values showed clear differences between T0 and T1, indicating that, in all patients, the manoeuvre had an expansive effect.

3.3. Pterygoid processes

From the study of the pterygoid processes distance, we found an average increase of 2.6 m.

3.4. First molar angulation

Expansion of the skeletal structures was associated with a minimal tipping of the maxillary first molar or second deciduous molar. Tipping for the teeth occurred in all subjects.

3.5. W-ANS, W-mid, W-PNS, H-ANS, H-PNS and H-mid

We found an average increase respectively of 6.3 mm, 2.43 mm, 3.1 mm, 3.9 mm, 0.5 mm and 1.7 mm.

In summary, the midpalatal suture was opened in all patients. A statistically significant difference was observed between the measurements of the maxillary, nasal cavities, and pterygoid processes distance width, performed before and after treatment.

The mean amplitude of the maxilla in T0 was 51.6 ± 2 and in T1 was evaluated at 55.1 ± 3, p ¼ 0.0002. The nasal cavities measurement was 29.07 ± 2 pre-treatment, and 31.5 ± 2 post-treatment, p ¼ 0.0001. The mean amplitude of the pterygoid

Table 1a
Value before RME.

Patient	Anterior suture	Middle suture	Posterior suture	Pterygoideus processes	Maxillary width	Right angle	Left angle
1	0	0	0	50,1	52,7	36,4	35,5
2	0	0	0	44,2	47,2	28,2°	28,2°
3	0	0	0	60,8	52,4	41,3°	32,7°
4	0	0	0	48,4	48,1	39,5°	27,2°
5	0	0	0	49	54,9	30,7°	32,6°
6	0	0	0	50,7	51,7	39,1°	36,7°
7	0	0	0	52,7	53,7	33,5°	30,1°
8	0	0	0	52,6	52,7	29,7°	33,7°
9	0	0	0	49,7	57,4	25,4°	30,5°
10	0	0	0	55,7	53,6	44,4°	38,4°
11	0	0	0	51,2	49,6	40°	36,7°
12	0	0	0	54,6	47,7	36,1°	36,1°
13	0	0	0	54,9	50,1	30,1°	28,4°
14	0	0	0	50,4	51,8	29,3°	32,4°
15	0	0	0	51,3	51,5	35,9	33,2
16	0	0	0	49,8	52,8	37,8	31,9
17	0	0	0	52,7	50,3	36,7	34,5
18	0	0	0	50,7	49,4	32, 8	31,7
19	0	0	0	54,2	53,9	34.3	32,9

Table 1b
Value after RME.

Patient	Anterior suture	Middle suture	Posterior suture	Pterygoideus processes	Maxillary width	Right angle	Left angle
1	2,7	2,4	1,4	50,8	54,1	40,3°	41,1°
2	6,2	5,6	5,1	48,4	53,4	31,2°	31,5°
3	4,1	3	1,8	61,8	56,7	48,1°	33,7°
4	2,7	2	1,7	52,3	51,2	39,4°	35°
5	2,7	2,2	0,8	52,6	56,3	35,8°	39,6°
6	3,4	3,3	1,4	51,9	54,3	43,6°	40°
7	5,7	4,2	2	54,1	58,3	33,6°	36,3°
8	4,9	3,5	2,9	54,2	57,7	38,9°	35,9°
9	3,7	3	1,5	50,7	60,8	31,3°	34°
10	2,3	1,8	1	56,7	53,6	48°	36°
11	3,2	2,8	2	52,5	50,7	41,9°	37,6°
12	5,8	2,8	1,2	59,2	50,4	38,1°	37,9°
13	5,8	4,4	3	60,1	55,7	32,3°	32,4°
14	5,4	4,5	1,5	55,9	58,2	44,9°	39,5°
15	4,2	3,2	1,9	52,1	53,5	38,1	36,1
16	3,2	3,9	2,1	50,7	60,4	43,2	34,8
17	4,5	2,7	1,7	59,2	57,4	40,3	37,8
18	3,6	2,8	1,8	53,2	49,9	36,7	34
19	5,1	3	2,2	56,3	54,6	37,2	39,8

Table 1c
Overall mean value.

	Anterior suture	Middle suture	Posterior suture	Pterygoideus processes	Maxillary width	Right angle	Left angle
T0	0	0	0	51,7	51,6	35,5°	32,8°
T1	4,1	3,1	1,95	54,3	55,1	39,1°	36,5°
Increase	4,1	3,1	1,95	2,6	3,5	3,6°	3,7°

Fig. 4. a,b: CB CT axial images. A Midpalatal suture before RME (a). Midpalatal suture opening after RME (b).

processes distance was 51.7 ± 3 pre-treatment, and 54.03 ± 3 post-treatment, *p* ¼ 0.0001.

W-ANS, W-mid, W-PNS, and H-ANS showed a significant increase (*P*, 0.001, *P*, 0.001, *P*, 0.001, *P*, 0.001), while H-PNS and H-mid showed a non-statistically significant increase.

3.6. Upper airways volume

At T0 the mean total upper airways volume was 60.8 mm^3 (SD = 11,5 mm^3), the mean nasal volume was 32.3 mm^3 with a standard deviation of 6,1 mm^3, the mean nasopharynx volume was 8.8 mm^3 (DS = 4.2 mm^3), the mean oropharynx volume was 11.3 mm^3, with a standard deviation of 2.4 mm^3 (Table 2).

At T1 the mean total upper airways volume was 70.3 mm^3 (SD = 11,5 mm^3), the mean nasal volume was 39.5 mm^3 with a standard deviation of 6,3 mm^3, the mean nasopharynx volume was 10.8 mm^3 (DS = 4.1 mm^3), the mean oropharynx volume was 14.9 mm^3, with a standard deviation of 2.9 mm^3. (Table 2).

The study shows an increase T0/T1: the total upper airways volume of 9.4 mm^3 (SD = 5.4 mm^3), the nasal volume of 7.2 mm^3 with a standard deviation of 6,3 mm^3, the nasopharynx volume of 2.0 mm^3 (DS = 4.3 mm^3), the oropharynx volume of 3.5 mm^3, with a standard deviation of 5.1 mm^3 (Table 3) (Fig. 5).

The results confirmed the evidence obtained in the descriptive analyses, meaning that the increase in total upper airways volume (V-TA) ($p < 0.001$), nasal volume (V-NC) ($p < 0.001$), nasopharynx volume (V-NPA) ($p < 0.001$) and oropharynx (V-OPA) ($p < 0.001$), were statistically significant.

The increased W-ANS, W-mid and W-PNS were closed linked to the enlarged midpalatal suture (*P*, 0.001). The increased W-PNS were closed linked to the enlarged pterygoid processes (*P*, 0.001).

The increased V-NC and V-NPA was closely linked to the enlarged W-PNS (P, 0.001) as well as V-OPA and consequently to the enlarged midpalatal suture and pterygoid processes.

3.7. Polysomnography data

Baseline: the apnea-hypopnea index (AHI) values ranged from 6.1 to 22.4 events per hour (average 16.3) (normal value < 5).

Table 3 shows polysomnography data in terms of average of obstructive AHI Range, Nadir SPO_2 (%), Duration of Longest Obstructive Apneas, Duration of Desaturation (S302 < 92%) ass% TST and Sleep Efficiency (%) at T0, after 2 (T1) and 4 months (T2) from RME.

Polysomnography presents a normalization of recording in the AHI in all patients at the end of 4 months. The increased V-NC and V-NPA were associated with changes in PSG findings with an AHI ¼ 0.5 (±1.3) and saturation ¼ 96.1 (±1.8)%.

3.8. Rhinomanometric data

The baseline rhinomanometric data (T0) showed a statistically significant difference between those measured at 2 (T1) and 4 months (T2) (Wilcoxon Z 5−4.86, P 5.000; Wilcoxon Z 5−5.39, P 5.000, respectively). The difference between rhinomanometric data at 2 and 4 months was also statistically significant (Wilcoxon Z 5−4.86, P 5.000).

The difference between baseline AHI and that at 2 (T1) and 4 months (T2) was statistically significant (Wilcoxon Z 5−4.0, P 5.000; Wilcoxon Z 5−5.15, P 5.000, respectively).

The difference between AHI at 2 and 4 months was also statistically significant (Wilcoxon Z 5−2.0, P 5.046).

Four months after the end of the orthodontic treatment (T2), all tests showing a normalization of functional examinations were confirmed.

4. Discussion

Respiratory problems associated with transverse maxillary deficiency have been widely discussed by orthodontists and otolaryngologists, given the relation between causes, effects and treatment.

RME anchored on teeth is performed more and more in young children with OSA, as the presence of an abnormal narrow palate is frequently noted with or without enlarged adeno tonsils [17], particularly after the demonstration of incomplete results of tonsillectomy and adenoidectomy (T&A) surgery and reoccurrence of abnormal breathing during sleep post T&A [18–20].

Today, RME is regarded as an important method to correct maxillary deficiency and this technique has been validated by many other authors as it makes the splitting of the midpalatal suture possible while producing certain changes in the nasal cavity, which improves breathing [21–24].

Increases in nasal width and height, and changes in nasal volume between pre and post-RME, assessed by Cone Beam computed tomography, have been observed by several authors [16,25]. This was also among the goals of this study, which were confirmed by the results.

It is no doubt that an improved breathing pattern is an important clinical achievement, as observed in this study immediately following RME. Our patients showed an increase in nasal cavity volume after RME, with this outcome being confirmed by an image manipulation program with 3D images, and by quantification of the measured areas.

The same results were observed in all measures of the naso-maxillary complex.

We found clear orofacial skeletal modifications related to RME, including the changes of the pterygoid processes in our subjects.

Table 2
Total, nasal, nasopharyngeal and oropharyngeal airway volume at T0 ant T1 and nasal cross-sectional height and width in the anterior, middle and posterior nasal region at T0 and T1.

Parameters	T0 Mean (SD)	T1 Mean (SD)	(T1-T0) Mean (SD)
Total upper airway volume (V-TA)	60.8 (11.5)	70.3 (11.5)	9.4 (5.4)
Nasal cavity volume (V-NC)	32.3 (6.1)	39.5 (6.3)	7.2 (6.3)
Nasopharyngeal airway volume (V-NPA)	8.8 (4.2)	10.8 (4.1)	2.0 (4.3)
Oropharyngeal airway volume (V-OPA)	11.37 (2.4)	14.94 (2.9)	3.57 (5.1)
Nasal cross-sectional height (ANS) (H-ANS)	24.8 (6.3)	28.7 (6.5)	3.9 (6.1)
Nasal cross-sectional width (ANS) (W-ANS)	15.4 (6.2)	21.7 (6.4)	6.3 (6.3)
Nasal cross-sectional height (midpoint) (H-mid)	29.2 (2.1)	30.9 (2.2)	1.7 (2.3)
Nasal cross-sectional width (midpoint) (W-mid)	29.7 (2)	31.5 (2)	1.8 (2)
Nasal cross-sectional height (PNS) (H-PNS)	19.4 (2.4)	19.9 (2.6)	0.5 (2.2)
Nasal cross-sectional width (PNS) (W-PNS)	20.7 (4.4)	23.8 (4.7)	3.1 (4.2)

Table 3
Polysomnographic data. Note the significant improvement in all the functional parameters achieved at T2. All data are displayed as mean _ standard deviation.

	T0	T1	T2
Obstructive AHI	Range 6.1–22.4 Averange 16.3 2.5	Range 0–9.1 Averange 8.3 2.3	Range 0–26 Averange 0.8 1.3
Nadir SPO_2 (%)	77.9 ± 8.4	90.2 ± 5.7	95.4 ± 1.4
Duration of longest obstructive apneas	39.8 ± 17.2	24.3 ± 12.3	12.1 ± 6.5
Duration of desaturation (S302 < 92%) ASS % TST	18.5 ± 3.2	5.8 ± 1.3	1.3 ± 1.4
Sleep efficiency (%)	88.5 ± 9.1	88.9 ± 5.7	89.8 ± 8.5

Abbreviations: TST, total sleep time; T0, before any orthodontic therapy; T1, after 4 weeks with the device; T2, 4 months after the end of the orthodontic treatment.

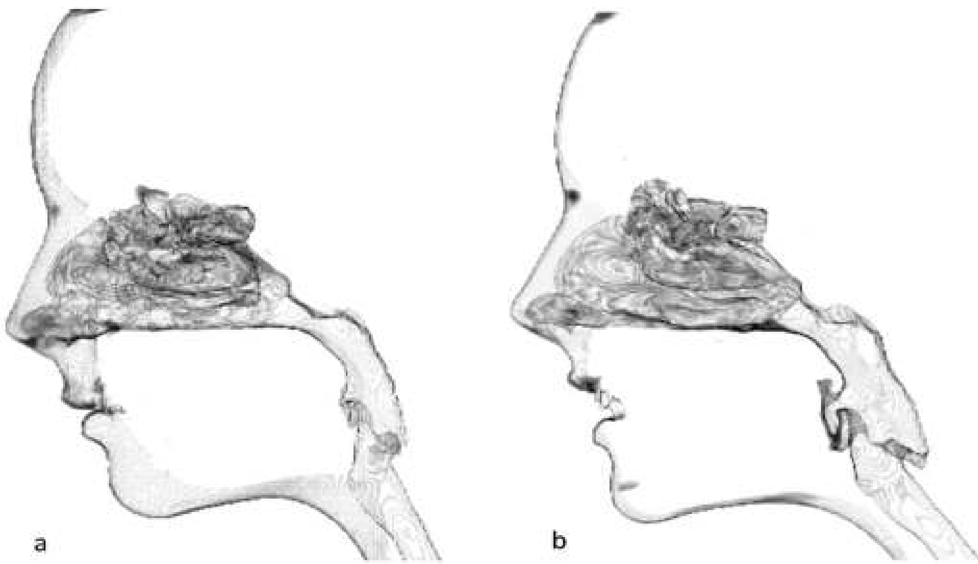

Fig. 5. a,b: 3D airway CT reconstruction on sagittal plane before (a) and After (b) RME. The functional improvements induced by RME can be clearly linked to the increased patency of the upper airways.

Imaging is only a part of a sleep-disordered-breathing investigation, and had to be integrated into the overall results, including those obtained during sleep with nocturnal polysomnography; but the 3D-CT provided valid information on the skeletal changes obtained with treatment.

The results we obtained show that the RME therapy widens nasal fossa, thus restoring a normal nasal airflow with disappearance of obstructive sleep-disordered breathing.

The improvement can be clearly linked to the skeletal expansion caused by the manoeuvre performed on the suture.

CBCT images before and after RME therapy confirm that the expansion occurs not only in the maxillary arch but also in the nasal cavity. This anatomic change brings about an increased patency of the upper airways, restoring normal airflow. This patency is the basis for the positive effects induced by the manoeuvre, and it acts on air exchange, with a net improvement of breathing disorders during sleep [26–28].

Increasing of upper jaw cross section also clearly affects the nasal cavities, and it is a true anatomic change that brings about an increased patency of the upper airways. This increase is also the basis for the positive effects induced by the RME manoeuvre on the respiratory function. Associated orthodontic movements can also indirectly improve the oropharyngeal space by modifying the resting posture of the tongue [29].

Several [30,31] studies demonstrate an increase in the volume of the upper airways as a result of lateral displacement of the walls of the nasal cavity, caused by the rapid expansion of the palate. Over the past decade the volumetric airways analysis with CBCT was investigated as well as the effects of RME on respiratory function.

In our series volume of the total upper airways, the nasal cavity, the nasopharynx and the oropharynx showed significant increases, consistent with some previous studies [31,32]. Kim et al. [32] demonstrated that volume of the nasal cavity increased continuously from pre-expansion to immediately after expansion, and to 1 year after expansion. They reported that nasopharyngeal volume showed a significant increase 1 year after expansion, compared with the initial volume.

In addition, we found a correlation between increased nasal osseous width at the PNS plane and expansion of nasopharyngeal volume: in fact the cross-sectional area of the upper airways at the PNS plane enlarged with the increase of maxillary width.

Referring to a previous study, the upper airways were divided into more segments in this study, resulting in significant changes in all its parts.

Kim et al. [32] also showed no changes in volumes of the inferior section of the upper airways and MCA, in accordance with the data reported in the literature.

Many studies agree that the expansion of the nasal cavity and the increased distance between the side walls and the septum caused a reduction in air resistance [33–37], facilitating physiological breathing. In our series, polysomnography presented a normalization of recording in the AHI in all patients at the end of the 4 months, and the baseline rhinomanometric data showed a statistically significant difference between those measured at 2 and 4 months.

Several methods have been proposed to evaluate changes in respiratory efficiency as a result of RME.

De Filippe et al. [33], through the use of morphometric 3D analysis and acoustic rhinometry, showed an increase in cross sectional in the area of the nasal cavities, followed by a 34% decrease in nasal resistances. In fact a follow-up to 60 months confirms the stability of the treatment. Enoki et al. [34] evaluated changes in respiratory function in 29 children through the use of three otolaryngology examinations: nasofibroscopy, acoustic rhinometria and rhinomanometry, carried out before, immediately after and 90 days after rapid expansion. Rhinomanometry showed a progressive decrease in resistance to both inhalation and extraction.

Iwasaki et al. [35] investigated the effects of RME on nasal respiratory flow in terms of pressure and speed in 22 subjects of average age of 9 years. Eighteen patients treated with RME benefitted from a 66.7% reduction in nasal resistance and a 46.5% decrease in blood pressure. In 2015 Fastuca et al. [36] evaluated respiratory response following RME on 15 subjects (average age 7.5) and observed a significant correlation between respiratory volume and blood oxygen saturation level (SPO_2). These results correlate the expansion of the jaw to an increase in the diameter of the airways, a decrease in respiratory resistance, and an improvement in the patient's respiratory pattern. Through polysomnography (PSG) the same authors found an improvement in the AHI with a reduction in apneic episodes of 4.2 per hour.

In the same year Ghoneima [37] showed how RME had positive effects in terms of pressure reduction, speed and airway resistance, and these changes were capable of changing the airflow pattern from turbulent to laminar. All the effects on respiratory function mentioned above make RME the therapy of choice in the case of patients with OSAS without obvious upper airways obstructions. In fact, under physiological conditions, the nose contributes 50% of respiratory resistance, and RME is able to significantly decrease these resistances [34].

The authors suggest careful evaluation of the maxillary skeleton base status as a possible common cause of OSAS and recommend resorting to RME therapy.

RME can improve nasal airflow, leading to better ventilatory function through increased upper airways volume, so it could be a therapeutic option for nasal obstruction.

Orthodontists may play an important role in the interdisciplinary treatment of OSAS because a high percentage of patients with OSAS suffer from maxillary narrowness. The authors' experience shows that RME treatment has a positive effect on children affected by chronic snoring and OSA [38,39]. By changing the anatomic structures, RME brings a functional improvement. It is always important to assess the condition of the upper jaw to consider RME therapy in the multidisciplinary treatment of OSAS in children.

5. Conclusions

The RME induces a volumetric expansion in the nasomaxillary complex as well as in all its structures, the nasal cavity, oropharynx and nasopharynx. This treatment had a positive effect on children affected by chronic snoring and OSA and caused an increase in volume of the nasal cavity and nasopharynx, with expansion of nasal osseous width and maxillary width. Enlarged nasal width at the PNS plane contributed to the increase in nasopharynx and oropharynx volume. The RME therapy restored a normal nasal airflow with disappearance of obstructive sleep disordered breathing, and 3D reformatting CBCT confirmed the real remodeling of craniofacial structure, leading to an increase patency of the upper airways.

Credit author statement

Paola Pirelli: Supervision Valeria Fiaschetti: Data curation, Writing- Original draft preparation Ezio Fanucci: Conceptualization, Methodology, Software Aldo Giancotti: Visualization, Investigation Roberta Condo': Writing- Reviewing and Editing Sabina Saccomanno: Software, Validation Gianluca Mampieri: Writing- Reviewing and Editing.

Conflict of interest

None declared.

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