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THREE DIMENSIONAL EVALUATION OF NASOPHARYNGEAL AIRWAY DIMENSIONS FOLLOWING SURGICALLY ASSISTED RAPID MAXILLARY EXPANSION

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ABSTRACT

Objective: The aim of the present study was to evaluate the nasopharyngeal and oropharyngeal airway changes following surgically assisted rapid palatal expansion (SARPE) using cone beam computed tomography (CBCT). **Subjects and Methods:** The sample consisted of 13 female adult patients with an age range of (28-43 years old) with bilateral skeletal posterior crossbite. CBCT was performed preoperatively and after 6 months postoperatively. Surgically assisted rapid palatal expansion under general anesthesia was performed for all patients. Hyrax palatal expander was used until correction of the posterior crossbite was achieved. Landmarks from CBCT were used to measure the volumetric changes in the nasopharyngeal and oropharyngeal airway dimensions as well as minimum cross sectional area after maxillary expansion. **Results:** There was a statistically significant increase of all airway dimensions (nasopharyngeal and oropharyngeal volumes as well as minimum cross-sectional area) after surgically assisted rapid palatal expansion (SARPE). **Conclusion:** Surgically assisted rapid palatal expansion (SARPE) resulted in a significant increase in the volume of the nasopharyngeal and oropharyngeal airways as well as the minimum cross-sectional area of the oropharynx. Therefore this treatment modality can be beneficial to improve respiratory capacity in patients with transverse maxillary constriction and obstructive sleep apnea.

KEYWORDS: Transverse maxillary deficiency, Maxillary Expansion, Pharyngeal airway, CBCT

INTRODUCTION

Dentofacial deformities can affect maxilla, mandible or both jaws. These deformities occur in the vertical, horizontal or transverse planes[(1)]. Transverse maxillary constriction (TMC) is the most prevalent deformity that affects the middle third of the face. It may occur solely or in association with other types of dentoskeletal deformities[(2,3)]. The incidence ranges from 3-18% in patients seeking orthodontic treatment[(2,4)]. It is characterized by maxillary constriction, unilateral or bilateral posterior crossbite and crowding of the dental arches. Patients with this deformity suffer from a narrow nasal cavity[(5,6)]. which is resistant to the nasal airway flow leading to breathing difficulties[(7)].

The upper airway has two openings, the oral cavity and the nasal cavity. They meet in the area called pharynx. The pharynx is divided into 3 parts: nasopharynx, oropharynx, and laryngopharynx. The nasopharynx lies superiorly and is dorsal to the nasal cavity and the soft palate. Below it lies the oropharynx which has both respiratory and digestive functions and is limited by the epiglottis inferiorly. The region of the pharynx below the epiglottis is called laryngopharynx[(8)].

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Previous studies have established a relationship between transverse maxillary deficiency and obstructive sleep apnea (OSA) [9,10]. The amount of air passing through both the nose and nasopharynx is confined by the diameter and shape of the latter[11] . Furthermore, the collapse of the upper airway that results from transverse maxillary constriction results in hypoxia with complications such as bradycardia and/or tachycardia which may lead to cardiovascular or cerebrovascular problems[10]. Besides TMC, other etiological factors of OSA are mandibular retrognathia, obesity, and pronounced cranial base flexion[9,11] . An increase in the volume of the lateral pharyngeal walls and the tongue also enhances the probability of developing this disorder[12].

Several treatment modalities are available to correct TMC depending on the patient's skeletal maturity. In children and adolescents up till 15 years of age, slow or rapid maxillary expansion (RME) which was initially introduced in the 1961 by Hass[13], are successful in treating this discrepancy, however they are ineffective in older ages due to the mid-palatal suture ossification Therefore, surgically-assisted rapid palatal expansion (SARPE) is indicated in subjects with mature mid-palatal suture[2]. To overcome the fusion of the sutures and the resulting resistance to expansion. Maxillary expansion widens the nasal floor and decreases the resistance to the flow of air which improves the respiratory function [10,14].

The majority of the studies on airway changes due to SARPE were 2-dimensional (2D) that used conventional cephalograms[15]. More studies are needed to assess the correlation between surgical maxillary expansion and upper airway changes. Hence, the aim of this study was to evaluate three-dimensionally the volumetric changes that occur in the upper airway following SARPE using CBCT.

SUBJECTS AND METHODS

Ethics committee approval

This clinical prospective study was approved by the Research Ethics Committee of the Faculty of Dentistry, Cairo University. The patients were informed about the details of the procedure and surgical intervention . An informed consent was signed by all of them prior to starting the treatment.

This study was conducted on 13 adult female patients, with an age range 28-43 years, mean age = 35.3 (±5.2) recruited from the outpatient clinic of the Department of Orthodontics, Cairo University. They were suffering from transverse maxillary deficiency that is skeletal in nature with difficulty in breathing assessed clinically through inspection of nasal flaring audible breathing. Inclusion criteria were: 1- More than 5 mm of transverse discrepancy; 2- Bilateral posterior crossbite; 3- No periodontal disease or mobility of teeth; 4- good oral hygiene 5- Absence of syndromes or cleft lip and palate; 6- No systemic diseases; 7- No history of orthodontic treatment or maxillofacial trauma ; 8- No smoking; 9- No medications that may affect metabolism of the bone; 10- No tumours or airway diseases.

Full orthodontic records including intraoral and extraoral photographs, study models and cone beam scans were obtained for the patients preoperatively (T1) and after 6 months postoperatively (T2) .

A short phase of orthodontic preparation was performed to allow for divergence of the upper central incisors. Pre-operatively, one week before the surgery, a hyrax expander appliance (DENTAURUM GmbH & Co., Ispringen, Germany) was constructed and cemented to the maxillary first premolars and first permanent molars using light-cured glass ionomer-resin cement then fixed with a 1.2 mm wire. It was checked for proper fitting and any discomfort (Figure 1).

FIG (1) Showing Hyrax expander cemented on the teeth before surgical intervention

Surgical Procedure

The surgical operation was performed under general anesthesia with nasotracheal intubation by an oral and maxillofacial surgeon at the Department of Oral and Maxillofacial Surgery, Cairo University.

Following a submucosal injection of a vasoconstrictor, a horizontal mucoperiosteal incision was performed 3-5mm above the level of the attached gingiva extending from the 1st molar of one side to the first molar of the other side . A full thickness mucoperiosteal flap was elevated exposing the anterior nasal floor and the piriform aperture anteriorly and the dissection was continued posteriorly towards the pterygomaxillary fissure. The technique involved a Lefort I osteotomy without down fracture of the maxilla. Lateral maxillary osteotomies were done 5 mm above the apices of the maxillary teeth using a 702 tapered fissure bur, extending from the piriform rim anteriorly to the pterygomaxillary fissure posteriorly. The procedure was performed bilaterally after which pterygomaxillary disjunction was done using a curved osteotome to facilitate the posterior lateral expansion of the maxilla. Then a midline osteotomy was performed between the maxillary central incisors using a bibevelled chisel to separate the intermaxillary suture followed by extending the osteotomy posteriorly towards the posterior nasal spine, separating the midpalatal suture. To ensure that complete separation of the mid-palatal suture was carried out, the hyrax palatal expander was activated by opening until reaching the maximum amount of aperture and a diastema appeared **(Figure 2)**; then it was deactivated with immediate regression, leaving 1 mm gap and the flap was sutured in place. Prophylactic antibiotic (Clindamycin 600 mg) and dexamethasone was prescribed on the preoperative day and one hour before surgery and continued every 12 hours postoperatively. The patients were instructed to be on soft diet for 1 month postoperatively with strict oral hygiene measures.

After a latency period of 5 days, the patients were instructed to activate the screw twice daily with one-quarter of a turn per time (0.25mm) to give a total value of activation of 0.5 mm/day [1]. Patients were instructed how to perform expansion at the same timing everyday, with 12-hours

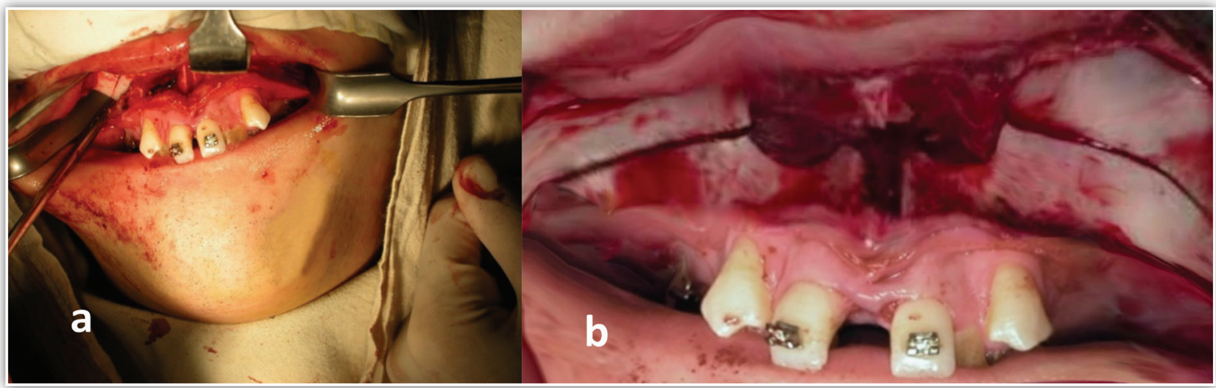

FIG (2a and 2b) Showing maxillary Lefort I and midpalatal suture cuts interval between activations. Expansion continued until over-correction of the crossbite was done until the palatal cusps of the maxillary molars occluded with the buccal cusps of the mandibular molars. The patients were monitored 3 times weekly for ensuring appropriate activation of the appliance. After expansion was complete (Figure 3), the screws were locked with a ligature wire and flowable composite and hyrax was left in place for stabilization for 6 months. For measurement of outcomes, the hyrax expander was then removed and patients undertook the second CBCT scan (T2) utilizing the same standardization method as the initial scan. Orthodontic treatment was continued for all the patients post-expansion.

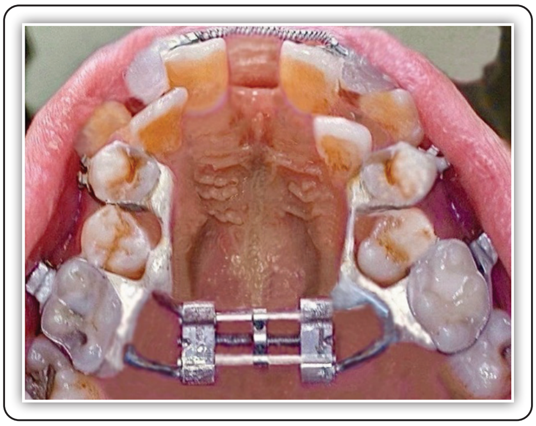

FIG (3) Showing completed palatal expansion

CBCT scans were performed using the same device (ProMax 3DMid, Proface, MaxPLANMECA, Helsinki, Finland) with parameters set at 12.5mA and 90 kV, total scan time of 9 sec with 360◦ rotation, Voxel size 200 um and image size 20.1 x 17.5cm. The field of view extended superiorly from the glabella and inferiorly to the 3rd cervical vertebra. The scans were taken with the patients in erect posture maintaining natural head position. Head position was supported laterally by the device's stabilizers, keeping Frankfort horizontal plane (FHP) parallel to the ground.. All patients were requested to occlude their teeth in centric occlusion, lips relaxed, tongue resting against the palate, stop swallowing and breathing during image acquisition. The Dicom (Digital Imaging and Communications in Medicine) files were extracted from the CBCT disks and then imported into Planmeca Romexis software version 5.3.5.80 (Asentajankatu 6- HELSINKI- Finland) for volumetric assessment) whereby coronal and sagittal reformatting was done, and a three-dimensional image was computed. The three dimensional model was then adjusted based on the reference planes displayed in Table (1).

The nasopharyngeal airway space is a small triangular section bound by the landmarks highlighted in Table (1) (Figure 4).

TABLE (1) The definitions of tomographic anatomical boundaries

	Anterior limit	Posterior limit	Superior limit	Inferior limit
Nasopharyngeal airway volume - cm^3	Line connecting the posterior nasal spine (PNS) to pterygomaxillary point (PTM)	The posterior wall of the pharynx		Line perpendicular to midsagittal plane passing through PNS
Oropharyngeal airway volume - cm3	The posterior border of the soft palate, tongue and uvula	The posterior wall of the pharynx	Line perpendicular to midsagittal plane passing through PNS	Line perpendicular to midsagittal plane intersecting C3ia
Minimum cross-sectional area -cm^2	The minimum cross-sectional area through the total airway region			

PNS: Posterior nasal spine CV2: Atlas vertebra (Second cervical vertebra)
CV3ia: Most inferior anterior point of third cervical vertebra (CV3)

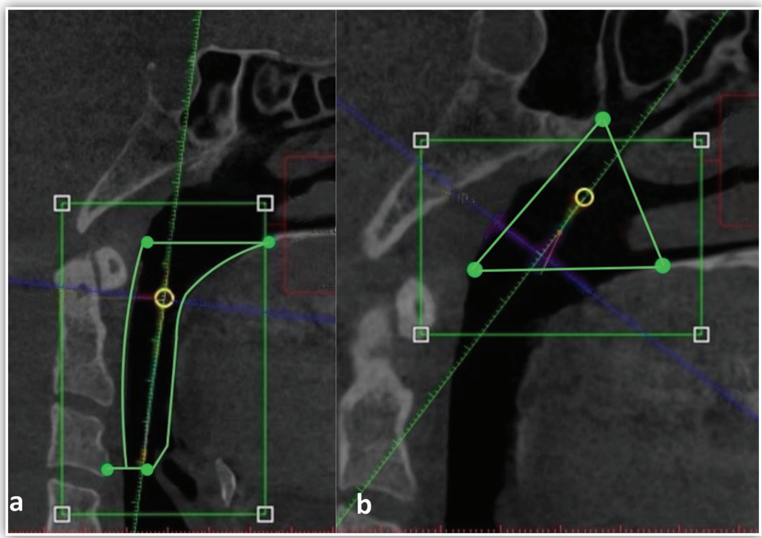

FIG (4a and 4b) Showing oropharyngeal and nasopharyngeal anatomic landmarks

The MPR (Multiplanar reformatted images) screen was utilized in aligning midsagittal plane with the middle of the nasal cavity which divided the axial cut into two equal segments. Afterwards, the airway assessment tool was used for volumetric rendering on the 3D volume rendered screen, through the selection of consecutive anatomic landmarks then performing a double click to display the nasopharyngeal and oropharyngeal airway volume automatically in cm^3. The darkest zone on the image indicated the airway (Figure 5,6).

The oropharyngeal smallest cross-sectional area was measured automatically in cm^2 using the predefined superior and inferior limits and a two-dimensional tool of the software (Figure 7).

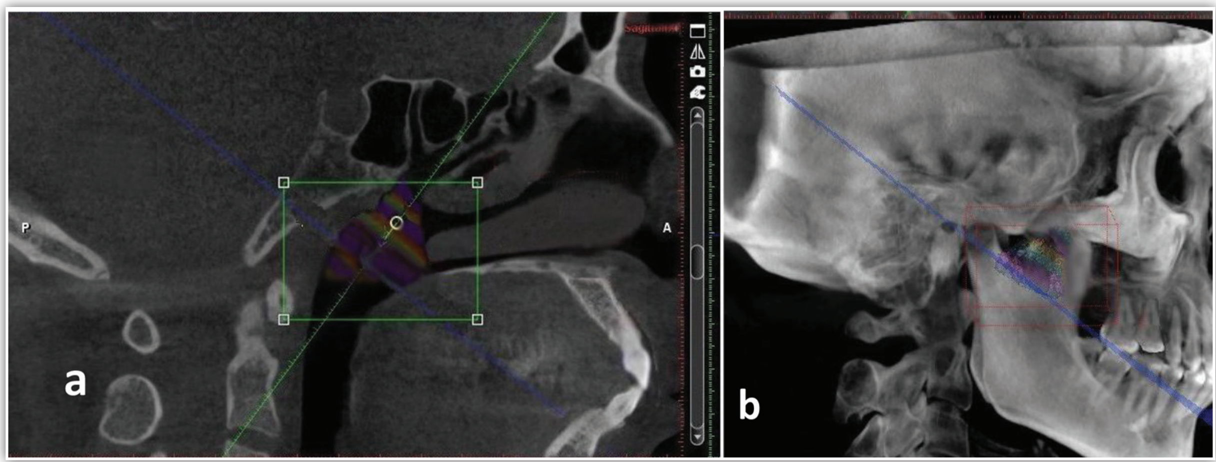

FIG (5a and 5b) Showing nasopharyngeal airway dimensions and 3D volume

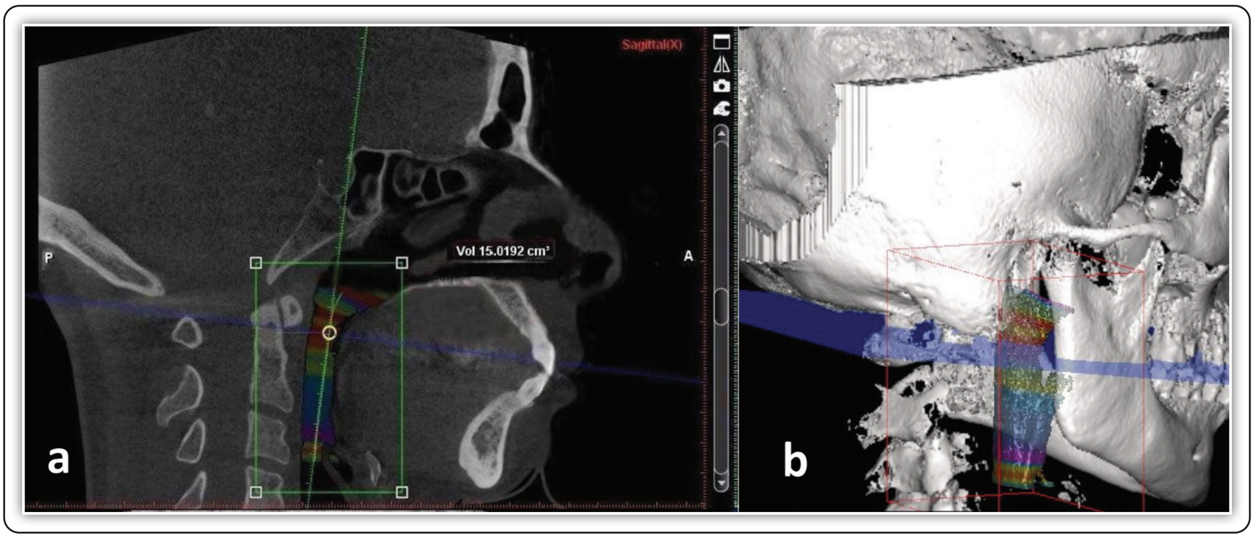

FIG (6a and 6b) Showing oropharyngeal airway volume

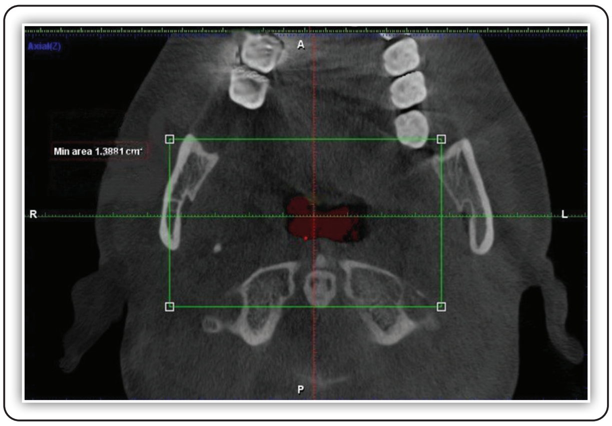

FIG (7) Showing minimum cross-sectional area of the oropharynx

Volumetric measurements and cross-sectional area were calculated and the values were entered in an excel sheet for statistical analysis. All measurements were repeated by the same observer after 2 weeks to assess the intra-observer reliability. The measurements error was calculated by intraclass correlation coefficient (ICC) . An ICC value >0.75 indicates excellent reliability.

Sample size calculation

A power analysis was designed to have adequate power to test null hypothesis that there is no difference between the pre and post-treatment measurements regarding airway cross-sectional area and volume. By adopting alpha (α) level of (5%), β level of 0.8 (Power = 80%); the effect size (d) for paired t-test of (0.875) calculated based on the results of a previous study (Vinha et al, 2016) [16] the minimum estimated sample size was 13 cases. Sample size calculation was performed using G*Power Version 3.1.9.2.

Statistical Analysis

Numerical data were explored for normality by checking the distribution of data and using tests of normality (Kolmogorov-Smirnov and Shapiro-Wilk tests). All data showed normal (parametric) distribution. Data were presented as mean and standard deviation (SD) values. Paired t-test was used to study the changes of each outcome. The significance level was set at $P \leq 0.05$. Statistical analysis was performed with IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp.

RESULTS

Treatment changes after 6 months of SARPE (T2) are displayed in Table (2) (Figure 8,9).

There was a statistically significant increase in minimal cross sectional area, oropharyngeal airway volume as well as nasopharyngeal airway volume at T2 (*P*-value <0.001) for each measurement, respectively.

TABLE (2) The mean, standard deviation (SD) values and results of paired t-test for comparison between measurements at T1 and T2

Measurement	T1 (n = 13)		T2 (n = 13)		Difference		*95% Confidence Interval for the difference*		*P*-value
	Mean	SD	Mean	SD	Mean	SD	Lower limit	Upper limit	
Minimal cross sectional area (cm^2)	1.38	0.16	2.1	0.25	0.72	0.24	0.58	0.87	<0.001*
Oropharyngeal airway volume (cm^3)	15.01	2.43	18.79	2.65	3.78	0.55	3.45	4.12	<0.001*
Nasopharyngeal airway volume (cm^3)	5.17	0.59	6.53	0.47	1.36	0.21	1.24	1.49	<0.001*

*: *Significant at* $P \leq 0.05$

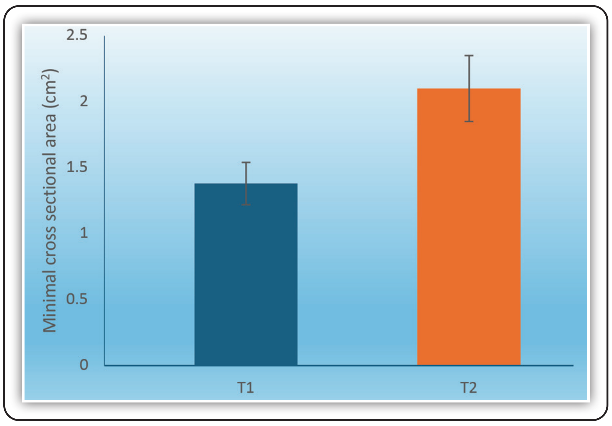

FIG (8) Bar chart representing mean and standard deviation values for minimal cross sectional area at T1 and T2

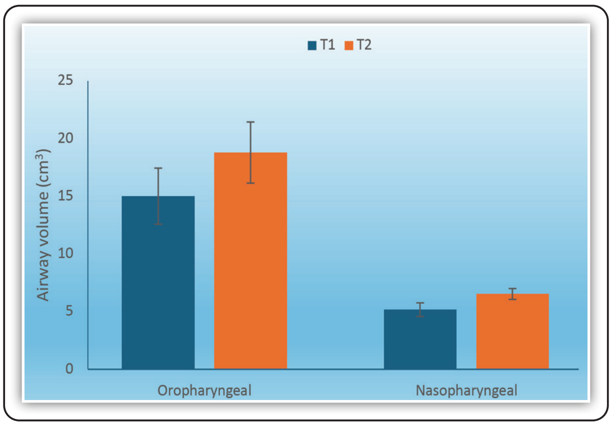

FIG (9) Bar chart representing mean and standard deviation values for airway volume measurements at T1 and T2

DISCUSSION

There is a close correlation between pharyngeal airway and craniofacial structures, therefore assessment of the pharyngeal airway volume is important for many specialists such as orthodontists, pediatric dentists, speech and ENT therapists. The anatomic proximity of the pharynx to the oral cavity advocates that any alteration in the intraoral volume can change the oropharyngeal dimension(16). The effects of surgical correction of dentofacial deformities on the upper airway has gained wide attention. Typically, maxillary and mandibular surgical advancement are sought for to treat OSA. Data associated with isolated maxillary expansion for the treatment of OSA is important to consider(9). It has been revealed by previous studies that maxillary expansion not only fixes the posterior crossbite in skeletally mature patients, which betters both skeletal and dental transverse relationships, however it also increases pharyngeal airway volume thus positively impacting the respiratory capacity of breathing as well as speech(17). It is believed that the widened maxillary bone releases the constricting effect on the upper airway(18). This can be beneficial for patients with OSA as documented by earlier studies(16).

It is interesting to note that some studies which adopted miniscrew anchored rapid palatal expansion (MARPE) yielded successful results in improving the volume of the nasopharynx with stable results one year after treatment[19]. Also, traditional RME resulted in increased nasopharyngeal volume[20]. Regarding oropharyngeal volume, some studies reported an increase that was not statistically significant[21]. Whereas others showed a statistical significant increase following RME[22] . Conversely, others reported no increase in the volume of the nasopharynx following RME by 4 months [23,24] . This has been elucidated by the fact that RME occurs more anteriorly than posteriorly[25,26]. Regarding the oropharyngeal volume with MARPE, a previous study reported no significant changes[27].

Similar controversies exist regarding the results of SARPE on nasopharyngeal and oropharyngeal dimensions. Buck et al[28] presented a systematic review on the effects of surgically-assisted rapid maxillary expansion (SARME) on the upper airway volume and concluded that the effects of SARME on the respiratory function still needed to be evaluated. Hence, this study was conducted.

The results of this study revealed a significant increase in the nasopharyngeal and oropharyngeal volumes as well as the minimum cross-sectional area of the oropharynx 6 months following SARME. This could be attributed to the change that occurred in the tongue position. SARME provides a parallel and uniform palatal expansion especially posteriorly which influences the palatal muscles [29]. Alterations in the position of these muscles may influence the retropalatal airway dimensions. Furhermore, the widening of the dental arch and bone bases due to expansion led to anterior displacement of the tongue in the oral cavity[9,22]. Aligned with these results is the study by Romulo et al [26] who reported an increase in oropharyngeal minimum cross-sectional area (OMCSA) that was statistically significant. Heildmaier et al [30] also reported significant increase in nasopharyngeal volume. Similarly, Akay et al [31] discovered a significant increase in the smallest distance from the tongue to the posterior limit of the oropharynx following SARME. There was also an increase in the nasopharyngeal airway dimensions. A study by Vinha et al[16] reported changes in the pharyngeal dimensions whereby the medium and the inferior parts of the pharynx increased transversely after SARME with pterygomaxillary disjunction ($P < 0.001$). Correspondingly, Liu et al [32] found an increase in the volume and the minimum cross-sectional area (MCA) following SARPE ($P<.05$). Additionally, Yazigi et al[33] documented a total upper airway increase which was significant 3 months after retention.

The results of our study also correlate with those of Medeiros who compared two variable techniques with SARME, with and without pterygomaxillary disjunction and found significant volumetric increases in the nasopharynx and oropharynx following hyrax stabilization in the pterygomaxillary disjunction group 6 months after stabilization. It is also in agreement with the study by Vinha et al [16], who declared that SARME contributed to pharyngeal enlargement particularly in the lower pharyngeal levels. Conversely, our results did not agree with those by Pereira-Filho et al[10] et al who reported no significant differences in the total airway volume 6 months following expansion. However they witnessed immediate post-expansion increase in the airway volume. They also found a statistically significant increase between the preoperative and postoperative smallest transverse section area after 6 months. This could be due to the different demarcation of the upper airway and the assessment methods. Likewise, in the study of Kurt et al[34] no significant differences were found in the nasopharyngeal airway dimensions after SARME. This could be attributed to the different surgical technique employed as well as different radiographic methods used for investigation which were 2-dimensional rather than 3-dimensional. Several factors may exist that cause variations in the measurements and results between the different studies. For example, amount of transverse discrepancy, patient positioning, tongue position[35], different population, and the type of software used[5].

We regard the methodology implemented in this study easy to standardize, allowing acquisition of reproducible and comparable measurements between the times studied, as well as with other studies. The advantages were emphasized in a systematic review conducted in 2011[36] as being fast, provides low dose of radiation, and easy of accessibility to the minimum cross-sectional area and the volumetric measurements of the upper pharyngeal airways.

During image acquisition in our study, the patients were asked not to swallow to reduce the tongue effect on the oropharynx. They were also requested to hold their breath at the end of expiration as this guarantees a static pharyngeal airway size, which can be documented consistently in all CBCT scans[33]. Our study was conducted on non-growing patients to exclude any effect of growth on the airway. There was a waiting period of approximately 6 months following palatal expansion completion in order to increase the stability of the results and also to allow adaptation of the oropharyngeal muscles including the tongue to the new oral space. Furthermore, this minimized any side effects due to surgical scarring and enough time had elapsed to allow for healing[16].

Three dimensional imaging as well as 3D reconstruction softwares[37,38] made it possible for researchers and clinicians to visualize and precisely measure alterations in the maxillofacial region[39]. However, only a few studies utilized three-dimensional methodologies to emphasize the understanding of the effects of SARPE on the airway[40]. Therefore, this study aimed to evaluate the airway changes that result from surgically assisted rapid palatal expansion (SARPE) using CBCT.

Surgical expansion of the maxilla could be carried out either through segmental Le Fort I osteotomy or by surgically assisted maxillary expansion. If the maxillary position needs correction in the three dimensions, then Lefort I with downfracture is opted for. SARPE is a more simple procedure and has been proven as a stable and efficient method[2,4,5,7]. We performed pterygomaxillary disjunction to facilitate transverse maxillary expansion as it has been previously denoted that absence of pterygoid plate separation results in non uniform maxillary expansion[23].

CONCLUSIONS

Surgically assisted rapid palatal expansion (SARPE) resulted in a significant increase in the volume of the nasopharyngeal and oropharyngeal airways as well as the minimum cross-sectional area of the oropharynx. Therefore, this treatment modality can be beneficial to improve respiratory capacity in patients with transverse maxillary constriction and obstructive sleep apnea.

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