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Evaluation Study

An improvement of upper airway flow in patients treated with rapid maxillary expansion: a Cone Beam Computed Tomography study

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ABSTRACT

Rapid Maxillary Expansion (RME) is an orthopaedic treatment used to correct the transverse deficit of the maxilla. Most often, this defect is diagnosed in mouth-breathing patients. Rapid Palatal Expander (RPE) treatment increases the upper airways' volume and decreases resistance, promoting physiological nasal breathing. The aim of this study is to measure the volume of the upper airways by employing Cone-beam Computed Tomography (CBCT) to evaluate the anatomical space where the major effects of RME occurred. Twenty-four subjects (mean age, 10.17 ± 1.75 years) treated with McNamara-type rapid palatal expander were selected. Two CBCT scans were taken for each patient: the first at the beginning (T0) and the second at the end of the treatment (T1). For each CBCT scan, Total Volume (TV), Retropalatal Volume (RPV) and Retroglossal Volume (RGV) were measured with the software ITK-Snap. The statistical analysis was performed using the paired samples t-test, with a p-value of 0.05. RPV significantly increased (Δ T1-T0: 680.75 mm^3 ± 792.63 mm^3, $P<0.05$). No significant changes were found in TV (Δ T1-T0: 452.92 mm^3 ± 3091.7 mm^3, $P>0.05$) and in RGV (Δ T1-T0: 166.92 mm^3 ± 666.97 mm^3, $P>0.05$). In this study, patients showed a statistically significant increase in RPV after RPE treatment. The CBCT scans provide only quantitative volumetric data, so it would be appropriate to determine the clinical significance of the obtained results with a functional examination (for example, rhinomanometry). The radiological protocol should be standardised to overcome limitations such as tongue posture during scan recording, swallowing and breathing control. Further studies are needed to evaluate the long-term stability of these effects on the airways.

INTRODUCTION

Several studies in the literature have observed a correlation between respiratory functions and orthodontic treatment, and due to the introduction of three-dimensional radiographs, research on this topic still arouses keen interest among orthodontists (1).

Rapid Maxillary Expansion (RME) is an orthopaedic treatment whose main objective is the opening of the median palatal and circummaxillary sutures in patients with a maxillary transverse deficit (2).

A consequence of the treatment with Rapid Palatal Expander (RPE) is an increase in the volume of the upper airways and a decrease in their resistance to airflow. A consequence of this is an improvement in nasal breathing and a reduction in the incidence of nasal respiratory problems in patients with maxillary transverse deficiency and mouth breathing (3); this is why this treatment is recommended for patients with obstructive pathologies of the upper airway tract, sleep disorders, and conductive hearing loss (4).

Airway changes resulting from RPE treatment were studied using different methods, which have proved reliable for evaluating pathological respiratory conditions. These included functional tests, such as rhinomanometry and acoustic rhinometry, radiological tests, such as lateral or posteroanterior teleradiographs and Cone-beam Computed Tomography (CBCT) (5-10).

Currently, CBCT is the most used method for assessing the upper airway volume. However, it is difficult to compare data from the literature due to a lack of standardisation (11-17). Head and tongue posture, breathing phase (inspiration or exhalation), patient mobility, anatomical limits of the volume considered, and the software used for the reconstructions are all variables that can change the results (18).

The aim of this study was to evaluate the changes in airway volume after RPE treatment employing CBCT scans and to identify the anatomical space in which the most significant volume increases were obtained.

MATERIALS AND METHODS

Eligibility criteria

This study selected 24 subjects (12 males and 12 females). The inclusion criteria were: transverse skeletal deficit of the maxilla; monolateral or bilateral skeletal cross-bite; CS1 or CS2 cervical vertebral maturation stage, according to Baccetti et al. (19). The exclusion criteria were: genetic or endocrine diseases that could affect the treatment plan; previous orthopaedic and/or orthodontic treatment; skeletal abnormalities or significant facial asymmetry (20, 21).

Rapid maxillary expansion

At the beginning of the treatment (T0), a CBCT was performed for every patient, and patients were in mixed dentition.

The transverse discrepancy of each one was measured on the dental casts using a calliper with 0.01 mm accuracy to quantify the millimetres of expansion needed. Since all subjects had a mixed dentition, the transverse discrepancy was the result of the difference between the superior intermolar distance (distance between the central fossae of the upper first permanent molars) and the inferior intermolar distance (distance between the top of the distobuccal cusps of the inferior first permanent molars). In addition, the patients were treated with an acrylic-splint rapid palatal expander (i.e. McNamara-type rapid palatal expander) composed of a Hyrax-type screw embedded into a wire-and-acrylic framework; the acrylic splints were bonded to the deciduous molars and the permanent first molars (22).

The patients' parents were instructed to activate the expansion screw twice a day until the palatal cusps of the posterior maxillary teeth approximated the buccal cusps of the mandibular posterior teeth: every activation was a 0.25 mm expansion. Once reached the correct expansion, the screw was blocked, and the expander was kept in place for six months: this period was necessary to allow the reorganisation of the mid-palatal suture. At the end of this period (T1), the expander was removed, cleaned and given to the patient to wear as retention at night for a further 6 months. If the expander was not sufficiently retentive, the patient wore a Hawley retainer (23). Finally, a CBCT was taken for each subject. CBCTs were performed using NewTom VGi evo (QR s.r.l, Verona, Italy).

Immediately before scanning the image, patients were instructed to inhale and hold their breath after exhalation, not to swallow, and to keep the teeth in maximum intercuspation and the tip of the tongue against the palate. During the radiographic examination, patients stood with the Frankfurt plane parallel to the floor. Three volumes were measured for each CBCT using the ITK-Snap software (www.itksnap.org):

- Total Volume (TV), between a horizontal plane passing through the upper margin of the frontal sinus and a horizontal plane passing through the lower margin of C3;
- Retropalatal Volume (RPV), between a line that connects the basion to the posterior nasal spine and a horizontal plane passing through the most posteroinferior point of the soft palate (Fig. 1);
- Retroglossal Volume (RGV), between a horizontal plane passing through the most posteroinferior point of the soft palate and a horizontal line passing through the highest point of the epiglottis (Fig. 2).

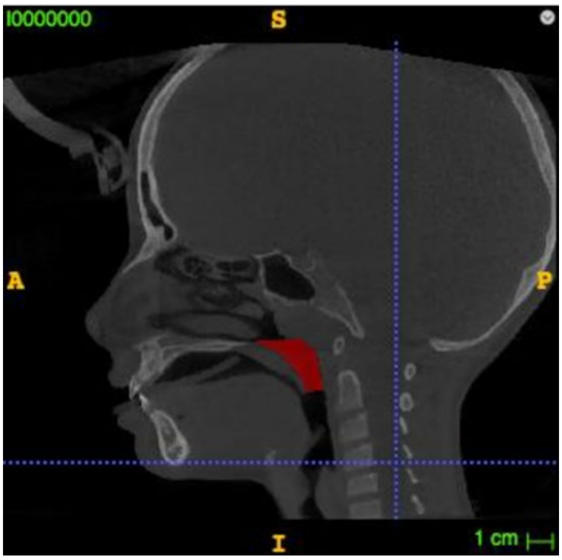

Fig. 1. *Retropalatal Volume (RPV).*

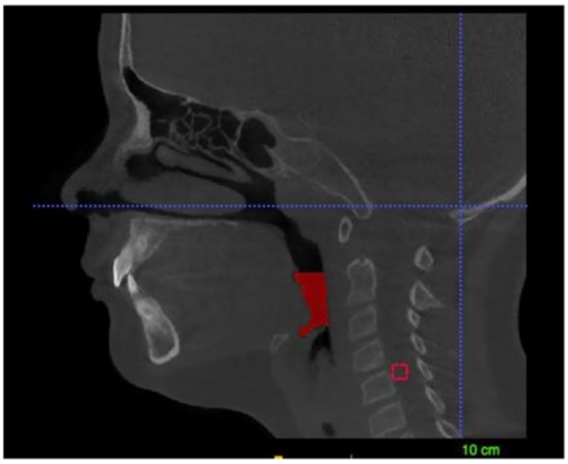

Fig. 2. *Retroglossal Volume (RGV).*

Statistical analysis

The statistical analysis was performed using STATA software (version 13; StataCorp LP, College Station, Texas, USA).

Mean ± standard deviation (SD) was calculated for all variables at T0 (pre-treatment) and T1 (after treatment). In addition, paired samples t-test was performed to evaluate the changes that occurred during treatment with RPE. The p-value was considered statistically significant if less than 0.05.

RESULTS

The mean age of the participants was 10.17±1.75 years. RPV significantly increased (Δ T1-T0: 680.75 mm^3 ± 792.63 mm^3, $P<0.05$). No significant changes were found in TV (Δ T1-T0: 452.92 mm^3 ± 3091.7 mm^3, $P>0.05$) and in RGV (Δ T1-T0: 166.92 mm^3 ± 666.97 mm^3, $P>0.05$) (Table I).

Table I. *Changes of the pre- (T0) and post-treatment (T1) variables.*

Variables	T0 (mm^3)	T1 (mm^3)	Δ T1-T0 (mm^3)	p-value
Total Volume (TV)	55910.58±11206.58	56363.5 ±11295.58	452.92 ± 3091.7	0.6218
Retropalatal Volume (RPV)	4676.83±1011.87	5357.58±1160.2	680.75 ± 792.63	0.0126*
Retroglossal Volume (RGV)	3598.58±1264.8	3765.5±1165.27	166.92 ± 666.97	0.4045

The values are expressed as mean ± standard deviation (SD) and their difference. It is also reported the p-value and the significance (*) obtained by the paired samples t test.

DISCUSSION

TV showed no statistically significant variation before and after treatment, probably because this volume had a wide range of variability, which was difficult to control. The high standard deviation value indicated this variability, determined by several factors, among which intraoral volume and the congestion of nasal and sinus mucosa.

More specifically, intraoral volume was considered by Iwasaki et al. as an index of the change in tongue posture following RPE treatment (15). As the appliance favours the transition from oral to nasal breathing, there is also a rise in the posture of the tongue and a reduction in the intraoral volume. Although a certain degree of congestion of the nasal and sinus mucosa could be identified, it was difficult to quantify the congestion of the nasal turbinates.

RPV showed a statistically significant increase (16% over the RPV at T0). This result is in agreement with many data reported in the literature: El and Palomo obtained an increase of 1719.9 ± 1510.7 mm^3 (P=0.046) of the retro-nasal volume, Iwasaki et al. reported an increase of 1413.9 mm^3 (P=0.02) in the nasal volume and Chang et al. showed a significant increase in the area of the airway section at the plane passing between the posterior nasal spine and the basion (P=0.0004) (12, 13, 15).

Also, Smith et al. identified a significant increase in the nasopharyngeal volume (P=0.00), with a mean increase of 522 ± 548 mm^3, corresponding to 16.1% of the initial volume (24). Zhao et al. performed a retrospective case-control study in which there was no increase in the nasopharyngeal volume despite increased intermolar distance after RPE treatment (11). A possible limitation of their study was the lack of standardisation of the tongue posture. Ribeiro et al. found an increase in the nasopharyngeal volume, but this was not statistically significant (P=0.11) (14).

Our results regarding RPV were lower than those reported in the literature. A possible explanation could be the age of the patients selected in our study (mean age = 10.17±1.75 years at T0), even if none were beyond the growth peak. As age increases, the skeletal effects of RPE decrease and therefore also those on the airways, as demonstrated by Baccetti et al., which identified a greater increase in the width of the nasal cavities in patients early treated compared to those treated at growth peak (25). Another possible factor that affects the increase in the RPV can be the number of activations performed. The greater the amount of the transversal defect and the number of activations necessary for its correction, the greater the volumetric gain, as the latter is related to the amount of skeletal expansion obtained.

According to a systematic review by Liu et al., the opening of the median palatal suture is directly related to that of the expander screw (26). Therefore, in patients with mild or moderate defects, the effects on airway volumes are more limited or absent. However, further studies are needed to correlate the amount of expansion

with the increase in the volume of the upper airways, perhaps dividing the sample into different subgroups based on the number of activations performed.
RGV did not show a statistically significant change. According to the literature, the effects of RPE on the oropharyngeal volume are somewhat controversial: Zhao et al., El and Palomo, Chang et al. and Iwasaki et al. did not find statistically significant variations of this volume (11-13, 15).

Ribeiro et al. identified a statistically significant variation in the oropharyngeal volume, but the latter was attributed to the lack of standardisation of the head and tongue posture, the breathing phase and the swallowing during the radiographic examination (14).

Zeng and Gao reported a slight statistically significant reduction in the oropharyngeal volume, with an extensive range of variability of this volume within the sample and a tendency of the section of the oropharynx to become oval: this could improve respiratory function, even if in a limited way (16). Smith et al. reported a non-statistically significant reduction in the oropharyngeal volume, probably linked to a palatal plane lowering following RPE treatment (24).

A possible case in which a particular increase in RGV can be identified is RME in patients with retruded mandible, in which the expansion of the maxilla releases the mandible forward, with a consequent increase in the retro-mandibular space, but studies are needed to test this hypothesis.

Moreover, several studies agree that RPE was effective in treating Obstructive Sleep Apnea Syndrome (OSAS) patients without other upper airway obstructions as a physiological nasal airflow was achieved (27-29). The improvements induced by RME in OSAS patients are mainly functional because the improvement in nasal airflow generates less sub-atmospheric inspiratory pressure, reducing the vulnerability to pharyngeal collapse (28). Since the increase in RGV was not statistically significant, it is impossible to affirm that the physiological nasal airflow was restored.

In order to complete this study, it would be necessary to combine the volumetric assessment of the upper airways with a functional assessment (i.e. rhinomanometry). Furthermore, a long-term evaluation of the stability of the obtained results would be useful. An adequate period of retention and the removal of the causal factors determining mouth breathing is indispensable for the stability of the treatment.

CONCLUSIONS

In this study, patients showed a statistically significant increase in RPV, equal to 16% of the initial volume, after treatment with RPE. No statistically significant changes were found in TV and RGV.

The volumetric increase obtained predisposes to a reduction in the resistance of the upper airways, promoting physiological nasal breathing and, therefore, a correction in craniofacial development. However, it would be necessary to complete the study with a functional examination (i.e. rhinomanometry) to evaluate the obtained results clinically.

The standardisation of the radiological protocol should be improved to overcome some limitations: tongue posture, swallowing, and respiratory phase is difficult to control in children.

It is appropriate to deepen the topic by looking for a possible correlation between variation in the volume of the airways and the amount of expansion. Finally, it would be useful to evaluate the long-term stability of the results obtained: an adequate period of retention and the removal of the causal factors for mouth breathing are indispensable for the stability of the treatment.

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