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Three dimensional assessment of the changes of the upper airway volume after mini-screw assisted rapid palatal expansion: prospective clinical study

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Abstract

Objectives: *To assess the tomographic changes in the upper airway dimensions of treated patients had constricted maxilla with age range from 18 to 21 years old, using the bicortically anchored mini-screw assisted rapid palatal expansion (MARPE).* ***Materials and methods:*** *The current study was conducted on 24 orthodontic patients with constricted maxilla. The expander appliance consisted of two molar bands attached to maxillary first molars and 2 bi-cortically inserted mini-screws. Expansion protocol was 2 turns/day for the first week, then 1 turn/day until completion of the expansion. CBCT was performed before and 3 months after completion of the expansion. The airway volume, and linear alterations were measured to assess the changes three months after completion of the expansion.* ***Results:*** *There was significant increase in nasal cavity volume, nasopharynx volume, nasal cavity transverse linear dimensions, vertical linear dimensions, and maxillary width ($p < .05$). Expanded nasal cavity and nasopharyngeal volumes correlated positively with nasal width and negatively with nasal height at ANS, and PNS planes. There were positive correlations between expanded volumes and maxillary width. Increased maxillary width correlated negatively with hard palate thickness ($p < .05$).* ***Conclusions:*** *MARPE caused a significant increase in the nasal cavity and nasopharynx airway volumes. The increase in the nasal cavity and the nasopharynx volumes was correlated positively with the increase in nasal width at the ANS and PNS planes and with the increase in maxillary width. The oropharynx was not found to be changed significantly in this study.*

Keywords: *Airway volume; Cone Beam Computerized Tomography; mini-screw assisted rapid palatal expansion.*

Introduction

maxillary expansion (RME) is a common orthodontic treatment procedure to correct transverse discrepancies. [1] However, buccal crown tilting is one of the adverse outcomes of traditional tooth-borne RME. [2] In addition, because of interdigitation of the mid-palatal suture and surrounding articulations, there is restricted skeletal expansion in late adolescents and adults. [3] surgically assisted rapid maxillary expansion (SARME) was employed, specifically the surgical release of the closed mid-palatal suture, to reduce these unfavorable consequences and potential limits. Previous studies have shown that following SARME, there was an increase in the volume of the nasal cavity but no statistically significant impact on oropharyngeal volume. [4] But because of their trauma, individuals often have

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reluctance to have surgery. It has recently been shown that mini-implant assisted rapid maxillary expansion (MARPE) for mature individuals reduces surgical harm and unfavorable dentoalveolar side effects while providing skeletal expansion comparable to SARME. [5] Increased volume and cross-sectional area of the nasal cavity have been reported after MARPE by Kim et al. [6]

Previous investigations have documented the impact of RPE and MARPE on the skeletal and dental structures. [7,8] Prior researches have used two-dimensional (2D) posteroanterior cephalograms, photographic analysis, and clinical tests to look into the impact of maxillary expansion on face characteristics immediately following period of expansion [9]. These techniques do, however, have drawbacks, including the inability to precisely detect structures in conventional radiographs. The accurate diagnosis of the airway spaces with 2D radiology, required additional specialized views, which means more radiation exposure. [10]

Cone-beam computed tomography (CBCT) can precisely assess the structures of the head and neck by providing a three-dimensional (3D) picture of the structures without magnification. There are few previous studies that compared the airway effect of the hybrid hyrax expander with two bi-cortically anchored miniscrews on patients in their late adolescent stage. Thus, the objectives of this study to evaluate the dimensional changes of the airway volume three months after completion of expansion in late adolescent patients, and to investigate correlations between changes of the airway volume and the maxillary expansion. The null hypothesis was that the dimension and volume of the airway would not be changed by the bicortically anchored MARPE.

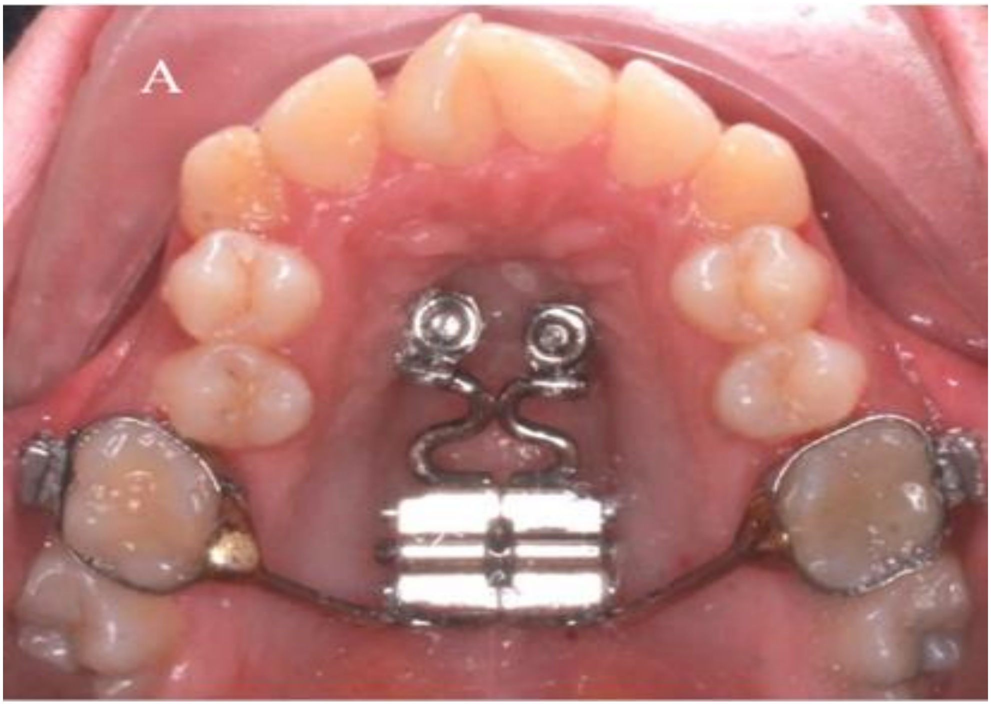
Materials and methods:

Twenty four patients indicated for rapid maxillary expansion aided by mini-implants were included in this study at the Department of Orthodontics, faculty of dentistry, Minia university. The study was approved by the Ethical committee of faculty of dentistry, Minia University (No. 103-2024). Digital CBCT data was collected both before expansion (T0) and three months after completion of the expansion (T1), specifically when the upper 1st permanent molars palatal cusps occlude with the lower 1st permanent molars buccal cusps.

The inclusion criteria were as follows, patients age between 18 and 21 years old, presence of skeletal bilateral posterior crossbite, no history of prior orthodontic treatment, absence of temporomandibular disorders, no history of surgical interventions such as adenoidectomy and tonsillectomy, and absence of craniofacial syndromes.

To estimate the sample size, previous study reported mean difference between slow and rapid maxillary expansion as regard anterior nasal cavity width that was 2.64mm^3 (95% CI= 0.83 to 4.45; $p = 0.007$), [11] a minimum number of patients was 24 patients with the following assumption; 90% power of the study, 0.05 alpha error with 95% confidence interval.

All subjects were treated by MARPE technique using two mini-implants that were inserted at the level of the upper 1st premolar in the sagittal plane, bicortically anchored (Figure 1). the expansion rate was two turns per day for the first week, then 1 turn per day until the posterior cross-bite was corrected. After the cross-bite was corrected a light curable flowable composite was injected in the expansion screw from the occlusal surface to prevent deactivation of the appliance, and the appliance was kept in place as a retainer for three months.



(Figure 1) Intra-oral view of the tooth-bone borne hybrid hyrax expander (A), and post-expansion occlusion (B)

All CBCT scans were recorded with the same machine (Scanora® 3D with auto-switch™, soredex, Helsinki, finland, with 85 kvp, 15 mA, and a field of view FOV of 4 cm). The first scan was taken pretreatment, and another scan was taken 3 months after completion of expansion for all patients. A total of 19 CBCTs were evaluated, and 5 were excluded due to patient drop out.

The CBCTs were reconstructed with digital imaging and communication in medicine (DICOM) data using OnDemand3D™ software (Cybermed Inc., Seoul, Korea), The CBCT scans were oriented in a standardized manner as described by Troung et al. [12] The landmarks and parameters used in the study are described in table 1,2, and 3, and figures 2:14. One investigator performed all measurements. Five randomly selected CBCTs were analyzed by the same investigator after 4 weeks for intra-rater reliability and another investigator for interrater reliability.

(Table 1) Three dimensional landmarks

Landmarks	
(N) Nasion	the most anterior point of the frontonasal suture that joins the nasal part of the frontal bone and the nasal bones.
ANS (anterior nasal spine)	The most anterior point of the tip of the anterior nasal spine in the midsagittal plane
PNS (posterior nasal spine)	Posterior nasal spine: a constructed radiographic point, the intersection of the continuation of the anterior wall of the pterygomaxillary fissure and the nasal floor
IBSS	Inferior border of the sphenoid sinus
S point	Mid-point of the sella turcica, it is constructed radiographic point.
Alar point	The most lateral point on the contour of the nostril
2^{nd} C.V.A.P	2^{nd} cervical vertebrae most anterior point
Crista galli	is a normal anatomical structure in the floor of the anterior cranial fossa
NFE (nasal floor edge)	Most lateral visible point of the nasal floor

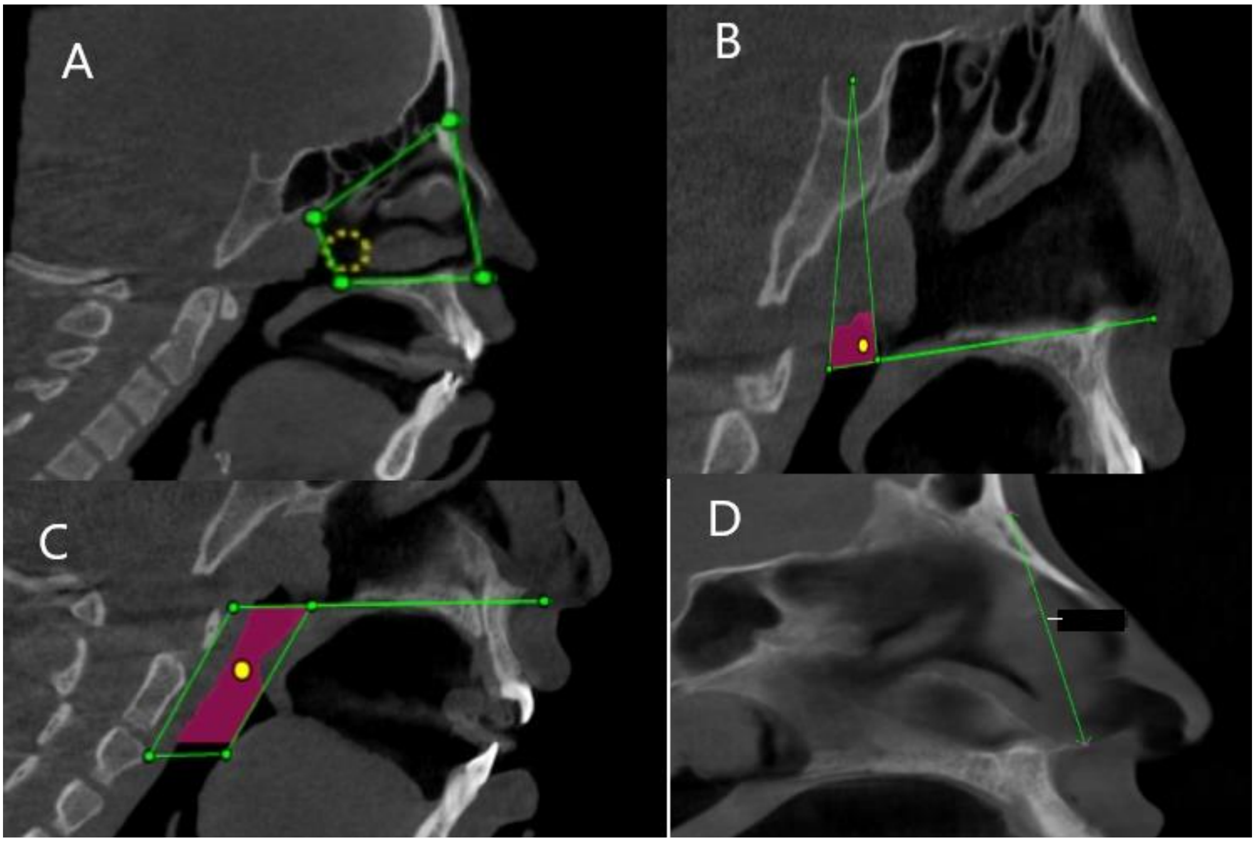
(Table 2) Planes used in this study

Planes	
Mid-sagittal plane	A plane passing vertically through the midline of the skull, subsequently dividing the skull into left and right halves of equal proportion particularly in a skull exhibiting bilateral symmetry

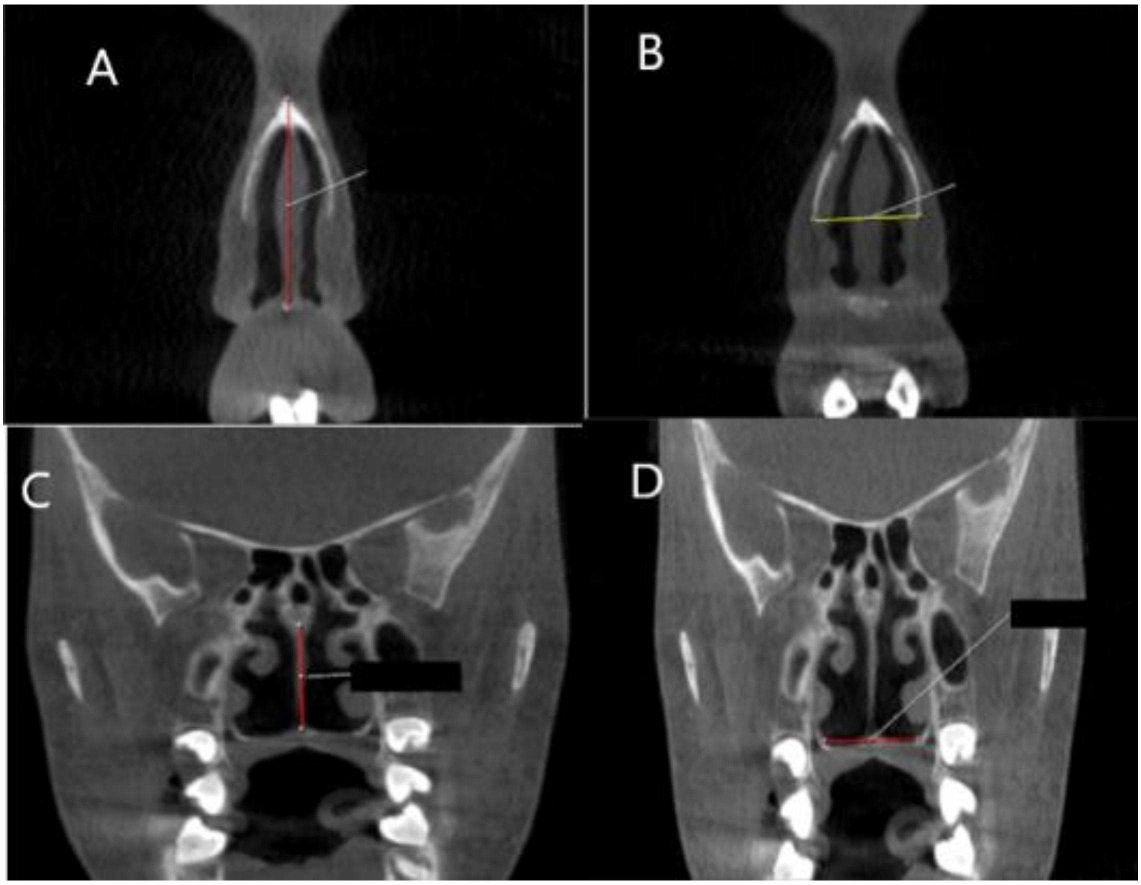
(Table 3) Volumetric, cross-sectional and linear measurements used in this study

Volumetric measurements	
Nasal cavity volume	Anterior limit: A line connecting N point to ANS in the Midsagittal plane Posterior limit: a line from the inferior border of the sphenoid sinus to the PNS in the Midsagittal Plane Superior limit: A curved line extending anteriorly from N point to Inferior Spheniod Sinus posteriorly to exclude the paranasal sinuses Inferior limit: the line connecting the ANS to the PNS in the midsagittal plane
Nasopharynx	A triangular volume confined between three lines as follow: - **A line constructed from PNS to S point** - **A line constructed from S point to a point where a horizontal constructed plane from ANS to PNS extended posteriorly to the posterior wall of the pharynx connected.** - **A line constructed from ANS to PNS extended posteriorly to posterior wall of the pharynx** - **This constructed triangle was confined between the anterior and posterior walls of the pharynx**

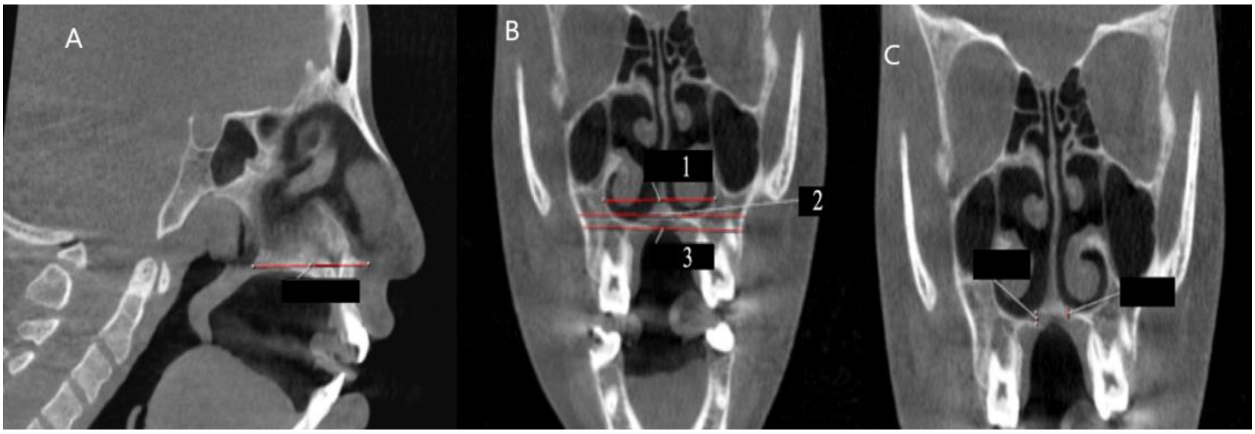
Oropharynx	Superior limit: a horizontal line extended from ANS to PNS extended posteriorly to the posterior wall of the pharynx. Inferior limit: The lower limit of the oropharynx was determined by a line parallel to the palatal plane, passing through the most anterior point of the second cervical vertebra Anterior limit: the anterior wall of the pharynx in the sagittal plane Posterior limit: posterior wall of the pharynx in the sagittal plane
Linear measurements	
Alar width	The measurement of the distance between most prominent points on the ala of the nose on the left and right
Vertical nasal length	The measurement of the distance from N point to ANS.
Nasal cross-sectional height at ANS	The height of nasal cavity at the cross-section passing through ANS
Nasal cross-sectional width at ANS	The greatest width of nasal cavity at the cross-section passing through ANS
Nasal cross-sectional height at PNS	The height of nasal cavity at the cross-section passing through PNS
Nasal cross-sectional width at PNS	The greatest width of nasal cavity at the cross-section passing through PNS
ANS-PNS	The distance between ANS and PNS
Nasal lateral width	The nasal width between the most lateral wall of the nasal cavity
Maxillary width at nasal floor	The width of maxilla tangent to the nasal floor at its most inferior level
Maxillary width at hard palate	The width of maxilla tangent to the hard palate at its most inferior level
Palate thickness	The average thickness of left and right sides 3 mm to mid-palatal suture
Cross-sectional measurements	
Cross-sectional area at PNS	Cross-sectional area of pharyngeal airway at the PNS plane



(Figure 2) A: nasal cavity volume, B: nasopharynx volume, C: oropharynx volume, D: vertical nasal length.



(Figure 3) A: nasal cross-sectional height at ANS plane, B: nasal cross-sectional width at ANS plane, C: nasal cross-sectional height at PNS plane, D: nasal cross-sectional width at PNS plane.



(Figure 4) A: sagittal cut showing the distance from ANS to PNS, B: coronal cut showing 1: the nasal lateral width, 2: Maxillary width at nasal floor, 3: Maxillary width at hard palate, C: coronal cut showing the palate thickness

Statistical analysis:

Statistical analysis was performed with SPSS 16 ® (Statistical Package for Scientific Studies), Graph pad prism & windows excel. Exploration of the given data was performed using Shapiro-Wilk test and Kolmogorov-Smirnov test for normality which revealed that the data originated from normal distribution. Accordingly, comparison between 2 different intervals was performed by paired t test. The significance level was set at $p \leq 0.05$. Pearson correlation test was used to identify correlations if data were normally distributed; if not, Spearman correlation was used. $P \leq 0.05$ was considered statistically significant.

Results:

Upper airway measurements:

Means and standard deviations of all volumetric, linear and cross-sectional measurements at T0 and T1 and changes between them were presented in table (4) and figures 5 to 7.

Comparison between T0 and T1 was performed by using Paired t test which revealed that there was a significant increase in all measurements except ANS-PNS in linear measurements that showed insignificant increase as $P<0.05$.

Table (4). Changes in the volumes, dimensions of the upper airway and changes of skeletal widths before (T0) and After (T1):

		T0		T1		Paired Differences					P value
						Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		
		Mean	Standard Deviation	Mean	Standard Deviation				Lower	Upper	
Volumetric	**Nasal cavity volume (mm^3)**	19346.80	700.46	22265.23	3308.37	2918.43	2608.11	869.37	913.66	4923.20	0.01*
	Nasopharynx (mm^3)	3434.73	626.44	4008.70	511.05	573.97	331.81	110.60	318.92	829.02	0.001*
	Oropharynx (mm^3)	7063.75	399.16	7171.20	527.08	107.45	568.44	116.03	132.58	347.48	0.36
Linear	**Vertical nasal length (mm)**	48.28	1.89	49.73	1.74	1.45	0.24	0.08	1.27	1.64	0.0001*
	Nasal cross-sectional height (ANS)(H-ANS) (mm)	44.53	1.93	46.23	2.26	1.70	0.40	0.13	1.39	2.01	0.0001*
	Nasal cross-sectional width (ANS)(W-ANS) (mm)	18.42	0.25	22.61	1.74	4.19	1.49	0.50	3.05	5.33	0.0001*
	Nasal cross-sectional height (PNS) (H-PNS) (mm)	18.72	4.54	20.04	3.96	1.31	0.59	0.20	0.86	1.76	0.0001*
	Nasal cross-sectional width (PNS) (W-PNS) (mm)	24.24	1.53	27.48	3.67	3.24	2.90	0.97	1.02	5.47	0.01*
	ANS-PNS (mm)	48.68	5.46	48.05	5.43	-0.63	0.48	0.16	-0.27	-1.00	0.004*
	Nasal lateral width (mm)	31.02	4.31	34.73	5.52	3.71	1.44	0.48	2.60	4.82	0.0001*
	Maxillary width (NF) (mm)	59.50	4.28	61.53	3.76	2.03	0.97	0.32	1.29	2.78	0.0001*
	Maxillary width (HP) (mm)	57.03	3.77	59.87	2.88	2.83	1.75	0.58	1.48	4.18	0.001*
Cross-sectional area at PNS (mm^2)		518.43	229.83	552.95	193.61	34.52	38.08	12.69	63.79	5.25	0.02*

paired t test
**significant difference as P<0.05.*

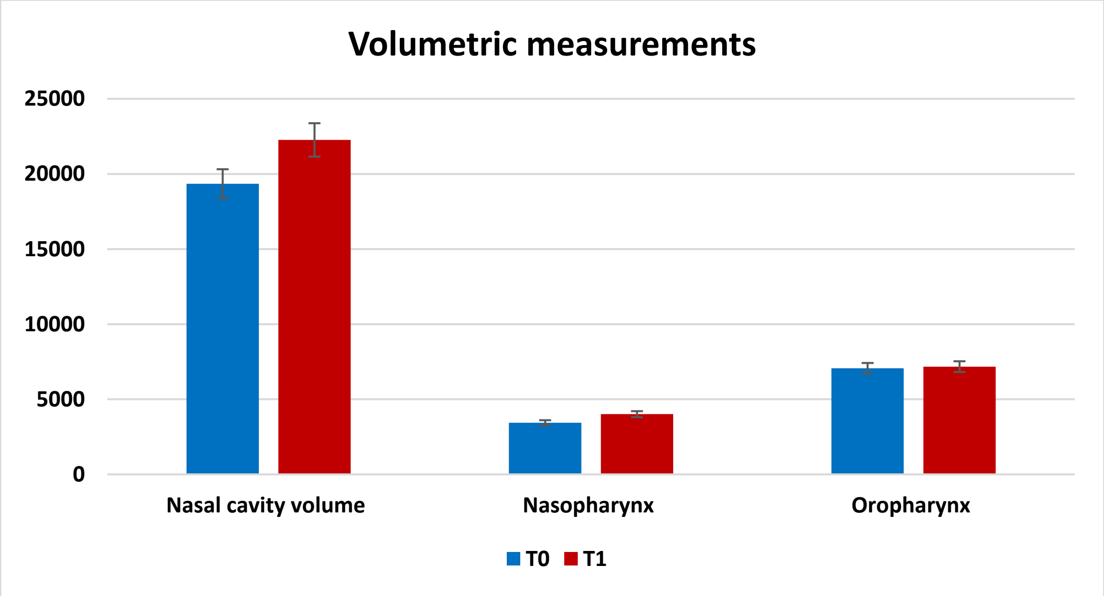


Figure (5): Volumetric measurements at T0 and T1.

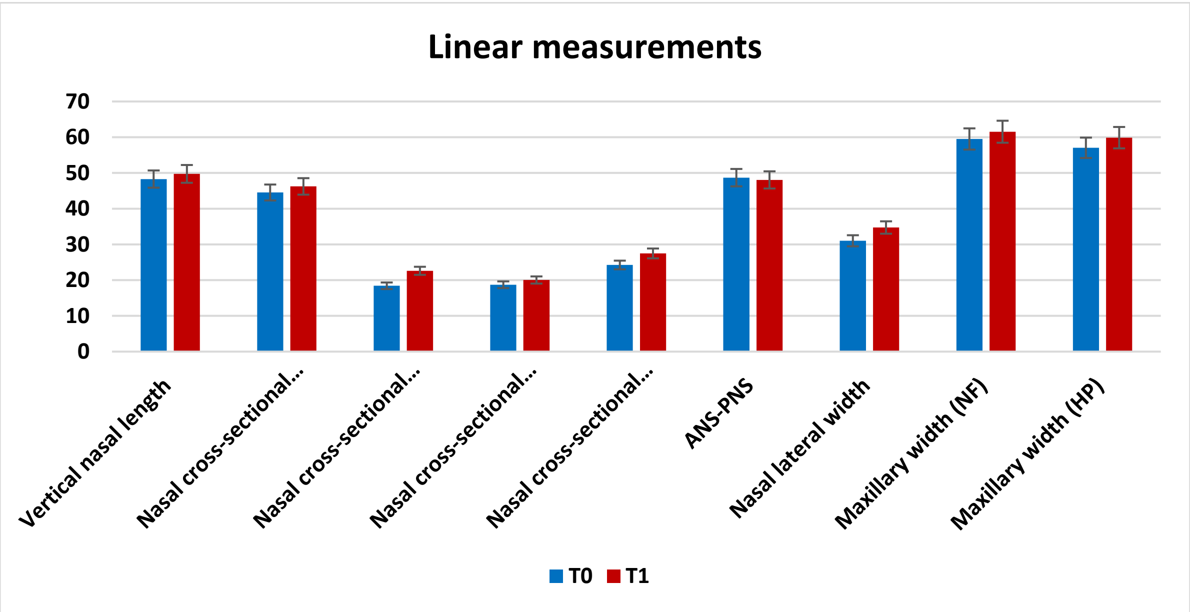


Figure (6): Linear measurements at T0 and T1.

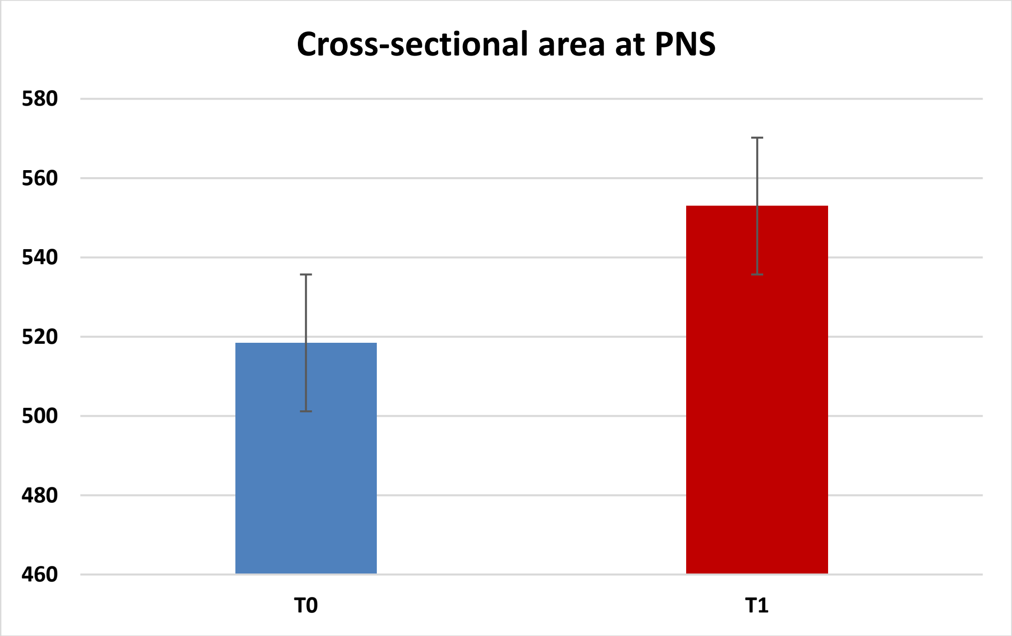


Figure (7): Cross-sectional area at T0 and T1.

Correlation Coefficient between significant changes of upper airway volume and other variables:

Enlargement of nasal cavity volume showed a positive strong significant correlation with nasal cross-sectional width (ANS)(W-ANS) as P= 0.0001, Nasal cross-sectional width (PNS) (W-PNS) as P=0.0001, Nasal lateral width as P= 0.01, Maxillary width (NF) as P= 0.05, Maxillary width (HP) as P=0.0001, and cross-sectional area (PNS) (Area-PNS) as P=0.0001. However there was negative strong significant correlation with vertical nasal length as P=0.01, Nasal cross-sectional height (ANS)(H-ANS) as P=0.0001, nasal cross-sectional height (PNS) (H-PNS) as P= 0.0001. On the other hand, there was insignificant correlation with alar width as P=0.21, ANS-PNS as P=0.11, palate thickness as P=0.11, as presented in table (5).

Enlargement of nasopharyngeal volume showed a positive strong significant correlation with alar width as P=0.03, nasal cross-sectional width (ANS)(W-ANS) as P=0.0001, nasal cross-sectional width (PNS) (W-PNS) as P=0.0001, ANS-PNS as P=0.01, Maxillary width (NF) as P=0.0001, Maxillary width (HP) as P=0.0001, Cross-sectional area (PNS) (Area-PNS) as P=0.0001. However there was negative strong significant correlation with vertical nasal length as P=0.0001, nasal cross-sectional height (ANS)(H-ANS) as P=0.0001, nasal cross-sectional height (PNS) (H-PNS) as P=0.0001, palatal thickness as P=0.01. On the other hand, there was insignificant correlation with nasal lateral width as P=0.1, as presented in table (5).

Table (5): Correlation coefficient between upper airway volume and other variables

Correlations	Change in nasal cavity volume		Change in nasopharynx volume	
	r	P value	r	P value
Alar width	0.46	0.21	0.71	0.03*
Vertical nasal length	-0.78	0.01*	-0.94	0.0001*
Nasal cross-sectional height (ANS)(H-ANS)	-0.94	0.0001*	-1.00	0.0001*
Nasal cross-sectional width (ANS)(W-ANS)	1.00	0.0001*	0.96	0.0001*
Nasal cross-sectional height (PNS) (H-PNS)	-0.99	0.0001*	-0.90	0.0001*
Nasal cross-sectional width (PNS) (W-PNS)	0.95	0.0001*	1.00	0.0001*
ANS-PNS	0.57	0.11	0.79	0.01*
Nasal lateral width	0.81	0.01*	0.59	0.10
Palate thickness	-0.58	0.11	-0.80	0.01*
Maxillary width (NF)	0.65	0.05*	0.85	0.0001*
Maxillary width (HP)	0.98	0.0001*	0.99	0.0001*
Cross-sectional area (PNS) (Area-PNS)	0.97	0.0001*	1.00	0.0001*

Pearson correlation coefficient test
*Significant correlation as P<0.05.

Other important Correlations:

Other important correlations were calculated and revealed that there was a significant strong positive correlation between Original Cross-sectional area (PNS) (Area-PNS) and original nasopharynx as P=0.0001, positive correlation between Change of Cross-sectional area (PNS) (Area-PNS) and Change of Maxillary width (HP) as P=0.02. There was a significant strong negative correlation between original Palate thickness and Change of Maxillary width (NF) as P=0.006, Original Palate thickness and Change of Maxillary width (HP) as P=0.001. On the other hand, there was an insignificant correlation between Original Palate thickness and Change of Nasal lateral width as P=0.38, as presented in table (6).

Table (6): Other important Correlations

Variable	Variable	r	P value
Original Cross-sectional area (PNS) (Area-PNS)	Original nasopharynx	0.99	0.0001*
Change of Cross-sectional area (PNS) (Area-PNS)	Change of **Maxillary width (HP)**	0.73	0.02*
Original Palate thickness	Change of **Nasal lateral width**	-0.33	0.38
Original Palate thickness	Change of **Maxillary width (NF)**	-0.82	0.006*
Original Palate thickness	Change of **Maxillary width (HP)**	-0.99	0.001*

Pearson correlation coefficient test
*Significant correlation as P<0.05.

Discussion

8% to 23% of adolescents and less than 10% of adults had transverse maxillary deficiency. In transverse maxillary deficiency, unilateral or bilateral cross-bite is the most frequently observed abnormality. [13] Resolving this problem has been associated with positive therapy outcomes related to swallowing, hearing, and nasal breathing. Maxillary transverse deficiency can be treated with a variety of appliances and treatment plans, which typically include maxillary expansion and mid-palatal suture separation. These consist of micro-implant assisted rapid palatal expansion (MARPE), surgically assisted rapid palatal expansion (SARPE), slow orthodontic expansion (SOE), and rapid palatal expansion (RPE). While each approach has a different set of adverse effects, they all aim to resolve the skeletal disharmony [14].

Transverse discrepancy can be corrected with orthodontic treatment using rapid maxillary expansion (RME). It has been frequently used to correct the posterior crossbites, eliminate dental crowding, widen smiles, and widen the maxillary arch transversely [15]. It was reported that the maxilla could be successfully expanded with the use of RME device and mini screws. A new study suggested that mini screw assisted rapid maxillary expansion (MARME) may be a stable and clinically effective therapeutic option for people with maxillary restriction [16]. Melsen’s histology investigations have led to a consensus that the use of traditional RPE should be restricted to patients under the age of 15 [17]. The majority of physicians believe that MARPE has increased the success rate in young adults in separating the midpalatal suture, despite the fact that effective palatal expansion has been documented in young individuals over the age of 15 using standard RPE. The published research studies make it clear that the effectiveness rate of MARPE was between 84% and 87% [18].

The present study was conducted to evaluate the 3-dimensional changes of the airway using the CBCT following mini-screw assisted rapid maxillary expansion.

The alterations in the upper airway's volume, vertical and horizontal dimensions caused by MARPE were the main focuses of this study. Significant increases in the volume of the nasal cavity and nasopharynx were recorded, which is consistent with some earlier researches. [19,20] Kim et al. [6] showed that from the time of pre-expansion to the immediate post-expansion period and the year following the expansion, the nasal cavity's volume increased constantly. They reported that the nasopharyngeal volume increased significantly one year following expansion, when compared to the original volume. [6] The volume of the nasal cavity and nasopharynx increased considerably in the current study three months following MARPE. Furthermore, the nasal cavity and nasopharyngeal volume expanded as a result of the increased nasal osseous width at the ANS and PNS planes, and inversely to the nasal osseous height at the ANS and PNS planes, while Li et al found that the nasopharyngeal volume expansion was contributed to only the increase in nasal osseous width at the PNS plane. [19] The maxillary width resulted in an increase in the upper airway's cross-sectional area at the PNS plane, which in consistent with Li et al results. [19] However, earlier study revealed no statistically significant changes in nasopharyngeal volume. [21] The age of the subjects, variations in the upper airway volume definition, the expansion modality, the degree of activation of the expansion screw, the quantity of punctured palatal and nasal cortical bone, skeletal features, and the measurement instruments employed could all be reasons for these discripancies of the results between studies.

It was found that palate thickness and increased maxillary width were inversely correlated, suggesting that the thicker hard palate exhibited greater resistance, although bone support of the hard palate to mini-screws was also essential. The maxillary width at hard palate, and at nasal floor was directly correlated with the nasopharynx's and the nasal cavity's enlarged volume, which is contrary to the findings of Li et al’s study. [19] This may be due to different age range, the type of appliance, amount of activation, and anatomical variations of the subjects included in the studies. In this study a conclusion could be addressed about a relationship between the volume increase and the maxillary expansion quantities, higher expansion amount of the maxilla will increase the nasal cavity and nasopharynx volumes.

Kavand et al. found that after rapid miniscrew-supported expansion, there was a considerable increase in the nasal cavity and nasopharyngeal volume, but not in the oropharyngeal volume [22] similar to the present study, while the oropharyngeal airway significantly increased, according to Mehta et al [23], may be due to different age range (11-15 years) of the sample, and the site of insertion of the miniscrews in the MARPE group.

Ghoneima et al. previously showed that the RME stresses primarily affected the anterior craniofacial sutures. Therefore, the current study's significant increase in airway, and vertical and transverse linear dimensions was restricted to the nasal cavity and nasopharynx [24].

There were no studies that compared the nasopharynx volumes and skeletal alterations in the nasal cavity between age groups, but evidence indicates larger nasal enlargements in younger individuals [25]. The present study showed significant increase in nasal cavity and nasopharynx dimensions in late adolescent individuals.

The pathogenesis of obstructive sleep apnea has been found to be significantly influenced by oropharyngeal airway constrictions [26], because of a correlation with the low tongue posture that patients with maxillary constriction frequently exhibit [27]. There was no significant increase in the oropharynx's airway volume in the current study, as earlier studies have shown [20,28]. Lack of MARPE impact on the size of the oropharynx was expected due to the remote anatomical relationship between the oropharynx and the maxillary complex.

The information gathered here supports hypothesis that the impact of MARPE in the upper airway is primarily localized and diminishes as it "descends" in the upper airway. As previously mentioned, the nasopharynx volume was statistically increased, also it should be mentioned that the nasal cavity showed a greater increase in volume than the nasopharynx. This is most likely due to the appliance's placement beneath the nasal cavity, which would have directly impacted any modifications to the nasal cavity. In contrast, the zygomatic buttress and pterygomaxillary junction would provide resistance, meaning that the nasopharynx volume would not be directly impacted [6]. The increase in the cross-sectional area of the airway showed a similar trend; the anterior segment showed a greater increase compared with the posterior segment which is consistent with previous studies [6,19]. In contrast to nasal cavity volume and nasopharyngeal volume, the oropharyngeal volume changed insignificantly which is consistent with previous studies [29,30].

limitations of this study are lack of a control group due to ethical issues, and relatively small sample size which might have an impact on the study power and the results' interpretation. Because of the relatively small sample size, it was unreliable to categorize data based on vertical skeletal pattern. The expander's presence before and after MARPE caused the tongue to move differently. Furthermore, the observation duration was short. Examining the upper airway after one year and again when the expander was taken out would be beneficial in the future. Finally, functional features of morphometric alterations would be best correlated with breathing testing. [19]

Conclusions

- **Mini screw assisted rapid maxillary expansion caused a significant increase in the nasal cavities' and nasopharynx's airway volumes which could be a useful technique to improve breathing in late adolescent patients with constricted maxilla.**
- **The increase in the nasal cavity and the nasopharynx volumes was attributed to an increase in nasal width at the ANS and PNS planes and concurrently with an increase in maxillary width.**
- **The oropharynx was not found to be changed significantly in this study.**
- **The thickness of the hard palate has an impact on the amount of maxillary width by MARPE.**

References:

1. Garrett BJ, Caruso JM, Rungcharassaeng K, Farrage JR, Kim JS, Taylor GD. Skeletal effects to the maxilla after rapid maxillary expansion assessed with cone-beam computed tomography. Am J Orthod Dentofacial Orthop 2008; 134: 8–9.

2. Rungcharassaeng K, Caruso JM, Kan JYK, Kim J, Taylor G. Factors affecting buccal bone changes of maxillary posterior teeth after rapid maxillary expansion. Am J Orthod Dentofacial Orthop 2007; 132: 428.e1–8.

3. Persson M, Thilander B. Palatal suture closure in man from 15 to 35 years of age. Am J Orthod 1977; 72: 42–52.

4. Buck LM, Dalci O, Darendeliler MA, Papadopoulou AK. Effect of Surgically Assisted Rapid Maxillary Expansion on Upper Airway Volume: A Systematic Review. J Oral Maxillofac Surg 2016; 74: 1025–43.

5. Park JJ, Park Y-C, Lee K-J, Cha J-Y, Tahk JH, Choi YJ. Skeletal and dentoalveolar changes after miniscrew-assisted rapid palatal expansion in young adults: A cone-beam computed tomography study. Korean J Orthod 2017; 47: 77–86.

6. Kim S-Y, Park Y-C, Lee K-J *et al.* Assessment of changes in the nasal airway after nonsurgical miniscrew-assisted rapid maxillary expansion in young adults. Angle Orthod 2018; 88: 435–441.

7. Lin L, Ahn H-W, Kim S-J, Moon S-C, Kim S-H, Nelson G. Tooth-borne vs bone-borne rapid maxillary expanders in late adolescence. Angle Orthod 2015; 85: 253–62.

8. Gunyuz Toklu M, Germec-Cakan D, Tozlu M. Periodontal, dentoalveolar, and skeletal effects of tooth-borne and tooth-bone-borne expansion appliances. Am J Orthod Dentofacial Orthop 2015; 148: 97–109.

9. Silva Filho OG da, Lara TS, Ayub PV, Ohashi ASC, Bertoz FA. Photographic assessment of nasal morphology following rapid maxillary expansion in children. J Appl Oral Sci 2011; 19: 535–43.

10. Choi J-Y, Oh SH, Kim S-H *et al.* Effectiveness of 2D radiographs in detecting CBCT-based incidental findings in orthodontic patients. Sci Rep 2021; 11: 9280.

11. Yacout YM, El-Harouni NM, Madian AM. Dimensional changes of upper airway after slow vs rapid miniscrew-supported maxillary expansion in adolescents: a cone-beam computed tomography study. BMC Oral Health 2022; 22: 529.

12. Truong CT, Jeon HH, Sripinun P, Tierney A, Boucher NS. Short-term and long-term effects of rapid maxillary expansion on the nasal soft and hard tissue. Angle Orthod 2021; 91: 46–53.

13. Egermark-Eriksson I, Carlsson GE, Magnusson T, Thilander B. A longitudinal study on malocclusion in relation to signs and symptoms of cranio-mandibular disorders in children and adolescents. Eur J Orthod 1990; 12: 399–407.

14. da Silva Filho OG, Santamaria M, Capelozza Filho L. Epidemiology of posterior crossbite in the primary dentition. J Clin Pediatr Dent 2007; 32: 73–8.

15. Bayram M, Ozer M, Arici S, Alkan A. Nonextraction treatment with rapid maxillary expansion and mandibular symphyseal distraction osteogenesis and vertical skeletal dimensions. Angle Orthod 2007; 77: 266–72.

16. Lee K-J, Park Y-C, Park J-Y, Hwang W-S. Miniscrew-assisted nonsurgical palatal expansion before orthognathic surgery for a patient with severe mandibular prognathism. Am J Orthod Dentofacial Orthop 2010; 137: 830–9.

17. Melsen B. Palatal growth studied on human autopsy material. A histologic microradiographic study. Am J Orthod 1975; 68: 42–54.

18. Lim H-M, Park Y-C, Lee K-J, Kim K-H, Choi YJ. Stability of dental, alveolar, and

skeletal changes after miniscrew-assisted rapid palatal expansion. Korean J Orthod 2017; 47: 313–322.

19. Li Q, Tang H, Liu X *et al.* Comparison of dimensions and volume of upper airway before and after mini-implant assisted rapid maxillary expansion. Angle Orthod 2020; 90: 432–441.

20. Chang Y, Koenig LJ, Pruszynski JE, Bradley TG, Bosio JA, Liu D. Dimensional changes of upper airway after rapid maxillary expansion: a prospective cone-beam computed tomography study. Am J Orthod Dentofacial Orthop 2013; 143: 462–70.

21. Abdalla Y, Brown L, Sonnesen L. Effects of rapid maxillary expansion on upper airway volume: A three-dimensional cone-beam computed tomography study. Angle Orthod 2019; 89: 917–923.

22. Kavand G, Lagravère M, Kula K, Stewart K, Ghoneima A. Retrospective CBCT analysis of airway volume changes after bone-borne vs tooth-borne rapid maxillary expansion. Angle Orthod 2019; 89: 566–574.

23. Mehta S, Wang D, Kuo C-L *et al.* Long-term effects of mini-screw-assisted rapid palatal expansion on airway. Angle Orthod 2021; 91: 195–205.

24. Ghoneima A, Abdel-Fattah E, Hartsfield J, El-Bedwehi A, Kamel A, Kula K. Effects of rapid maxillary expansion on the cranial and circummaxillary sutures. Am J Orthod Dentofacial Orthop 2011; 140: 510–9.

25. Baccetti T, Franchi L, Cameron CG, McNamara JA. Treatment timing for rapid maxillary expansion. Angle Orthod 2001; 71: 343–50.

26. Johal A, Patel SI, Battagel JM. The relationship between craniofacial anatomy and obstructive sleep apnoea: a case-controlled study. J Sleep Res 2007; 16: 319–26.

27. Linder-Aronson S. Adenoids. Their effect on mode of breathing and nasal airflow and their relationship to characteristics of the facial skeleton and the denition. A biometric, rhino-manometric and cephalometro-radiographic study on children with and without adenoids. Acta Otolaryngol Suppl 1970; 265: 1–132.

28. Ribeiro ANC, de Paiva JB, Rino-Neto J, Illipronti-Filho E, Trivino T, Fantini SM. Upper airway expansion after rapid maxillary expansion evaluated with cone beam computed tomography. Angle Orthod 2012; 82: 458–63.

29. Shetty A, Ratti S, Nakra P, Shetty S, Mohammed A, Saidath K. Evaluation of Soft Tissue and Airway Changes in Individuals Treated with Mini-Implant Assisted Rapid Palatal Expansion (MARPE). J Long Term Eff Med Implants 2022; 32: 7–18.

30. Anéris FF, El Haje O, Rosário HD, de Menezes CC, Franzini CM, Custodio W. The effects of miniscrew-assisted rapid palatal expansion on the upper airway of adults with midpalatal suture in the last two degrees of ossification. J World Fed Orthod 2023; 12: 150–155.