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A Prospective Evaluation of Pharyngeal Airway Changes After Surgical Correction of Skeletal Class II Malocclusion - A CBCT Study

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Abstract

Background: Mandibular advancement and maxillary impaction surgeries are performed to treat the skeletal class II malocclusion. These surgeries have impact on the pharyngeal airway space. CBCT being a 3-dimensional imaging technology can provide the volumetric details and also can provide the linear measurements.

Objectives: The aim of the study was to evaluate the pharyngeal airway changes after surgical correction of skeletal class II malocclusion using CBCT. The volume & Area in coronal, sagittal & axial plans of entire pharyngeal airway were evaluated & compared before & after surgical correction.

Methodology: A total of 12 individuals, aged between 16 - 35years with Skeletal Class II malocclusion were selected, who were included in two groups: Group 1: Class II malocclusion patients requiring mandibular advancement with genioplasty. Group 2: Class II malocclusion patients requiring vertical impaction of maxilla with genioplasty. All the 12 patients were subjected to CBCT scan pre- and post- surgery. Data regarding the Volume and Area of the airway was recorded.

Results: For group 1 Area of the airway were increased post- surgically. There was decrease in Volume of the airway post- surgically. For group 2 Volume of the airway were increased post- surgically. There was decrease in Area of the airway post surgically.

Conclusion: The Mandibular advancement Surgery & Maxillary Superior Impaction surgery with Mandibular autorotation, results in an increased Area & Volume of the pharyngeal airway space.

Keywords: CBCT, Mandible advancement surgery, Maxillary impaction surgery, Pharyngeal airway.

1. Introduction

The Pharyngeal Airway (PA) being the vital structure connecting the oral & nasal compartments to the lungs, creates a path for the exchange of respiratory gases. It is composed of three parts; i.e., the nasopharynx, oropharynx, and hypopharynx. The nasopharyngeal airway (NA) is a cone-shaped tube that consists of muscles and mucosa. It also includes the adenoid, a complex network of lymphatic tissues located in the posterior area, which produces antibodies, or white blood cells, that help fight infections. Typically, the adenoids undergo involution during adolescence and may disappear by adulthood. In growing children, predisposing factors, repeated infection, or inflammation usually led to adenoid hypertrophy and constriction of the posterior airway. 1 However adenoid enlargement persists into adulthood in some individuals. The oropharyngeal airway (OA) lies between the soft palate and the hyoid bone. Many reports have demonstrated a relationship between various malocclusion patterns and variations in the size and form of the oropharyngeal airway caused by palate and/or tongue position.2,3 Normal respiratory activity has an influence on the growth of maxillofacial structures, favouring their harmonious growth and development. The presence of any obstacle in the respiratory system, i.e. in the nasal and pharyngeal regions, causes respiratory obstruction and forces the patient to breathe through the mouth.4 Vertical discrepancies include maxillary vertical deficiency, maxillary vertical excess & open bite which has characteristics like increased total facial height due to an increased lower facial height, mandible rotated downwards & backwards, increased interlabial distance, increased maxillary incisor exposure, sunken cheeks & gummy smile. Skeletal Class II patients due to mandibular retrusion have a narrower anteroposterior pharyngeal dimension, specifically in the nasopharynx at the level of the hard palate and in the oropharynx at the level of the tip of the soft palate and the mandible.5 Orthodontists have attempted to limit vertical dimension increases in growing patients by one or more of the following approaches: (1) high-pull head- gear with or without a splint, (2) extraction therapy, (3) bite-blocks (passive or active), (4) vertical-pull chin- cup, and (5) any combination thereof. In case of non -growing patients molar intrusion, maxillary superior repositioning with mandibular auto rotation surgery, with or without genioplasty is a popular option.14 In the hierarchy of orthognathic surgeries based on UNC data bases maxillary superior repositioning is the most stable procedure followed by mandibular advancement.16 Surgical movement of the maxilla and mandible to correct dentofacial deformities will affect the position of the musculature and soft tissue attached to these structures. The position and tension of the tongue, lips, soft palate, and hyoid bone will inevitably change as their associated skeletal structures are moved6 , and this influences the size of the total nasal airway, oral cavity, and the pharyngeal airway volume and shape. Mandibular advancement via bilateral sagittal split osteotomies (BSSO) has also been shown to significantly improve oropharyngeal dimensions of the airway and effectively treat obstructive sleep apnea (OSA).8 Most of the previous studies of the pharyngeal airway and malocclusion, as well as facial morphology, have been carried out using a two-dimensional (2D) lateral cephalogram.9 It is difficult to obtain precise sizes of the airway and to reproduce the soft tissue structures accurately from lateral cephalograms alone, due to the superimposition of the right & left structures in lateral cephalogram. Cone-beam computed tomography (CBCT) provides 3Dreconstructed images from multiple sequential planar projection images. Thus, making it possible to visualize sites of interest by adjusting the image orientation and rotation. CBCT along with computer software capable of rendering volumetric data and segmenting different areas of the airway, helps clinicians and researchers evaluate changes in the airway that occur in response to orthodontic and orthognathic treatment and impact breathing quality.12 The following Research Hypothesis is proposed: Surgical procedures like maxillary superior repositioning & mandibular advancement led to increase in airway volume.

The objectives of the study are:

1. To Evaluate the airway following surgical correction of patients with Skeletal class II mandibular retrusion malocclusion before and after BSSO mandibular advancement & genioplasty.
2. To Evaluate the airway following surgical correction of patients with Skeletal class II Open bite malocclusion, before and after Maxillary Le Forte I superior Impaction with mandibular autorotation & genioplasty.
3. To compare the airway changes between the abovementioned surgical modalities.

Materials and methods

A total of 12 individuals, aged between 16 - 35years with Skeletal Class II malocclusion were selected. Detailed clinical examination & written consent was obtained from all the individuals. Ethical clearance for the study was obtained from the Institution (Ref no.CODS/IEC/1828/2016-1017). The individuals were divided into two groups of 6 subjects each according to the surgical procedure performed. Group 1: Skeletal Class II malocclusion patients with mandibular skeletal retrusion, requiring mandibular advancement & genioplasty Group 2: Skeletal Class II malocclusion patients with skeletal vertical maxillary excess requiring vertical impaction of maxilla & genioplasty

Inclusion criteria

1. Individuals between 16 - 35years of age.
2. Skeletal Class II malocclusion patients with anterior open bite needing surgical Le Forte I impaction of the maxilla & genioplasty
3. Skeletal Class II malocclusion patients due to mandibular retrusion needing BSSO mandibular advancement & genioplasty.

Exclusion criteria

1. Previous history of orthodontic /orthognathic intervention.
2. Medically compromised or syndromic individuals.

Methodology

Sample size estimation was done using the formula n = Z2 pq / e2 , where n = number of subjects in each group. Z = critical value at 95% confidence level. p = prevalence of significance. q = prevalence of non-significance. e = margin of error.

12 Patients, 6 each, who reported to the Department of Orthodontics and were planned for treatment with either Mandibular advancement with Genioplasty OR Maxillary Vertical Impaction with Genioplasty for treatment of Skeletal Class II MO, were selected. All necessary records like facial photographs, Lateral Cephalograms and study models were taken and a thorough planning procedure was followed for each case.

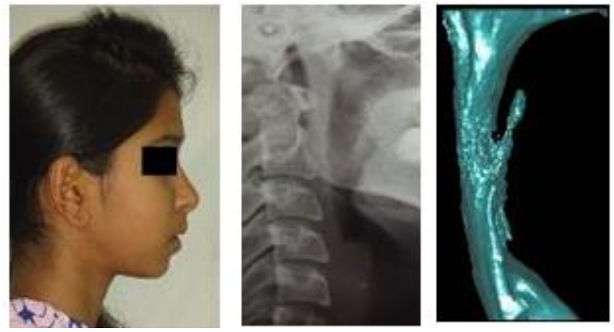
After identification of the subjects based on inclusion criteria and exclusion criteria.

Six patients fulfilling the criteria for Group I & six patients fulfilling the criteria for Group II were shortlisted. All the 12 patients were subjected to CBCT scan (Planmeca, Topamax) before surgery and immediately after surgery.

The patients were seated in the upright position. The Frankfort horizontal plane was parallel to the floor. Head orientation was the same for each CBCT image performed by the same experienced operator. The patients were asked not to swallow during the scan (Figure 1).

Figure 1: Patient position and orientation during CBCT imaging. The maxillo- facial regions were scanned for 19 seconds using a CBCT machine with a FOV of 8x11, kvp 90, 10 mA used to view, analyze, and manipulate the CBCT scans. CBCT evaluation was done using inbuilt software (Romaxies- v.3.6.1) to perform the volumetric analysis of the airway & area of the entire pharyngeal airway space region using coronal, sagittal & axial slices were determined for both Group 1 (Figure 2-3) and Group 2 (Figure 4-5).

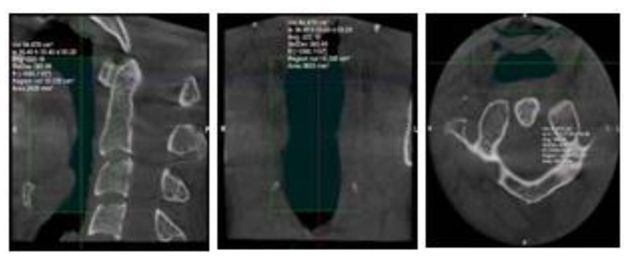
A specific standardized area was defined to measure the changes in the pre- and post-operative airway. The polygon was formed by landmarks joining PNS, cervical vertebrae, hyoid, soft palate & the base of tongue. The superior the superior border was bounded by a line from the PNS to the most antero-superior point of the 2nd cervical vertebrae (C2). The inferior border, which is parallel to the superior border is formed by joining the most antero-inferior point of 4th cervical vertebrae to the postero-inferior point of body of the hyoid. The anterior border comprised the posterior soft palate and the base of tongue. The posterior border was the posterior pharyngeal wall.



(A)

(B)

Figure 2: (A) A patient included under Group 1. (i) pre-surgical photograph, (ii) lateral cephalogram and (iii) 3D volumetric construction of airway using CBCT. (B) A patient included under Group 1. (i) postsurgical photograph, (ii) lateral cephalogram and (iii) 3D volumetric construction of airway using CBCT



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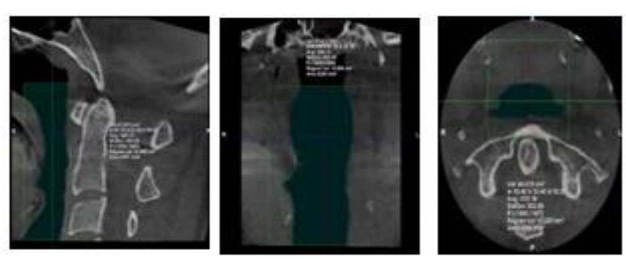


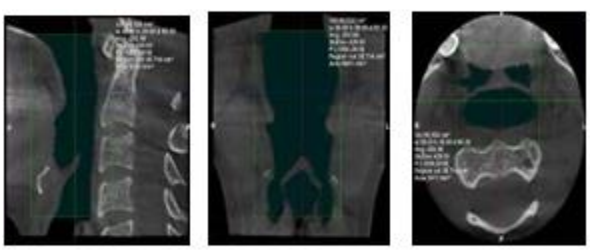
(B)

Figure 3: (A) Pre-surgical CBCT images of patient under Group 1 in (i) Sagittal, (ii) Coronal and (iii) Axial sections. (B) Post-surgical CBCT images of patient under Group 1 in (i) Sagittal, (ii) Coronal and (iii) Axial sections.

(A)

(B)

Figure 4: (A) A patient included under Group 2. (i) pre-surgical photograph, (ii) lateral cephalogram and (iii) 3D volumetric construction of airway using CBCT.



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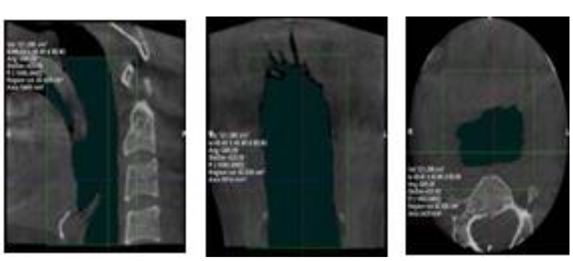


(B)

Figure 5: (A) Pre-surgical CBCT images of patient under Group 2 in (i) Sagittal, (ii) Coronal and (iii) Axial sections. (B) Post-surgical CBCT images of patient under Group 2 in (i) Sagittal, (ii) Coronal and (iii) Axial sections.

Results

The Dicom images are were accessed with Romexis software version 3.6.1. The imported Dicom files were viewed in explorer tab. The axial plane was oriented to determine the height of the region. The sagittal was oriented to determine the anterior extent of the airway. The superior-anterior border was marked at C4, all the three planes were oriented in X, Y & Z axis. The Region growing tool in the software was marked in all the three planes from superior landmark to the inferior landmark. The marked area was assessed for volume by region growing tool. The software provides the volume of the marked region within the specified area. Automatic readings are obtained and displayed on the monitor. The readings determine height, width and depth. With the delimitation of the polygon, the software generated the image and measured the Volume of the airway & Area of the entire pharyngeal airway space region using coronal, sagittal & axial slices. Data were tabulated & analyzed using Paired sample t-test & Independent sample t-test.

	N	**V** (in mm^3)	**C** (in mm^2)	**S** (in mm^2)	**A** (in mm^2)
Pre-surgical CBCT	06	8607.0	4498.83	2034.166	612.5000
Post-surgical CBCT	06	12157.8	6031.00	3099.666	1141.333

Table 1: Mean Values obtained for all the Volume & Area for Group I. (N- total number of samples, V Volume, C- Area in Coronal section, S- Area in sagittal section, A- axial section).

	N	V (in mm^3)	C (in mm^2)	S (in mm^2)	A (in mm^2)
Pre-surgical CBCT	06	19635.2	6360.833	4049.500	1763.833
Post-surgical CBCT	06	23936.8	8119.83	4513.666	1903.333

Table 2: Mean Values obtained for all the Volume & Area for Group II. (N- total number of samples, VVolume, C- Area in Coronal section, S- Area in sagittal section, A- axial section)

Parameters	Mean	SD	t	p- value
$V_{pre} - V_{post}$ (in mm^3)	-3550.83	4.23747	-2.053	P<0.095, NS
$C_{pre} - C_{post}$ (in mm^2)	-1532.16667	1456.60158	-2.577	P<0.050, HS
$S_{pre} - S_{post}$ (in mm^2)	-1065.50000	567.34355	-4.600	P<0.006, HS
$A_{pre} - A_{post}$ (in mm^2)	-528.83333	400.85230	-3.232	P<0.023, HS

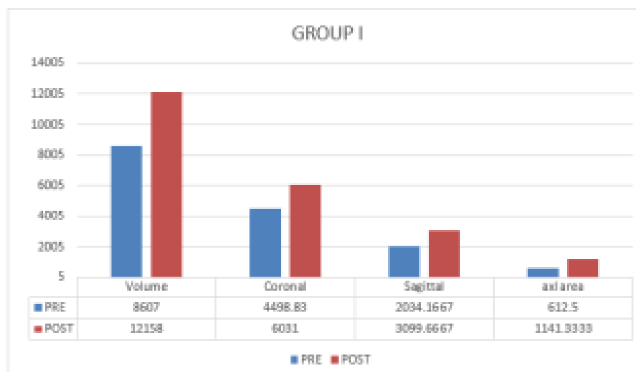
Table 3: Paired sample t- test for Group 1. (SD- standard deviation, t – paired 't' test parameter, V- volume, Ccoronal plane, S- sagittal plane, A- axial plane, pre-presurgical CBCT parameter, post– post-surgical CBCT parameter, NS- not significant, HS- highly significant).

Parameters	Mean	SD	t	p- value
$V_{pre} - V_{post}$ (in mm^3)	-4301.67	3.96680	-2.656	P<0.045, HS
$C_{pre} - C_{post}$ (in mm^2)	-1759.00000	5150.96414	-0.836	P<0.441, NS
$S_{pre} - S_{post}$ (in mm^2)	-464.16667	1549.36418	-0.734	P<0.496, NS
$A_{pre} - A_{post}$ (in mm^2)	-139.50000	681.47069	-0.501	P<0.637, NS

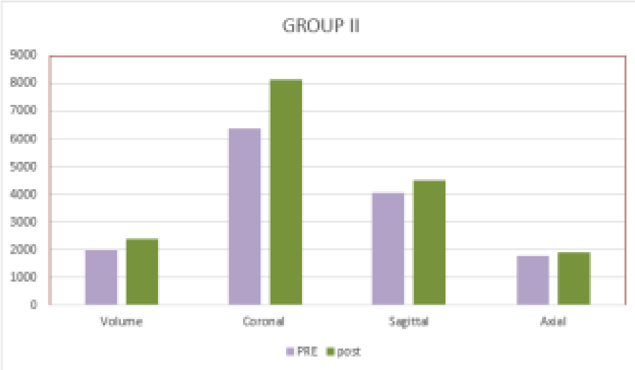
Table 4: Paired sample t- test for Group 2. (SD- standard deviation, t – paired 't' test parameter, V- volume, Ccoronal plane, S- sagittal plane, A- axial plane, pre-presurgical CBCT parameter, post– post-surgical CBCT parameter, NS- not significant, HS- highly significant)

Parameters	Group	Mean	SD	T	p- value
V_{pre} (in mm^3)	Group 1	8.6070	3.13840	-2.825	P<0.018, HS
	Group 2	19.6352	9.03434		
V_{post} (in mm^3)	Group 1	12.1578	1.60412	-3.379	P<0.007, HS
	Group 2	23.9368	8.38645		
C_{pre} (in mm^2)	Group 1	4498.8333	1387.07901	-1.098	P<0.298, NS
	Group 2	6360.8333	3915.98261		
C_{post} (in mm^2)	Group 1	6031.0000	1442.20068	-1.947	P<0.080, NS
	Group 2	8119.8333	2197.11879		
S_{pre} (in mm^2)	Group 1	2034.1667	332.15142	-5.279	P<0.000, HS
	Group 2	4049.5000	874.18711		
S_{post} (in mm^2)	Group 1	3099.6667	687.59717	-1.948	P<0.080, NS
	Group 2	4513.6667	1639.42010		
A_{pre} (in mm^2)	Group 1	612.5000	389.51495	-4.989	P<0.001, HS
	Group 2	1763.8333	409.65762		
A_{post} (in mm^2)	Group 1	1141.3333	507.48741	-2.522	P<0.030, HS
	Group 2	1903.3333	538.66267		

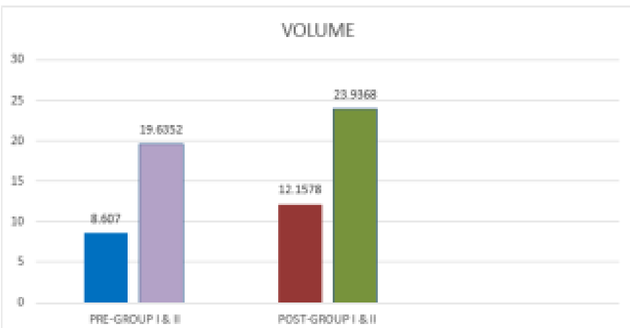
Table 5: Unpaired sample t- test for each parameter under volume and area for both the groups. (SD- standard deviation, t – paired 't' test parameter, V- volume, Ccoronal plane, S- sagittal plane, A- axial plane, pre- presurgical CBCT parameter, post– post-surgical CBCT parameter, NS- not significant, HS- highly significant)



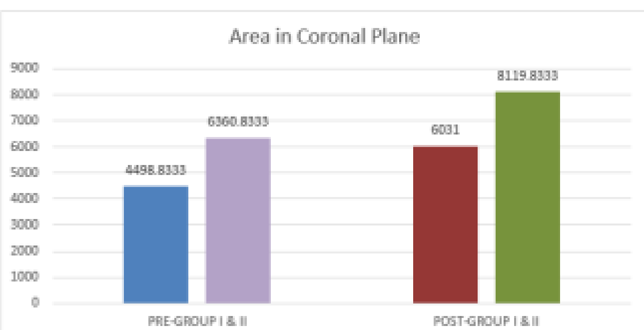
Graph 1: Demonstrating the paired t-test for Group I. The values of all the Volume and Area in coronal, sagittal & axial planes for pre- and post- surgical CBCT were used to bar a graph. BLUE BARS- Pre-surgical, BROWN BARS- Post-surgical.



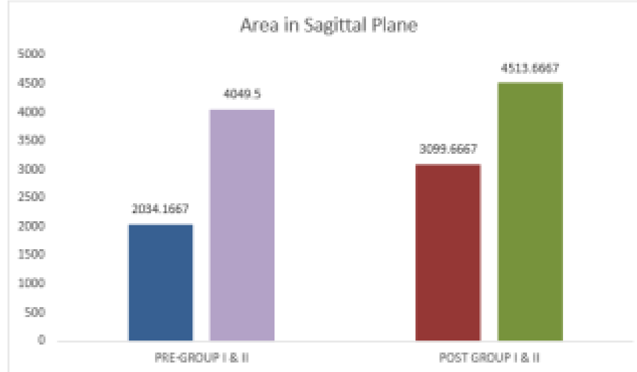
Graph 2: Demonstrating the paired t-test for Group II. The values of all the Volume and Area in coronal, sagittal & axial planes for pre- and post- surgical CBCT were used to bar a graph. PURPLE BARS- Pre-surgical, GREEN BARS- Post surgical.



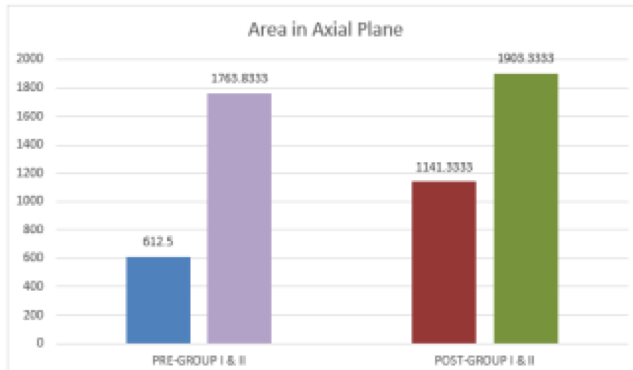
Graph 3: Mean Regional Volume of the airway pre- and post- surgically in Group 1 and Group 2. (All values are in mm3).



Graph 4: Mean Area of the airway in coronal plane preand post- surgically in Group 1 and Group 2. (All values are in mm3).



Graph 5: Mean Area of the airway in sagittal plane preand post- surgically in Group 1 and Group 2. (All values are in mm3).



Graph 6: Mean Area of the airway in axial plane pre- and post- surgically in Group 1 and Group 2. (All values are in mm3).

Discussion

Researchers have shown that respiratory function influences craniofacial growth and occlusion. Impaired nasal respiratory function is associated with airway inadequacy, which can result in mouth breathing. This change in breathing pattern leads to lowering of the mandible and the tongue and an extended head posture. These postural changes are reflected in changes in craniofacial growth and anomalies of dental position. Downward and backward rotations of the mandible have been observed in growing children with upper airway obstruction caused by enlarged adenoids, and the treatment of nasal obstruction in growing patient's results in a more normal pattern of dentofacial development.49 Orthognathic surgery aims to restore proper dental occlusion and facial harmony through the modification of the position, shape, and size of the facial bones. Bone movement implies secondary positional and tensional changes in the attached soft tissues. These new soft tissue relationships introduce significant changes in the facial appearance and, in addition, in the entire pharyngeal airway space dimensions.5 Mandibular advancement surgery has been shown to be very efficacious in the elimination of obstructive sleep apnea (OSA) because it enlarges the pharyngeal airway space (PAS), and tightens the upper airway muscles and tendons.44 Favorable improvement of OSA can be achieved with maxillomandibular advancement. An increase in the PAS is achieved by the advancement of the skeletal attachment of the suprahyoid and velopharyngeal muscles and tendons. Moreover, when a counter-clockwise rotation of the maxillomandibular complex is performed in patients with high occlusal plane morphology, the genial tubercles move forward more than the teeth, thereby maximizing the advancement of the hyoid bone, base of the tongue, and related soft tissues.44 The advent of cone-beam CT (CBCT) has provided the chance to evaluate the airway using a non-invasive, rapid, low radiation scan. CBCT has proved to be a practical technique for the quantitative assessment of the PAS, with important advantages over other current scanning systems. It is fast scanning (60-90second) technique that is more cost-effective than other systems such as spiral CT or magnetic resonance imaging.39 CBCT is highly accurate in its measurements, the images are not distorted, and the relative range of the CT units for different tissues provides a method to rapidly segment the airway. CBCT achieves highly correlative linear, cross-sectional area and volumetric measurements in addition to morphometric analysis of the airway. While acquiring CBCT images, the narrowest region in an awake subject, sitting upright and breathing quietly, is located chiefly in the oropharynx. Thus, making it quite efficient to evaluate the changes in oropharyngeal airway space.32 CBCT is being used extensively in daily practice by orthodontists. In spite of drawbacks like radiation exposure & cost it has one of the key advantages of CBCT over 2D radiography is its ability to provide 3D volumetric, surface and sectional information about the craniofacial structures. This has enabled orthodontists and researchers in the field to overcome the substantial limitations of 2D radiographs, including magnification, geometric distortion, superimposed structures and inconsistent head position. It allows the visualization of internal anatomic structures, like the upper & lower airway, by eliminating external structures. It also provides the linear, angular, planar as well as volumetric analyses.10, 11 Cephalometry was widely used to quantify airway space until the past decade. Aboudara et al. 53 compared airway assessments using cephalometry and CBCT and found that cephalometric precision was low due to great variability of this region. Thus, the results of cephalometric studies are limited compared to CBCT studies as cephalometric assessment of airway space uses landmarks that change between pre- and post-operative periods. This justifies the use of three-dimensional analysis of upper airway space in the present study, providing volumetric changes by comparing pre- and post-operative CBCT scans.46 All the 12 patients were subjected to CBCT scan (Planmeca, Topamax) before surgery and immediately after surgery. To evaluate the Volume of the airway & Area of the entire pharyngeal airway space region using coronal, sagittal & axial slices were determined. Data were tabulated & analyzed using Paired sample t-test &

Independent sample t-test. (fig 2) & (fig 3) The results of this study show that for GROUP I (cases of mandibular advancement surgery) the Volume of the airway did not increase significantly according to the assigned p-value, however, it can be said that there is 95% of increase post- surgically. There was a highly significant increase in the Area of the Airway in all three planes, namely Coronal, Sagittal & Axial. In this study, the mean increase in Airway Volume after Mandibular advancement Surgery was 3550.83 mm3 postsurgically. This increase is better than the results obtained by Isidor S et al. where the increase in Airway Volume was 2506 mm3 , 47 & the results obtained by Ghoneima A et al. where airway volume increased by 1034mm3 . 43 The increase in Airway Volume obtained by Ristow O et al. of 3136.7 mm3, 51is comparable to the results of this study. Oliveira et al, however recorded a much higher increase in Airway Volume of 6901 mm3 which is almost double the increase compared to this study.

Highly significant increase was recorded for the Airway Area measured in coronal, sagittal and axial planes with p values of, <0.050, <0.006 and <0.023 respectively for Group I mandibular advancement cases in the present study. The study of Lenza MG et al. showed no significant increase in area of the Airway in coronal, sagittal & axial planes.34

In GROUP II cases of maxillary impaction surgery, the Airway Volume increase was highly significant. The increase in Area of the Airway in all three planes, namely Coronal, Sagittal & Axial, was not significant.

There are no references in literature for comparison of Airway measurement changes after maxillary superior impaction surgery. However, Maxillo-mandibular advancement and its effect on Airway change has been reported, which is being cited here for the sake of completion. It however can by no means be compared to Maxillary Superior Impaction with mandibular Autorotation. This may be seen as a further scope for investigation in relation to Airway changes after such Surgeries. Butterfield K et al. conducted a study where pharyngeal airway space was analysed after Maxillomandibular advancement in the treatment of OSA using CBCT and found that there was significant increase in overall airway measurements compared to control subjects. This shows the impact of mandibular advancement surgeries on the pharyngeal airway space and its implication in treating OSA.52 Furthermore, Fairburn et al. 54 and Goncalves et al.55 found greater increase in Airway Area in cases of maxillomandibular advancement compared to mandibular advancement alone. Schendel SA et al,44 they found about 23.7% increase in the mean volume of the airway & Broujerdi et al. 40 also concluded to have obtained 28% increase in the volume after Maxillo mandibular advancement. The unpaired t-test was performed for all the individual Volume and Area measurements of Group I & II. The mean value of the Volume, Area in coronal, sagittal & axial sections of the airway was higher in Group II than in Group I Pre-surgically & post surgically. The difference was highly significant in the Airway Volume Pre- & Post Surgically. The Airway Area also was highly significantly higher in the Group II in Pre- & Post Axial and Presurgical Sagittal measurements. It can thus be inferred that Class II Vertical Dysplasia patients had a larger Airway Volume & Area than the patients with Class II mandibular retrusion, and the trend continued post surgically also. This comparison of Airway measurements in between the two groups shows that Class II Skeletal Malocclusions with mandibular retrusions have reduced airway volume & Area compared to Class II malocclusion characterized with Vertical maxillary excess to start with. This trend continued after surgery also. Can it thus be speculated that these patients inherently or developmentally have a reduces airway which in turn resulted in a retruded mandible? In other words, Is a reduced Airway the main etiologic factor in the development of Class II malocclusion with mandibular retrusion? This sample size is however too small to conclude this. It may well be the scope for further research in the field with a much larger sample. The Null Hypothesis proposed is thus rejected.

The Mandibular advancement Surgery & Maxillary Superior Impaction surgery with Mandibular autorotation, results in an increased Pharyngeal Airway Space.

Conclusion

The mean volume difference obtained by paired t-test of 3550.3 mm3 is indicative that mandibular advancement surgery has definitive effect on the pharyngeal airway space. Whereas, with mean total volume of 4301.67 mm3, the maxillary impaction surgery has better effect on the pharyngeal airway space than mandibular impaction. It can thus be inferred that Class II Vertical Dysplasia patients had a larger Airway Volume & Area than the patients with Class II mandibular retrusion, and the trend continued post surgically also. The Area of the airway measured in coronal, sagittal and axial planes showed significant difference when observed pre- and post- surgically with $p<0.05$, suggesting that the linear measurements of the pharyngeal airway have increased after both the surgeries. The unpaired t-test was performed for all the individual Volume and Area measurements of Group I & II. The mean value of the Volume, Area in coronal, sagittal & axial sections of the airway was higher in Group II than in Group I Pre surgically & post surgically. The difference was highly significant in the Airway Volume Pre & Post Surgically. The Airway Area also was highly significantly higher in the Group II in Pre & Post Axial and Pre-surgical Sagittal measurements.

The comparison of Airway measurements in between the two groups shows that Class II Skeletal Malocclusions with mandibular retrusions have reduced airway volume & Area compared to Class II malocclusion characterized with Vertical maxillary excess to start with. This trend continued after surgery also. It can thus be inferred that Class II Vertical Dysplasia patients had a larger Airway Volume & Area than the patients with Class II mandibular retrusion, and the trend continued post surgically also. Based on the obtained results it is indicative that CBCT imaging is effective in determining the changes in pharyngeal airway space due to mandibular advancement and maxillary impaction surgeries. The increase in the Volume and Area in coronal, sagittal and axial planes of the airway have been noted post- surgically in both the groups, suggesting a positive impact on the pharyngeal airway space. Thus, it is concluded that the Mandibular advancement Surgery & Maxillary Superior Impaction surgery with Mandibular autorotation, results in an increased Pharyngeal airway space.

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