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Effects of orthopedic maxillary expansion on nasal cavity size in growing subjects: A low dose computer tomography clinical trial

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ABSTRACT

Objective: The aim of this retrospective clinical trial was to evaluate the effects of rapid maxillary expansion on skeletal nasal cavity size in growing subjects by use of low dose computer tomography.
Methods: Eight Caucasian children (three male; five female) with a mean age of 9.7 years (SD ± 1.41) were the final sample of this research that underwent palatal expansion as a first phase of orthodontic treatment. The maxillary expander was banded to the upper first molars and was activated according a rapid maxillary expansion protocol. Low-dose computer tomography examinations of maxilla and of the low portion of nasal cavity were performed before inserting the maxillary expander (T0) and at the end of retention (T1), 7 months later. A low-dose computer tomography protocol was applied during the exams. Image processing was achieved in 3 steps: reslicing; dental and skeletal measurements; skeletal nasal volume computing. A set of reproducible skeletal and dental landmarks were located in the coronal passing through the first upper right molar furcation. Using the landmarks, a set of transverse linear measurements were identified to estimate maximum nasal width and nasal floor width. To compute the nasal volume the lower portion of the nasal cavity was set as region of interest. Nasal volume was calculated using a set of coronal slices. In each coronal slice, the cortical bone of the nasal cavity was identified and selected with a segmentation technique. Dependent *t*-tests were used to evaluate changes due to expansion. For all tests, a significance level of $P < 0.05$ was used.
Results: Rapid maxillary expansion produced significant increases of linear transverse skeletal measurements, these increments were bigger in the lower portion of the nasal cavities: nasal floor width (+3.15 mm; SD ± 0.99), maximum nasal width (+2.47 mm; SD ± 0.99). Rapid maxillary expansion produced significant increment of the total nasal volume (+1.27 cm^3 ± SD 0.65). The anterior volume increase was 0.58 cm^3 while the posterior one was 0.69 cm^3.
Conclusion: In growing subjects RME is able to significantly enlarge the dimension of nasal cavity. The increment is bigger in the lower part of the nose and equally distributed between the anterior e the posterior part of the nasal cavity.

1. Introduction

Orthopedic maxillary expansion (OME) is a clinical procedure that has been used for more than a century [1]. It is usually performed when maxillary transverse deficiency is observed [2]. In growing subjects the use of orthopedic transversal forces expressed by palatal expander is able to disarticulate the mid palatal suture separating the two half maxilla [3]. When the 2 half maxilla are kept expanded for a retention period the space obtained separating the 2 half maxilla is substitute by new formed bone [3]. Maxillary transversal bone augmentation causes a widening of the nasal cavity floor and subsequently an increase of nasal cavity size [4]. Rapid maxillary expansion (RME) is the most used and evaluated palatal expansion protocol [5]. The dento-skeletal effects of RME have been extensively evaluated; it produces significant dental and skeletal transverse increases [3–13].

It is important to clarify the effects of OME on nasal cavity dimensions, because an enlargement of nasal airway can potentially affect nasal resistance and consequently mouth/nasal breathing modality [14].

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The new imaging techniques, such as low dose computed tomography (CT), offer the possibility to make a more precise evaluation of the effects of OME on nasal cavity dimensions.

Because of the limitations with the use of postero-anterior cephalograms, including the difficulty in reproducing head posture and errors in identifying landmarks [15,16], different authors have proposed the use of CT scanning to evaluate the effects of OME [17,18]. Since 1979, when Montgomery applied for the first time CT to evaluate the dimension of nasal cavities [19], several studies have evaluated nasal cavities size by the use of standardized CT scanning examinations [3,6–12]. The majority of these studies were aimed to evaluate the skeletal and the dentoalveolar changes produced by RME. The use of CT allows measurement of transverse dimensions with greater resolution in any area of the maxilla [18]. It also offers the ability to compute nasal cavity volume [20].

The aim of this retrospective clinical trial was to evaluate the effects of RME on nasal cavity size in growing subjects by use of low-dose CT. The null hypothesis was that RME has no effect on skeletal nasal size.

2. Methods

Eight Caucasian children (three male; five female) with a mean age of 9.7 years (SD ± 1.41), who underwent maxillary expansion as a first phase of orthodontic treatment, were the final sample of this retrospective clinical trial.

The sample of this research was part of the sample of a Randomized Clinical Trial (RCT) comparing the skeletal and dento-alveolar effects of RME and slow maxillary expansion (SME) [21].

On the base of the results obtained in previous research [8] a power analysis was executed. The cephalometric parameter used to perform the power analysis was: NW (Nasal Width; mu1 − mu2 = 1.89; sigma 1.18). The results of the power analysis showed that to offer 89% power at a 95% confidence interval will be necessary to enroll eight subjects.

On this basis, eight subjects satisfying the following inclusion criteria were selected and included in this research: constricted maxillary arch, upper and lower first molars erupted, unilateral or bilateral posterior crossbite (inversion of the transversal occlusal dental relationship). Exclusion criteria were age above 15 years, history of previous orthodontic treatment, periodontal disease, systemic disease that could have affected craniofacial growth, or presence of a craniofacial congenital syndrome.

The study sample was treated at the Department of Orthodontics of the University of Naples Federico II, Italy, between May 2006 and October 2007.

Low Dose CT examinations of maxilla and of the low portion of nasal cavity were performed before inserting the maxillary expander (T0) and at the end of retention (T1), 7 months later when the expander was removed. The study was approved by the Ethics Committee and informed consent was obtained from the parents of all subjects.

The maxillary expander (Leone Orthodontic Products, Sesto Fiorentino, Firenze, Italy) used for all the subjects was banded to the upper first molars (Fig. 1). The maxillary expanders were banded using glass ionomer cement (Multi-Cure Glass ionomer Cement, Unitek, Monrovia, CA, USA) in accordance with the manufacturer's instructions. The screw of the palatal expander was initially turned eight times (1.6 mm initial transversal activation). Afterwards patients were instructed to turn the screw three times during each following day (0.6 mm activation per day).

The maxillary expansion was continued until a mild dental overcorrection (2 mm) was achieved compared to the ideal transversal occlusion relationship. The active expansion period was on average 12.6 days. At the end of the active expansion period, the screw was locked with light-cure flow composite (Premise Flowable; Kerr Corporation, Orange, CA, USA). The palatal expander was removed seven months after it was inserted, at the end of the retention period (T1). During this period no other fixed orthodontic appliances were used in any patients.

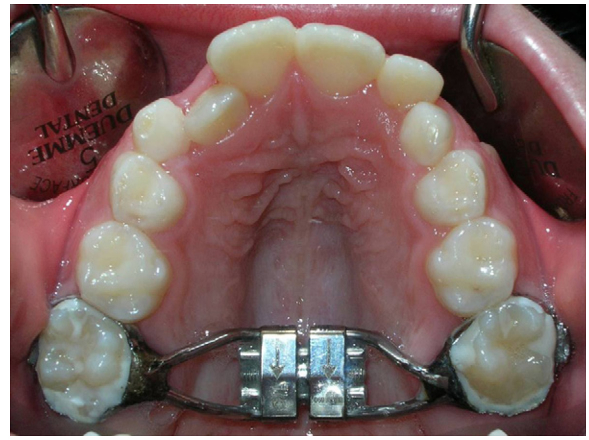

Fig. 1. The maxillary expander banded to the upper first molars.

All CT examinations were performed by one trained radiologists with CT scanners (MX 8000 IDT6, Philips Medical Systems, Best, The Netherlands). A low dose CT protocol was applied during the CT examinations. The following low dose parameters were set for all the acquisitions: KV 80, mAs 28, Pitch 1, CDTIVol 2.5 mgy [22,23].

2.1. Images and data processing

Image processing was achieved in 3 steps using Mimics software version 8.11 (Materialise Medical Co, Leuven, Belgium): reslicing; dental and skeletal measurements; skeletal nasal volume computing.

2.2. Reslicing

In order to obtain comparable images between the pre and posttreatment examinations, the original scans (i.e. slices) were reformatted (i.e. reoriented) in a reproducible manner for each patient. For this purpose, a set of reproducible palatal landmarks were defined and reported in Table 1.

The scans were reoriented so that: LPFP and RPFP were lying in the same coronal and axial scans; and ANS and PNS were in the same axial and sagittal scan. The sagittal plane passing through ANS and PNS was called the "sagittal reference plane".

2.3. Dental and skeletal measurements

A set of reproducible skeletal and dental landmarks were located in the coronal scans obtained after reslicing and are reported in Table 2. Among the reoriented scans, the coronal scan

Table 1
Palatal landmarks.

Landmarks	Definitions
Anterior nasal spine (ANS)	The most anterior point of the anterior nasal spine
Posterior nasal spine (PNS)	The most posterior point of the posterior nasal spine
Left palatal foramen point (LPFP)	The most posterior and external point of the left palatal foramen
Right palatal foramen point (RPFP)	The most posterior and external point of the right palatal foramen

Table 2
Defined skeletal and dental landmarks.

Skeletal landmarks	Definitions
RNW (right nasal wall)	Most external point of the cortex bone separating the maxillary sinus and the nasal cavity of the right side located in the coronal scan passing through FURMF (Fig. 2)
LNW (left nasal wall)	Most external point of the cortex bone separating the maxillary sinus and the nasal cavity of the left side located in the coronal scan passing through FURMF
RNF (right nasal floor)	Junction of palatal cortical alveolar bone and cortical bone surrounding nasal cavity of the right side located in the coronal scan passing through FURMF (Fig. 2)
LNF (left nasal floor)	Junction of palatal cortical alveolar bone and cortical bone surrounding nasal cavity of the left side located in the coronal scan passing through FURMF (Fig. 2)
Dental landmarks	**Definitions**
RCP (right cusp point)	Apex of the mesiopalatal cusp of the first upper right molar
LCP (left cusp point)	Apex of the mesiopalatal cusp of the first upper left molar

passing through first upper right molar furcation (FURMF) was identified (Fig. 2). Using the landmarks reported in Table 2, a set of transverse measurements were made and reported in Table 3.

2.4. Skeletal nasal volume computing

The region of interest (ROI) [24] was the lower portion of the nasal cavity. It was extended anteroposteriorly from ANS to PNS and superiorly to the lower limit of the right middle turbinate located in the axial slice passing through the FURMF point (Fig. 3). Total Nasal Volume (TNV) was calculated using a set of coronal slices passing through the ROI, 5 mm distant from each other. In each coronal slice, the cortical bone of the nasal cavity was identified and selected (Fig. 3) with a segmentation technique (i.e. isolation and definition of the ROI) [25,26]. Once the ROI was marked off three-dimensionally, the volume of the nasal cavity was computed in mm^3 by the software program using surface rendering (Fig. 4) [26], finally the volume data were converted and reported as cm [3]. Additionally, anterior and posterior nasal volumes (ANV and PNV) were evaluated

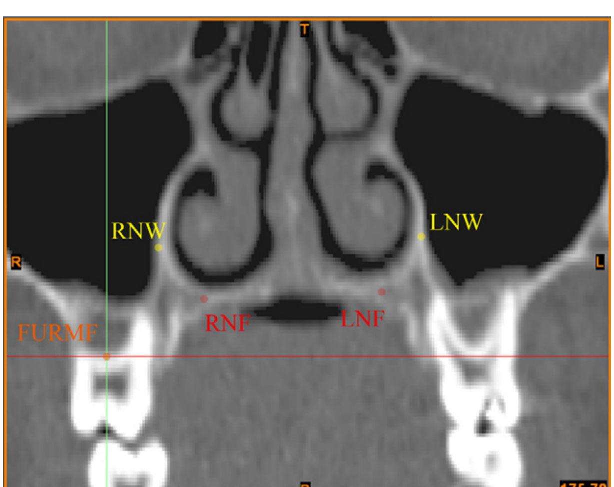

Fig. 2. RNF, LNF, RNW, LNW points located in the coronal scan passing through the first upper right molar furcation (FURMF).

Table 3
Transverse measurements.

Measurement	Definitions
MNW (maximum nasal width)	RNW to sagittal reference plane + LNW to sagittal reference plane
NFW (nasal floor width)	RNF to sagittal reference plane + LNF to sagittal reference plane
IMW(inter-molar width)	RCP to sagittal reference plane + LCP to sagittal reference plane

separately using the anterior and posterior slices, respectively (Fig. 4). All of the subjects displayed a discontinuous cortical nasal cavity outline in the first and last coronal slices. For this reason, these slices were not considered evaluating the nasal volume.

2.5. Statistical analysis

The same calibrated operator performed all measurements and repeated all measurements 1 month later. Statistical analysis was performed using the means of the two measurements as recommended by Baumrind and Frantz [27]. All data were preliminary tested for normality and for equal variance. Dependent *t*-tests was used to evaluate changes due to expansion from T0 to T1 within the sample groups. Independent *t*-test was used to evaluate differences between the anterior and the posterior nasal cavity volume. For all the tests, a significance level of $P < 0.05$ was used (SigmaStat 3.5, Systat Software, Point Richmond, CA.). Systematic and random errors were calculated comparing the first and second measurements with paired t tests and Dahlberg's formula [28], at a significance level of $P < 0.05$. All measurement error coefficients were found to be adequate for appropriate reproducibility of the study (Table 4).

3. Results

RME produced significant increases of all linear transverse dental and skeletal measurements and of skeletal nasal volumes. The average amounts of linear and volumetric increments are reported in Table 5.

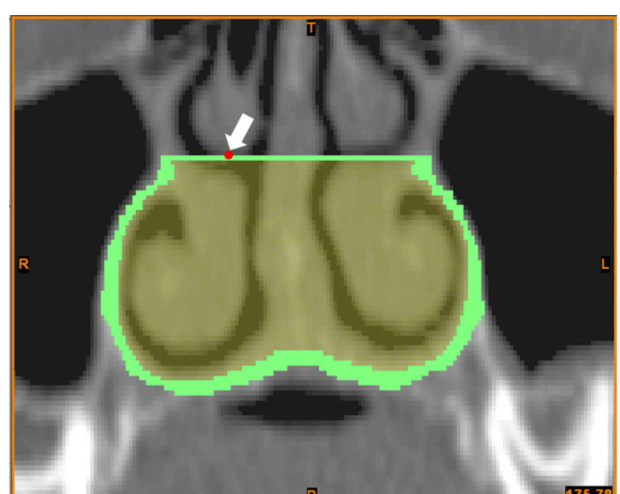

Fig. 3. Upper limit of the ROI (red point at the lower margin of the right middle nasal turbinate) and segmentation of the nasal cavity (green outline). (For interpretation of the references to color in figure legend, the reader is referred to the web version of the article.)

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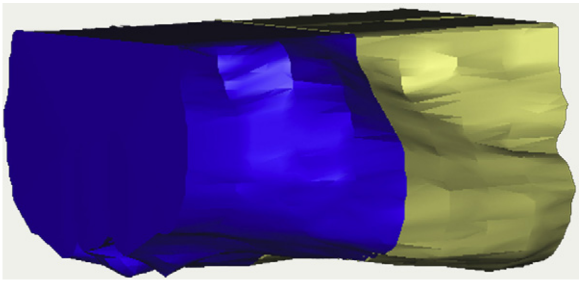

Fig. 4. Three dimensional visualization of anterior (blue) and posterior (yellow) skeletal nasal volumes. (For interpretation of the references to color in figure legend, the reader is referred to the web version of the article.)

Table 4
Measurement reproducibility.

Variable	*t* (*P*)	Significance	*σ*	*r*
MNW	0.887	NS	0.263	0.988
NFW	0.986	NS	0.252	0.994
IMW	0.938	NS	0.288	0.985
TNV	0.933	NS	0.340	0.985

NS: not significant.

No statistical difference ($P = 0.54$) was found within the sample group comparing volume increase for the anterior and posterior region of the nose (respectively ANV and PNV).

4. Discussion

Maxillary expansion is certainly one of the most effective orthopedic procedures used in orthodontics. It has specific orthodontic indications when a posterior cross bite or a constricted maxillary arch is observed. In this study the orthopedic maxillary expansion produced significant skeletal augmentation in the skeletal nasal cavities. The results of this research show that another indication of maxillary expansion could be the nasal hypoplasia when it is correlated, in growing children, to a transversal deficit of the maxilla. The amount of skeletal change obtained with RME was comparable to a previous study [13]. Greater increases in width were observed in the nasal floor region (NFW) rather than in the maximum nasal width region (MNW), thus supporting the reverse "V" shape opening model of the craniofacial complex [29]. According to this model the lower regions of the nose should benefit of a major dimensional increment subsequently orthopedic maxillary expansion [29].

Differing from other studies [20], we evaluated skeletal nasal cavity volume, rather than airway space volume, as a parameter for determining nasal cavity changes. To the best of our knowledge, no previous study has investigated the effects of RME on skeletal nasal cavity volume with the accuracy offered by CT. Differing from skeletal nasal cavity volume, airway space could be affected by an inflammatory (such as viral or allergic rhinitis) or atrophic status of the nasal mucosa. In particular, because allergic rhinitis is more frequent in specific seasons, the choice to evaluate the efficacy of the palatal expansion by the airway space parameter [20] could be a potential methodological bias that was avoided in this study.

No statistical difference was found regarding changes in ANV and PNV. These two parameters had a similar increase after the palatal expansion. This finding suggests a uniform anteroposteriorly opening of the mid-palatal suture. Our findings, in contrast with previous studies using PA cephalograms [30], showed that the dimensional increase of the nasal cavity occurring during maxillary expansion extends to the posterior region of the nose, thus supporting the results of the study conducted by Palaisa et al. [13]

For the retrospective design of the study we limited our evaluation to the lower portion of the nasal cavity. For this reason the results of this study related to the volume augmentation are underestimated and should be considered in qualitative terms. Nevertheless, since that the lower portion of the nose is more affected by maxillary expansion compared to the upper portion, the volume changes estimation at this level can anyway reveal the possibility to increase nasal volumes in growing patients offered by orthopedic maxillary expansion.

The literature reports several systemic effects of orthopedic maxillary expansion, such as: mouth breathing restoration [14], improvement of vertical and sagittal facial growth [31], positive effects in patients with conductive hearing loss [32], changes of head posture [33], increase of nasopharyngeal airway adequacy [33], improvement of respiratory function in OSAS patients [34], resolution of nocturnal enuresis [35]. The significant anatomic changes produced by orthopedic maxillary expansion on the skeletal nasal cavity size could be responsible for many of the above mentioned several systemic effects. However more researches are needed to correlate, at a higher level of evidence, the increase of skeletal nasal cavity dimension with the reported several systemic effects of RME.

5. Conclusion

RME produces significant skeletal transverse augmentations in the palatal and nasal regions. These increments are bigger in the lower portion of the nasal cavities. Moreover RME is able to increase significantly skeletal nasal cavity volume. The volume increase is equally distributed between the anterior e the posterior part of the nasal cavity.

Conflict of interest statement

The authors do not have any conflict of interest.

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Table 5
Comparison between the pre- and post-expansion stages of RME (paired *t*-test).

Variables	Preexpansion		Postexpansion		Change		Significance
	Mean	SD	Mean	SD	Mean	SD	*P*
IMW (mm)	38.16	1.60	43.64	2.82	5.41	2.05	*
NFW (mm)	19.20	3.37	22.35	3.59	3.15	0.99	*
MNW (mm)	26.32	1.86	28.78	2.54	2.47	0.99	*
ANV (cm^3)	8.21	2.11	8.80	2.16	0.58	0.33	*
PNV (cm^3)	7.81	1.94	8.50	2.37	0.69	0.34	*
TNV (cm^3)	16.02	3.98	17.30	4.48	1.27	0.65	*

* $P < 0.05$.

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