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# Effects of rapid vs slow maxillary expansion on nasal cavity dimensions in growing subjects: a methodological and reproducibility study

## ABSTRACT

**Aim** To evaluate the methodological feasibility of a RCT comparing skeletal changes of nasal cavity size obtained with RME and SME, assessed via CBCT.

**Methods** Twenty Caucasian children with a mean age of 10.4 years were recruited and allocated to receive RME (10 subjects, mean age 10.4 years) or SME (10 subjects, mean age 10.5 years). Inclusion criteria: constricted maxillary arch, upper and lower first molars erupted, unilateral or bilateral posterior crossbite. Exclusion criteria: age above 15 years, history of previous orthodontic treatment, periodontal disease, systemic disease affecting craniofacial growth, or craniofacial congenital syndrome. CBCT examinations were performed before treatment (T0) and 7 months after expander removal (T1). Changes of nasal width (NW), palatal width (PW) and total nasal volume (TNV) were assessed; palatal and nasal expansion was also calculated as a percentage of the increase of intermolar width IMW (PW% and NW%).

**Results** The correlation between the first and the second readings ranged from 0.991 to 0.995 for linear measurements and was of 0.915 for volumetric

measurements. The method error, as described by the value of  $\alpha$ , was in general less than 0.3 mm for linear measurements and 0.372 cm<sup>3</sup> for volumetric measurements. All linear transverse skeletal and dental measurements and the nasal volume increased with both RME and SME protocols.

**Conclusions** The reported methodology can be reasonably used to investigate the transverse dimension of nasal cavity. The PW% and NW% parameters more accurately described the efficacy of the two expansion protocols as compared to their corresponding absolute measurement (PW and NW).

**Keywords** Maxillary expansion; Maxillary transverse deficiency; Nasal width; Palatal width.

## Introduction

Maxillary transverse deficiency (MTD) represents one of the most common skeletal deformities of craniofacial region [Kiliç et al., 2008]. Rapid maxillary expansion (RME) and slow maxillary expansion (SME) are mainly used for the treatment of MTD [Martina et al., 2012]. The biological and clinical effects of these two expansion protocols have been deeply investigated [Lagravère et al., 2005; Lagravère et al., 2006]. During RME, heavy and continuous forces are transmitted to the maxilla in a short lapse of time, producing an immediate increase of maxillary transverse widths. On the contrary, SME occurs with lower forces distributed over longer periods. Both expansion protocols are effective in producing transverse changes of the maxilla [Schiffman and Tuncay, 2001; Cordasco et al., 2014].

The effects of maxillary expansion are not limited to the maxilla but can influence the anatomy and the physiology of the nasal cavity [da Silva et al., 1995; Basciftci et al., 2002; Timms, 1984]. RME can widen the nasal aperture by promoting the separation of the maxillary bones in a pyramidal shape in which maximum expansion is at the level of the incisors (i.e. below the nasal valves) and the center of rotation at the frontonasal suture [Haas, 1961]. In this respect, several CT studies [Garib et al., 2005; Garrett et al., 2008] showed that RME significantly enlarged the dimension of nasal cavity with nasal floor separation to be about one-third of appliance expansion [Garib et al., 2005; Garrett et al., 2008]. RME can also increase the total volume of nasal cavity, since its lateral walls are displaced apart during the skeletal expansion, as confirmed by a recent meta-analysis [Buck et al., 2016]. A combination of these phenomena could result in a reduction of nasal airway resistance and nasal breathing improvement [Buck et al., 2016].

To date, no randomised trials have compared the

effects of RME and SME on the dimensions of nasal cavity. From a clinical perspective, it would be important to clarify the effects of different maxillary expansion protocols on volume and dimension of the nasal cavity and, consequently, the effects on nasal resistance and mouth breathing [Haralambidis et al., 2009].

CT or CBCT allows measurements of transverse dimensions with greater resolution in any area of the maxilla [Podesser et al., 2004]. They also offer the ability to compute volume of the nasal cavity [Haralambidis et al., 2009]. In this respect, we performed the present randomised pilot study to:

- 1) evaluate the methodological feasibility of a RCT comparing linear and volumetric skeletal effects on nasal cavity size of RME and SME, assessed via CBCT;
- 2) to estimate the standard deviation of the treatment effect size to inform the sample size calculation for a future definitive RCT.

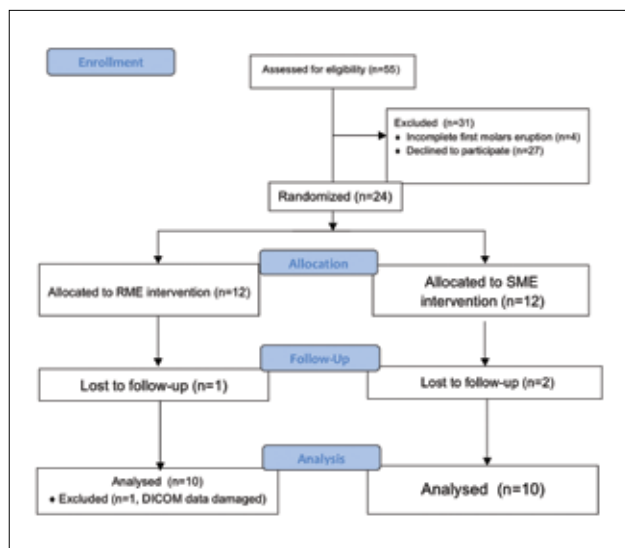


FIG. 1 Flow diagram showing the phases of the trial: enrollment, allocation, follow-up, analysis.

## Materials and methods

This randomised, with parallel groups (1:1), interventional pilot study was approved by the Ethics Committee of the University of Messina, Policlinico Universitario G. Martino (Italy), and was conducted according to the Declaration of Helsinki [Declaration of Helsinki, 2009]. Subjects were enrolled and treated between January 2014 and December 2016 and all patients’ parents signed an appropriate informed consent.

### Human subjects

Fifty-five patients scheduled to undergo maxillary expansion were selected from a larger pool of subjects attending orthodontic treatment at the Department of Orthodontics, University of Messina (Italy). Patients were included in the study if they met the following selection criteria: constricted maxillary arch, upper and lower first molars erupted, unilateral or bilateral posterior crossbite. Exclusion criteria were age above 15 years, history of previous orthodontic treatment, periodontal disease, systemic disease that could have affected craniofacial growth, or craniofacial congenital syndrome. Detailed information regarding the enrollment process and the amounts of drop-outs during the different stages of this trial are reported in the Flow Diagram (Figure 1). Twenty Caucasian children (10 boys; 10 girls) with a mean age of 10.4 years (range 8–13) were eventually evaluated for the final results of the present pilot study (Table 1).

Patients were allocated to receive RME or SME according to a randomised balanced block protocol using sex as stratification factor. The random allocation sequence was generated and participants were assigned to one of the two groups. For each patient, medical and orthodontic history was collected before treatment. Finally, ten patients were included in the RME group (mean age 10.4 years) and ten patients were included in the SME group (mean age 10.5 years) (Table 1).

Sample characteristics	Total (n=16)	RME (n=8)	SME (n=8)	Significance*
Age (mean ± sd)	10.4 ± 1.55	10.4 ± 1.72	10.5 ± 1.41	NS
Sex				
Male	10	6	4	NS
Female	10	4	6	
Skeletal maturity				
CVMS 1	7	3	4	NS
CVMS 2	11	6	5	
CVMS 3	2	1	1	
RME = Rapid Maxillary Expansion; SME = Slow Maxillary Expansion * Significance for comparison of group means calculated by paired t test or chi-square test. NS, not significant.				

TABLE 1 Demography, clinical characteristics and descriptive statistics of the sample of the study.



FIG. 2 Hyrax expander used to perform maxillary expansion in both groups.

**Intervention**

The conventional Hyrax expander was used to perform maxillary expansion in both groups (Figure 2). 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. Patients in the RME group were instructed (R.N. and A.L.G.) to turn the screw four times a day (0.8 mm per day). In the SME group, patients were instructed to turn the screw twice per week (0.4 mm per week).

In both groups, the maxillary expansion was performed until 2 mm of overexpansion was achieved, as assessed by clinical inspection. Each subject was provided with a custom diary and was asked to report the appliance activations. The diary was checked at each visit by the clinical examiners. The active expansion period averaged 8.5 days for the RME group and 126.2 days for the SME group. At the end of the active expansion phase, the screw was locked with acrylic resin. The expander was removed in both groups seven months after insertion, i.e. at the end of the retention period (T1).

**CT examinations**

CBCT examinations were performed immediately before treatment (T0) and at the end of retention period (T1), 7 months apart. The data were collected and stored in a personal computer as DICOM (Digital Imaging and Communications in Medicine) files. One trained radiologist performed all CBCT examinations by using i-CAT CBCT scanner (Imaging Sciences International, Hatfield, Pa) setting the acquisition parameters as follows: 120 kV, 5mA, 4s to 6s exposure time. Image processing was achieved using Mimics 8.11 Software (Materialise, Inc., Ann Arbor, MI, USA). In order to obtain comparable images between pre- and post-treatment examinations, the original scans views were re-oriented for each patient [Grauer D et al., 2009]. For this purpose, a set of reproducible palatal landmarks were defined (Fig. 3). The scans were reoriented so that:

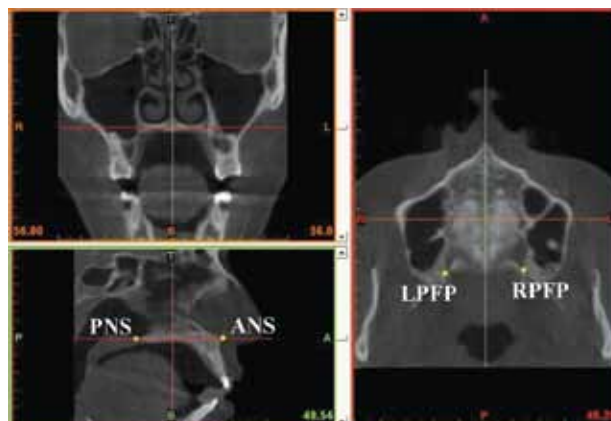


FIG. 3 Landmarks used for the reslicing process.

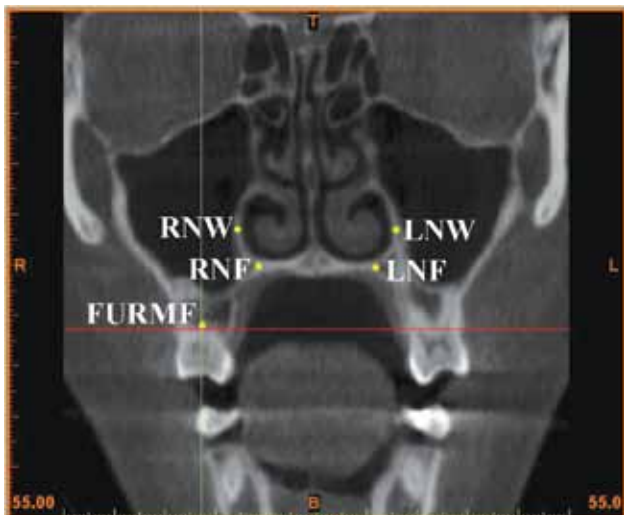
Skeletal Landmarks	Definitions
RNW (Right Nasal Wall)	Most external point of the lateral cortical nasal bone of the right side located in the coronal scan passing through FURMF (Fig. 2)
LNW (Left Nasal Wall)	Most external point of the lateral cortical nasal bone of the right side located in the coronal scan passing through FURMF (Fig. 2)
RNF (Right Nasal Floor)	Junction of palatal cortical alveolar bone and lateral cortical nasal bone 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 lateral cortical nasal bone 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

TABLE 2 Skeletal and dental landmarks used in this study to perform palatal and nasal measurements.

- 1) LPFP and RFPF were lying in the same coronal and axial scans;
- 2) ANS and PNS were in the same axial and sagittal scan.

The sagittal plane passing through ANS and PNS was considered as sagittal reference plane.

After reslicing, reproducible skeletal and dental landmarks were located in the coronal scans (Table 2, Fig. 4). Among the reoriented scans, that one passing through the first upper right molar furcation (FURMF) was identified. On this coronal scan, the nasal width (NW), the palate width (PW) and the inter-molar width (IMW) were measured as linear distances between the above mentioned landmarks (Table 2). Since each patient required a different amount of maxillary expansion, we created two parameters to evaluate the efficacy of



**FIG. 4** Skeletal landmarks located in the coronal scan passing through the first upper right molar root furcation (FURMF). RNW = Right Nasal Wall, LNW = Left Nasal Wall, RNF = Right Nasal Floor, LNF = Left Nasal Wall.

the expansion protocol: NW% and PW%. These two parameters were obtained by calculating the change of the NW and HPW as a percentage of the increase of IMW according to the following two formulas:

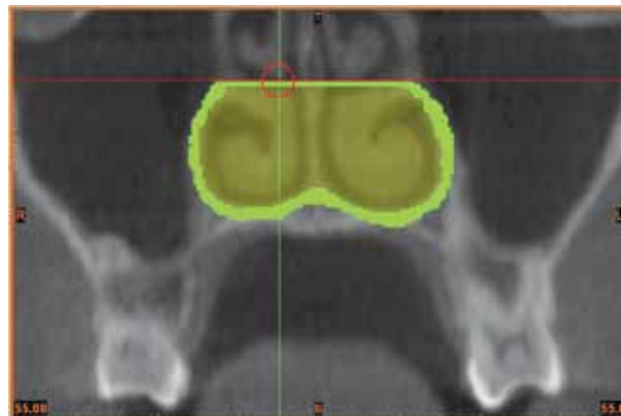
$$NW\% = (NW \times 100) / IMW \text{ (NW\% Formula),}$$

$$PW\% = (PW \times 100) / IMW \text{ (PW\% Formula)}$$

The region of interest (ROI) [Yushkevich et al., 2006] was the lower portion of the nasal cavity. It was extended antero-posteriorly 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. 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 segmented (Fig. 5) [Graueret al., 2009; Yushkevich et al., 2006]. Once the ROI was marked off three-dimensionally, the volume of the nasal cavity was computed in cm<sup>3</sup> by the software programme using surface rendering [Radt et al., 2006]. 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 in computation of the nasal volume. Finally, the entire measurement process was repeated 1 month later by the same trained operator for all CBCT recordings in order to determine intra-observer variation.

**Statistical analysis**

Descriptive statistics was performed to analyse demographic and clinical characteristics of the study sample. For the comparisons between the two groups, Student’s t-test and chi-square test were used respectively for numerical (age) and categorical (gender, skeletal maturity) characteristics.



**FIG. 5** Upper limit of the region of interest (ROI), detected at the lower margin of the right middle nasal turbinate, and segmentation of the nasal cavity (green outline).

Variable	t (p)	Significance	σ	r
NW (mm)	0.879	NS	0.223	0.991
PW (mm)	0.953	NS	0.241	0.995
IMW (mm)	0.918	NS	0.293	0.994
TNV (cm3)	0.949	NS	0.372	0.915

Significance based on paired Student’s t test; σ values obtained from Dahlberg’s formula<sup>24</sup>; r value obtained from Intraclass Correlation Coefficient (ICC). NS = Not significant.

**TABLE 3** Reproducibility of the measurements performed in this study.

Inferential statistical analysis was carried out using the means of the two measurements as recommended by Baumrind and Frantz [1971]. Normal distribution of the data was preliminarily checked for each investigated parameters using the Shapiro-Wilk test. Differences and correlation between the two intra-observer readings were tested using the paired Student’s t-test and Intraclass Correlation Coefficient (ICC) respectively. The random error between the first and second measurements was also calculated by Dahlberg’s formula [Dahlberg, 1940]. Data analysis was performed using SPSS Statistics software (IBM Corporation, 1 New Orchard Road, Armonk, New York, USA). Significance level was set at p <0.05.

**Results**

Descriptive statistics revealed no differences between the two groups for age, sex and skeletal maturity (Table 1). Thus, the random assignment of participants to both groups was validated. No differences were found between the two readings for both linear and volume

Variables	Preexpansion		Postexpansion		Change	
	Mean	SD	Mean	SD	Mean	SD
IMW (mm)	36.33	1.23	42.44	2.22	6.11	1.89
PW (mm)	17.61	2.71	21.43	2.19	3.82	1.29
NW (mm)	24.12	1.13	27.25	1.97	3.13	0.82
PW%	-	-	-	-	55.21	18.20
NW%	-	-	-	-	46.08	22.48
TNV (cm <sup>3</sup> )	17.84	4.21	1.52	4.14	1.68	0.41

**TABLE 4** Descriptive statistics of data obtained from transversal measurements in RME group.

measurements. The correlation between the first and the second readings was very high, with values ranging from 0.991 to 0.995 for linear measurements and with a value of 0.915 for volumetric measurements. The method error, as described by the value of  $\sigma$ , was in general less than 0.4 mm (Table 3). Hence, all measurement error coefficients were found to be adequate for appropriate reproducibility of the study.

In the evaluation of the changes between T0 and T1, all linear transverse skeletal and dental measurements and the nasal volumes increased with both RME and SME protocols (Table 4, 5). The palatal width (PW) increased on average 3.82 mm in the RME group and 2.54 mm in the SME group. The average increase of nasal width (NW) was 3.13 mm for RME group and 2.67 mm for SME group. The dental expansion obtained for the correction of posterior cross-bite was 6.11 mm in the RME group and 6.67 mm in SME group. According to the values of PW% and NW%, the increment of palatal width and nasal width represented, respectively, the 55.21% and 46.08% of the dental expansion obtained with RME protocol. In SME group, the values of PW% and NW% were found to be 34.46% and 32.80%. The total nasal volume (TNV) increase was, on average, 1.68 cm<sup>3</sup> for RME and 1.25 cm<sup>3</sup> for SME. The sample size calculation for a further RCT study was performed considering the volumetric data variation of nasal cavity dimension (TNV) of RME (1.68) and SME (1.25) and setting sigma at 0.57. The analysis revealed that 28 patients must be enrolled for each group to perform a definitive RCT with 80% of power and at significance level of .05.

## Discussion

To the best of our knowledge, this is the first feasibility study assessing the methodology of a RCT comparing the volumetric skeletal effects on nasal cavity size in growing subjects of RME and SME. In this respect, a comprehensive evaluation of the effects of both palatal expansion protocols on the surrounding structures could be helpful in providing clinicians with more specific

Variables	Preexpansion		Postexpansion		Change	
	Mean	SD	Mean	SD	Mean	SD
IMW (mm)	37.82	3.89	44.49	5.18	6.67	2.36
PW (mm)	17.64	5.21	20.18	4.66	2.54	1.62
NW (mm)	25.21	2.68	27.88	3.30	2.67	0.74
PW%	-	-	-	-	34.46	17.70
NW%	-	-	-	-	32.80	10.04
TNV (cm <sup>3</sup> )	1581	331	1706	357	1.25	0.84

**TABLE 5** Descriptive statistics of data obtained from transversal measurements in SME group.

guidelines for their use.

In this study, both RME and SME group protocols showed to be able to increase basal palatal bone and nasal skeletal volume. The amount of skeletal change obtained with RME was comparable to previous findings [Palaisa et al., 2007]. In both groups, skeletal expansion was observed more in the palate (PW) than in the nasal region (NW), thus confirming that both protocols induce a reverse "V" shape opening of the mid-palatal suture [Timms, 1984; Wertz, 1970].

The PW% parameter was introduced to compensate for the fact that subjects enrolled in this study did not require the same amount of maxillary expansion for the correction of posterior cross-bite. In fact, the SME group showed a greater amount of dental expansion (6.67 mm) as compared with the RME group (6.11 mm). As a result, the PW% parameter could more accurately describe the efficacy of both protocols in expanding the palatal bone as compared to its corresponding absolute measurement (PW). For the same reason, a similar parameter was introduced to evaluate the changes in the nasal width, i.e., NW%.

In this study, we evaluated nasal skeletal dimensions, rather than airway space volume [Podesser et al., 2004; Fastuca et al., 2015] as a parameter for determining nasal changes. The reason behind this choice was that airway space could be affected by seasonal inflammatory (i.e., viral or allergic rhinitis) or atrophic status of the nasal mucosa; hence, using the airway space as parameter to assess the efficacy of expansion protocols on nasal cavity could be a potential bias.

Our evaluation was limited to the lower portion of the nasal cavity. This area is expected to be mostly affected by maxillary expansion, [Palaisa et al., 2007; Caprioglio et al., 2014; Cordasco et al., 2013] and the results confirmed this hypothesis. Moreover, the upper nasal cavity, which is mainly designated to the olfactory function, does not have a well-defined upper limit, making it difficult to evaluate changes in this area.

All forms of quantitative assessment raise questions as to the reliability and reproducibility of the methodology used for this purpose [Podesser et al., 2004; Nucera

et al, 2016]. The methodology presented in this study showed excellent accuracy in detecting pre- and post-treatment palatal width, nasal width and nasal volume, with high reproducibility found for both linear and volumetric measurements. The method error was larger for the volumetric measurement (value = 0.372) than for linear variables (values ranging from 0.223 to 0.293), which seems reasonable considering that the nasal computing process was methodologically more complex than simple linear measurements. In general, the method error was small and markedly below the effect of the therapy in both groups. These outcomes suggest that the present methodology can represent a useful supplement to orthodontic diagnosis and can, therefore, be recommended.

## Conclusions

- The manual segmentation and the nasal volume computing procedures were found to be highly reliable and reproducible. This result indicates that the proposed methodology can be used to investigate the linear and volumetric modifications of nasal cavity induced by different maxillary expansion protocols.
- The PW% and NW% parameters can describe the efficacy of different expansion protocols more accurately than their corresponding absolute measurements (PW and NW). PW% and NW% calculated respectively the palate and nasal expansion as percentage of the amount of dental expansion and were introduced because patients usually cannot require the same amount of maxillary expansion for the correction of posterior cross-bite.
- Preliminary findings suggest that 28 patients must be enrolled for each group to perform an RCT with adequate power.

## Conflicts of interest

None to declare.

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