Curriculum Vitae

I. Name

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II. Education

University of Maryland School of Dentistry
Baltimore, MD
Certificate in Orthodontics and Master of Science in Biomedical Sciences,
Expected Graduation May 2021

University of Maryland School of Dentistry Baltimore, MD
Doctor of Dental Surgery, May 2018

University of Maryland, College Park, MD
Bachelor of Science in Physiology and Neurobiology, May 2014

III. Research

Master's Thesis
University of Maryland School of Dentistry Department of Orthodontics
Baltimore, MD
Evaluating oropharyngeal airway volume in patients with Class II dental relationships with extraction vs non-extraction orthodontic treatment
July 2018- Present

Journal of General Dentistry Publication
University of Maryland School of Dentistry Department of Orthodontics
Baltimore, MD
What every general dentist needs to know about clear aligners
Published July 2020

Research Assistant
University of Maryland School of Dentistry Department of Orthodontics
Baltimore, MD
Dental and Skeletal Changes seen on CBCT with Damon Self-ligating Bracket System vs. Conventional Bracket System
2017

Research Program
University of Maryland Gemstone Honors Society, College Park, MD
Evaluating Linear-Radial Electrode Conformations for Tissue Repair and

Organizing a Device for Experimentation
August 2010- May 2014

IV. Honors and Awards

Gaylord Fund Recipient
2019

Dr. Henry S. Hohouser Memorial Scholarship Award
2019

Alpha Omega International Dental Fraternity: Baltimore Alumni Chapter Award
2018

Omicron Kappa Upsilon (OKU)- Phi Chapter, Class of 2018 Alumni
2018

Russell Gigliotti Memorial Scholarship
2016- 2017

Pierre Fauchard Oral Health Foundation Student Scholarship Award
2017

University of Maryland Dental School General Scholarship
2016-2017

Charles Hennessey Scholarship
2015-2016

Maryland Senatorial Scholarship
2014-2018

Gorgas Odontological Honors Society Member
2017-2018

Gamma Pi Delta Prosthodontics Honors Society Member
2017-2018

Abstract

Title of Thesis: Evaluating oropharyngeal airway volume in patients with Class II dental relationships with extraction vs non-extraction orthodontic treatment

Candidate: Ariana Feizi, Master of Biomedical Science, 2021

Thesis Directed by: Dr. Monica Schneider, Clinical Associate Professor and Director of Predoctoral Orthodontics, Department of Orthodontics

Purpose: The purpose of this study is to demonstrate that the oropharyngeal volume does not decrease as a result of premolar extractions and orthodontic treatment.

Materials and Methods: Cone-beam CT's were obtained for twenty-seven orthodontic patients before and after treatment. Nine patients were treated with four premolar extractions, and eighteen treated non-extraction. Total oropharyngeal airway volume (TV) and minimum area of constriction (MAC) were measured using InVivo Anatomage Software.

Results: The initial and final TV of the non-extraction group were correlated ($p = 0.61$). The TV in the non-extraction cases showed a significant increase ($p = .037$).

Conclusion: There was no significant change in TV in Class II patients that underwent orthodontic treatment with extractions, however; patients that were treated non-extraction had a significant increase in TV. There was no significant change in MAC in either group.

Evaluating Oropharyngeal Airway Volume in Patients with Class II Dental Relationships with Extraction vs Non-Extraction Orthodontic Treatment

by

Ariana G. Feizi

Thesis submitted to the Faculty of the Graduate School of the University of Maryland, Baltimore in partial fulfillment of the requirements for the degree of Master of Science

2021

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I would also like to thank Dr. Tarun "Ty" Saini for his generous support in making this study possible.

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Introduction and Literature Review:

Dental Crowding and Orthodontics

Dental crowding is one of the most common chief complaints of patients seeking orthodontic treatment. Depending on the severity and the etiology, there are several approaches to resolve dental crowding which include interproximal reduction, arch expansion, or extraction of teeth. After the fusion of the mid-palatal suture, transverse skeletal expansion to increase arch length becomes less effective and unpredictable with traditional tooth-borne appliances, and the need for reducing tooth mass becomes indicated. After about age 15 in girls and 16 in boys, there is little to no basal skeletal movement, and changes in width are due to tipping of the teeth within the confines of the alveolus (Vanarsdall, 1999).

While there are numerous treatment philosophies in orthodontics, one widely accepted set of guidelines was proposed by William Proffit in the 1990's. According to Proffit, individuals with a Class I dental relationship and less than four millimeters of crowding rarely necessitate extractions to resolve the malocclusion. Patients with a Class I dental relationship and five to nine millimeters of crowding are considered "borderline cases" and may necessitate extractions. Patients with a Class I malocclusion and more than nine millimeters of crowding often require extractions in conjunction with their orthodontic treatment (Proffit, 2019). Depending on the periodontal health of the individual, extraction treatment of dental crowding may prevent future dehiscence or fenestrations or other detrimental periodontal effects. When treatment planning for extractions, it is critical to evaluate the proclination of the incisors. Often times, extraction of premolars allows for correction of proclined incisors to their ideal angulation within the alveolar bone. According to Little et al., excessive proclination of the incisors has deleterious effects on both the facial esthetics and the long-term stability of the teeth (Little et al., 1990).

In addition to resolving crowding, extractions of permanent teeth can facilitate correction of Angle's Molar classification. Specifically, orthodontic treatment in adolescents with Class II or Class III malocclusions often involves extraction of four premolars to improve molar and canine relationships. In patients that present with a Class II Angle's molar and canine classification, one treatment philosophy that is commonly applied is extraction of maxillary first premolars and mandibular second premolars. The particular extraction pattern may deviate depending on the patient's presentation and the provider's preference of biomechanics with the goal remaining to allow for proper intercuspation of posterior teeth, and also allows for improvement of overjet and anterior coupling.

Cone Beam Computed Tomography in Orthodontics

As imaging technology continues to evolve, so does the availability of information that dental providers are able to collect. 2D imaging, while still widely implemented, has many limitations including magnification errors, geometric distortion, superimposition of structures, projective displacements which elongate or foreshorten structures, rotational errors, and linear projective transformation (Kapila, 2011).
Over the past 30 years, technological advancements have allowed 3D Cone Beam Computed Tomography (CBCT) to become more affordable and more readily available in orthodontic practices (Scarfe, 2008). Three-dimensional imaging has many advantages for orthodontic treatment, and according to Agrawal et al., "CBCT provides an excellent

tool for accurate diagnosis, more predictable treatment planning, more efficient patient management and education, improved treatment outcome and patient satisfaction" (Agrawal et al., 2013).

A CBCT image is acquired when the x ray source and detector rotate around the patient's head, and a beam of radiation is directed through the middle of the area of interest onto an x-ray detector (Scarfe, 2008). While traditional CT uses a fan shaped beam, CBCT uses a round or rectangular cone-shaped beam. Only one rotation of the gantry around the patient's head is sufficient to capture the image, as the exposure incorporates the entire field of view. During this rotation, hundreds of sequential images are acquired at small degree intervals. Each of these images is a 2D projection, similar to lateral or PA cephalometric images, which each being taken at a slightly different angle than previous (Scarfe, 2008). These 2D images are combined to comprise the 3D volume.

CBCT provides imaging of high diagnostic quality with sub-millimeter resolution, shorter scanning times, and exposes patients to a radiation dose that is 10 times less than conventional CT scans during maxillofacial exposure (Kumar et al., 2015). CBCT also offers high dimensional accuracy with only 2% magnification that can be self-corrected to produce an orthogonal image with a 1:1 ratio of structures in reproduced in the image (Kumar et al., 2015).

CBCT, while applicable in all dental specialties, is particularly beneficial in diagnosis and treatment planning in orthodontics. CBCT can aid in the placement of temporary anchorage devices by accurately identifying root morphology and position, bone density, and localization of existing root damage as compared to more traditional imaging modalities such as 2-D panoramic or periapical radiographs. According to Kumar et al., this imaging modality is also the tool of choice for orthodontists to be used for "cephalometric analysis…assessing facial growth, age, airway function and disturbances in tooth eruption" (Kumar et al., 2015).

Various CBCT analysis software allows the user to isolate the anatomical region most frequently affected by obstructive sleep apnea (OSA) – the oropharynx – bounded superiorly by the nasopharynx and inferiorly by the epiglottis. The software then is able to compute the total volume within the given limits and can also measure the cross-sectional area of an axial slice of the image. The airway width and anterior-posterior dimension of the airway in the smallest axial slice can also be measured using certain analysis programs. These measurements provide the user with numerical values to objectively evaluate and compare airway dimensions in OSA patients versus unaffected individuals.

Sleep Disordered Breathing

Sleep disorders pose a major public health problem in the United States, and the National Commission on Sleep Disorders estimates that, "mild sleep-disordered breathing affects 7 to 18 million people in the United States, while 2 to 4 million Americans have moderate to severe disease" (Ting et al., 2015). Of these sleep disorders, OSA is one of the most prevalent and is associated with neurocognitive and cardiovascular comorbidities. OSA is characterized by episodes of partial or complete airway obstruction, specifically in the upper airway, that may disrupt normal sleep patterns (American Thoracic Society, 1996). This breathing disorder is a result of an interaction of many anatomic factors, sleep-related factors, and central nervous system control of respiration (Ting et al., 2015). The anatomic factors that play a role in OSA include a round airway, soft palate length and volume, upper airway length, pharyngeal fat deposits, adenotonsillar hypertrophy, tongue volume, class II skeletal profile, and morphological deviations of the cervical spine (Ting et al., 2015). Although diagnosis of OSA must be confirmed with a sleep study, dental professionals can help to identify individuals at risk with the help of routine diagnostic imaging. It is estimated that up to 93% of women and 82% of men with moderate to severe OSA may go undiagnosed (Park et al., 2011). Individuals with undiagnosed OSA may present for routine dental visits, making dental imaging a reasonable and practical method for screening for OSA risk factors.

Orthodontics and Airway

The oropharynx is defined by Netter as the region of the upper airway that lies superior to the laryngopharynx and inferior to the nasopharynx, extending from the soft palate to the epiglottis (Netter, 2019). This region is of particular interest in orthodontic airway evaluation, as most obstructions in OSA occur in the oropharynx and it is proposed to be the region of the airway most directly affected by position of the mandible and the soft tissue changes that occur with orthodontic treatment (Haskell et al, 2009). Class II craniofacial patterns are often linked to smaller upper airway size, deficient mandibles, and steep mandibular plane, and are at a higher risk for obstructive sleep apnea (Sutherland et al., 2012). This relationship was initially recognized by Edward Angle in 1907, who was widely acknowledged as the father of American Orthodontics (Angle, 1907). These class II individuals usually present with hyperdivergent mandibular planes and convex profiles. While surgical intervention is often the ideal treatment to improve the profile and dental relationship for these patients, many prefer less invasive options such as orthodontic camouflage treatment involving extraction of teeth (Zhang et al, 2015).

In recent years, there has been a strong interest in the role of orthodontics, specifically orthodontic treatment with extractions, contributing to the development of OSA. It has been proposed that extraction of premolars decreases the space available in the oral cavity for the tongue which forces the tongue back into the oropharynx. This retrusive position of the tongue is proposed to result in a decreased airway volume and contribute to obstruction of the airway. However, this theory has yet to be proven with radiographic studies.

Literature Review

Previous studies have measured associations between craniofacial morphology and airway volume, and thus a possible predisposition to sleep disordered breathing. A study by Yap et al. concluded that increased lower face height and maxillomandibular angle were present in patients with sleep disordered breathing (Yap, et al., 2019). However, these measurements were taken from soft tissue landmarks on patient photographs and dental models, and not skeletal cephalometric measurements. A related study by Galeotti et al. measured craniofacial landmarks using lateral cephalograms and their correlations with severity of OSA (Galeotti, et al., 2019). A significant correlation was found between maxillomandibular discrepancy (measured by ANB angle) and severity of OSA (Galeotti, et al., 2019). This study also found a correlation between maxillomandibular hyperdivergent growth patterns and a reduction of nasopharyngeal width (Galeotti, et al., 2019).

A study by Buchanan et al. in 2016 evaluated the upper airway dimensions of 16 obstructive sleep apnea (OSA) and 16 control subjects using a cone-beam computed tomography. The average area, volume, total volume and total length of the upper airway were measured, and it was found that OSA subjects had a significantly smaller average and total airway volume as compared to controls (Buchanan et al., 2016). OSA subjects had a significantly larger airway length measurement, but the average anterior-posterior airway measurement was not found to be significant between the groups (Buchanan, 2016). This is in contrast to the results of Ogawa et al. and Schwab et al. who concluded that anterior-posterior airway measurement of OSA subjects was significantly smaller than that of controls (Ogawa et al., 2007) (Schwab et al., 2003). Buchanan et al. suggest that the lack of significant difference in A-P measurements between groups may be as a result of patient positioning at the time of image acquisition. Dental CBCTs are commonly taken with the patient standing upright, whereas medical CTs historically studied to evaluate OSA patients are taken with the patient in a supine position. A study by Camacho et al. was the first to compare airway morphology between upright and supine patient positions using CBCT, and found that "the minimum cross-sectional area decreased from 124±29 mm^2 to 30±5 mm^2 when the patient was scanned in the supine position" (Camacho et al., 2014). The authors proposed that this change in dimension may be due to a change in position of the tongue, where the tip and base of the tongue, the palate, and the epiglottis sit more posteriorly in a supine patient. As such, the cross-sectional area and the anterior-posterior dimension of the airway may measure as a smaller value if the imaging is done with the patient laying supine.

Previous imaging studies have determined standards for healthy subjects and for patients with OSA. In a 2010 CBCT study, Enciso and colleagues determined that individuals whose pharyngeal lateral dimension measures less than 17mm in the A-P have a 3.9 times higher likelihood of having OSA (Enciso et al., 2010). Schwab et al. found that the airway volume and average airway area per slice measured on MRI were significantly smaller in OSA subjects after controlling for sex, ethnicity, age, craniofacial size, and parapharyngeal fat. Therefore, the smaller the airway volume, the higher the risk of developing OSA (Schwab et al., 2003)..

Extractions for Orthodontics and Airway

Research on oropharyngeal airway has led to inconsistent results regarding changes in airway volume from extraction of teeth for orthodontic purposes (Chen, et al., 2012) (Bhattacharyya et al., 2000). With the increased availability of CBCT in orthodontic practices, a 3-dimensional evaluation of airway is able to provide practitioners with accurate information regarding airway volume after orthodontically-driven extractions are done. Using digital software, airway volume changes can accurately be measured before and after treatment to better understand the implications of orthodontic treatment on the oropharynx in patients of differing craniofacial morphologies and dental malocclusions. In a study on class I patients, Wang et al. concluded that airway size decreases after orthodontic extraction treatment (Wang et al., 2012). Chen and colleagues came to the same conclusions, and also found that this decrease in airway was correlated to the amount of retraction of the patient's lower incisors (Chen et al., 2012). These studies measured the position of the hyoid bone in addition to the average cross-sectional areas of the nasopharynx, palatopharynx, glossopharynx, and they hypopharynx, with the greatest decrease in area observed in the hypopharynx (Chen et al, 2012). Wang et al. also concluded that the changes observed in pharyngeal airway size were no different in individuals with hyperdivergent or non-hyperdivergent mandibles (Wang et al., 2012). In contrast, a study by Maiitah et al. conducted in the same year found that airway size remained unchanged after first premolars were extracted in orthodontic patients with bimaxillary protrusion (Maiitah et al., 2012).

With the exception of a single case study and one preliminary study by Zhang et al., little research has been done to investigate airway dimensions in class II hyperdivergent patients. Zhang and colleagues found that the volume, height, and cross-sectional area of the airway were not significantly changed after orthodontic treatment with extractions of premolars (Zhang et al., 2015). The aim of the present study is to further investigate this phenomenon and evaluate oropharyngeal airway in extraction as compared to non-extraction class II orthodontic patients.

Research Questions

1) Does extraction of premolars for orthodontic treatment in Angle's Class II patients lead to a decrease in oropharyngeal airway volume?
2) Is there a relationship between pre-treatment and post-treatment airway volumes in Class II patients that undergo orthodontic treatment with 4 premolar extractions?
3) Is there a relationship between pre-treatment and post-treatment airway volumes in Class II patients that undergo orthodontic treatment without extractions?
4) Does extraction of premolars for orthodontic treatment in Angle's Class II patients lead to a decrease in cross-sectional area of minimum constriction of the airway?

Hypothesis

There is no significant decrease in oropharyngeal airway volume or cross-sectional area of minimum constriction in orthodontic patients treated with extractions compared to patients treated non-extraction.

Materials and Methods:

Subjects:

Approval for this research was obtained from the Human Research Protections Office (HRPO) of the University of Maryland and found to be exempt from Institutional Review Board evaluation because all data were pre-existing, and the subjects were unidentifiable from the data set (submission HP-00087953). Twenty-seven patients were retrospectively selected from the records of two private practice orthodontic offices: Dr. Raj and Ty Saini or Dr. Norman Boucher. All patients were determined to have a Class II dental occlusion (either cusp to cusp, end-on molar relationship or full step Class II). Eighteen subjects treated with conventional brackets and no extractions were included in this study as the control group. Nine subjects with the same initial inclusion criteria but who underwent orthodontic treatment with four premolar extractions were included in the present study as the extraction group. The inclusion criteria are listed below:

Inclusion criteria:

- Post-pubertal patients, CVMS IV-V
- Class II occlusion
- No surgical intervention
- Initial and post alignment CBCT
- No missing dentition, excluding 2^{nd} and third molars

The sample size used in the present study is in agreement with published radiographic studies evaluating OSA. Studies by Korayem and colleagues and Ogawa and colleagues each used 10 OSA subjects and 10 control subjects for radiographic analysis of airway, and they concluded that the upper airway in OSA subjects presented with a smaller minimum cross section airway when compared to control subjects (Korayem et al, 2013)(Ogawa et al., 2007).

In the present study subjects had no missing teeth prior to initiating orthodontic treatment (ignoring second and third molars) and no craniofacial abnormalities. The extraction group consisted of subjects who each had four premolars extracted as part of their orthodontic treatment. All subjects were treated with .022" slot MBT Twin bracket fixed appliances systems. Demographic information of subjects is presented in Tables 1a and 1b.

Demographic Information of Subjects:

Table 1a: Demographic Information of Subjects in Extraction group.

Patient ID	Sex	Ethnicity	Initial Age (yrs)	Final Age (yrs)	CVMS
1	M	B	14	16	4
*2	F	A	32	--	5
3	M	C	13	17	4
4	F	A	18	21	5
*5	F	C	46	--	5
6	M	A	15	16	5
7	F	A	11	13	4
8	M	B	12	14	4
9	F	A	13	16	4

** indicates subjects treated at the office of Dr. Norman Boucher. All other subjects were treated by Dr. Ty Saini. Final age was not available for the two subjects treated at Dr. Boucher's office.*

Table 1b: Demographic Information of Subjects in Non-extraction group.

Patient ID	Sex	Ethnicity	Initial Age (yrs)	Final Age (yrs)	CVMS
10	F	C	12	13	4
11	F	C	13	15	4
12	M	C	13	14	4
13	F	A	17	18	5
14	M	A	13	14	4
15	F	A	11	13	4
16	F	C	12	13	4
17	F	A	13	14	4
18	F	A	11	14	4
19	F	C	12	14	4
20	F	B	13	15	4
21	M	B	14	17	4
22	M	C	15	18	4
23	F	C	14	15	4
24	M	A	12	14	4
25	M	C	14	16	4
26	M	A	12	16	4
27	M	C	15	18	4

All subjects were treated orthodontically at the office of Dr. Ty Saini.

Procedures:

Two CBCT images were obtained for each patient by the orthodontic practices. One pretreatment image which was designated as time point "Initial" and one post-alignment image was designated as time point "Final" was acquired and de-identified by the orthodontic practices that provided us with these images. Both practices utilized i-CAT Platinum by Imaging Sciences for CBCT scans. Patients were scanned with a field of view of 16 cm x 13 cm and 0.3 voxel resolution for 8.9 seconds. The machine rotated around the patient one time and exposed the patient to approximately 87 micro-Sieverts of radiation. From the 3D CBCT images, 2D lateral cephalograms were extracted for cephalometric analysis. Cervical vertebral maturation stage (CVMS) was measured on each extracted lateral cephalogram to confirm that the patient was in stage 4 or 5, as defined by McNamara et al. in 2002 (Baccetti, Franchi, & McNamara, 2002). Individuals in stage 4 and above have largely completed craniofacial growth, with peak mandibular growth having already occurred.

The practices provided the investigator with these de-identified CBCT images, which were analyzed using Anatomage InVivo6 3D Imaging Software to measure oropharynx volume. All files were labeled with a computer-generated number; therefore, data collection was carried out without the investigator knowing which images corresponded to which subject. Matching Initial and Final timepoints for each subject patient's ID number was done after all data collection was complete.

Each DICOM file was opened with Anatomage InVivo6 software and was first oriented with the Frankfort Horizontal plane parallel to the floor as demonstrated in Figures 1 and 2, with the center of the patient's head in view, as determined by presence of the nasal spine and the nasopalatine foramen in the image slice being analyzed.

Figure 1: Orientation of 3D volume of Frankfurt Horizontal plane

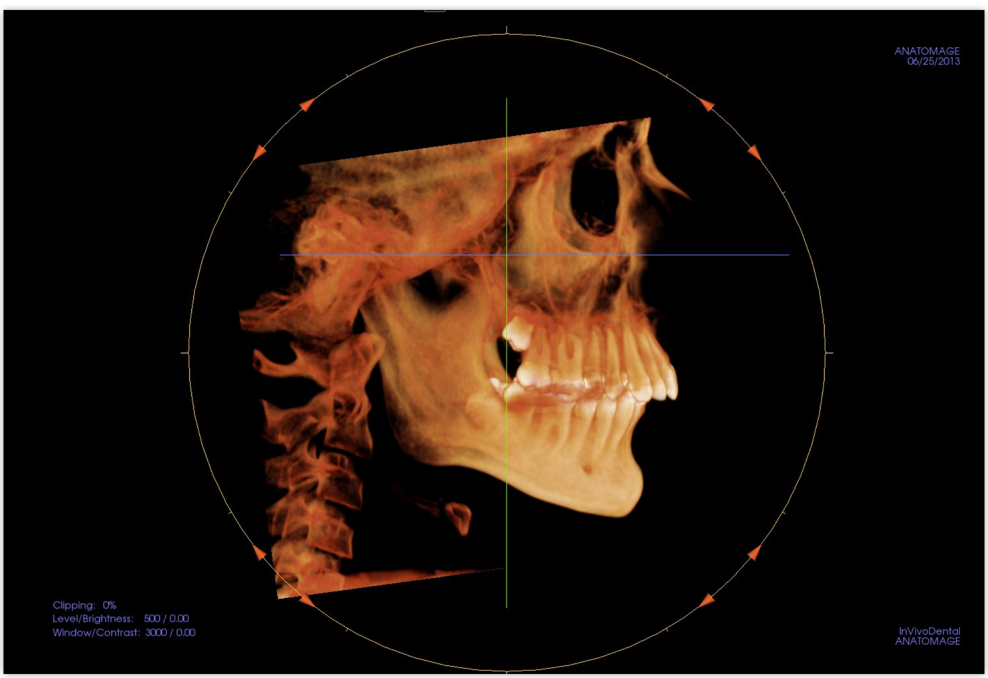
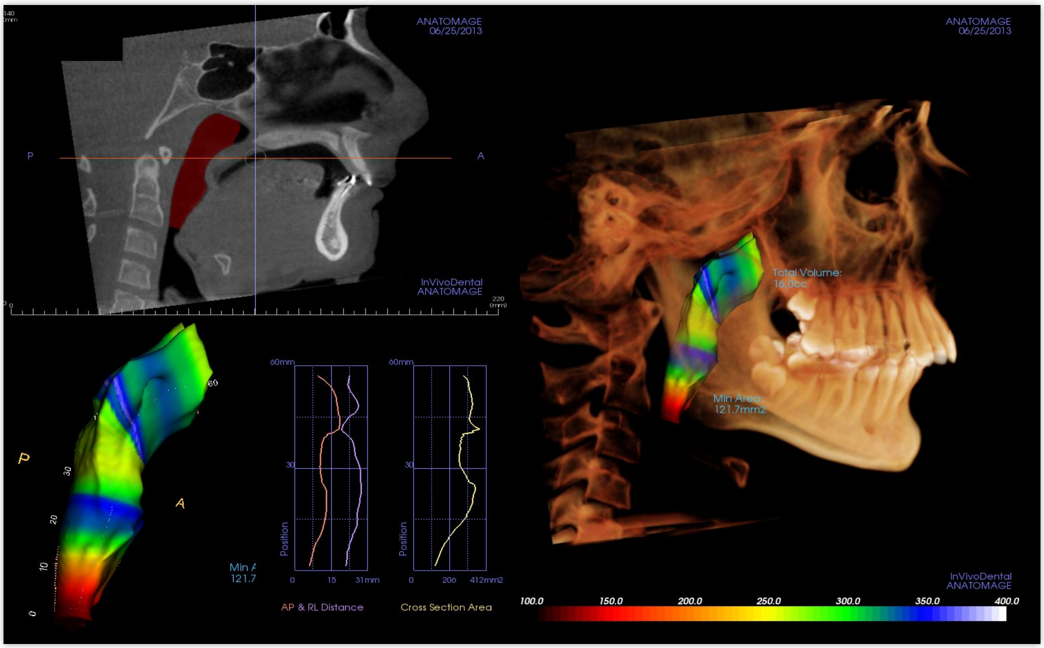


Figure 2: Identification of midline by presence of nasopalatine foramen

The limits of the oropharynx were demarcated using InVivo6 Software, which provided a 3D rendering of the oropharynx extracted for volumetric evaluation. Using the Airway Assessment tool in the Anatomage InVivo 6 software, the upper and lower limits of the oropharyngeal airway were indicated by the investigator, the author, by clicking on the anatomical landmarks as defined by previous airway studies by Ogawa and Stefanovic et al (Ogawa et al., 2007) (Stefanovic et al., 2013). These include the posterior nasal spine of the palatine bone and the most inferior portion of the second cervical vertebra. Horizontal lines parallel to the Frankfort Horizontal plane were drawn through these two points, and the total three-dimensional volume of the airway between these two horizontal lines was calculated by the software as depicted in Figure 3. The software also reported the minimum cross-sectional area of the oropharyngeal airway. These measurements were recorded for each CBCT image. Studies of the upper airway based on

CBCT scans are considered to be reliable in defining the border between soft tissues and void spaces, and provide accurate cross sectional areas and volumes of the pharyngeal airway (Gurani et al., 2016).

Figure 3: Measurement and volumetric rendering of oropharynx



Statistical Analysis:

Three statistical tests were done to analyze the data in the present study.

1) To determine intra-rater reliability, all measurements were repeated by the same investigator after one week. The correlation between the two sets of measurements was calculated using a Spearman Rho test.

2) A second Spearman Rho test was conducted to evaluate for possible correlation between the initial and final airway measurements of each patient.

3) The changes in total airway volume and minimum area of constriction from Initial time point to Final in each group were evaluated with a Wilcoxon test.

4) **Results:**

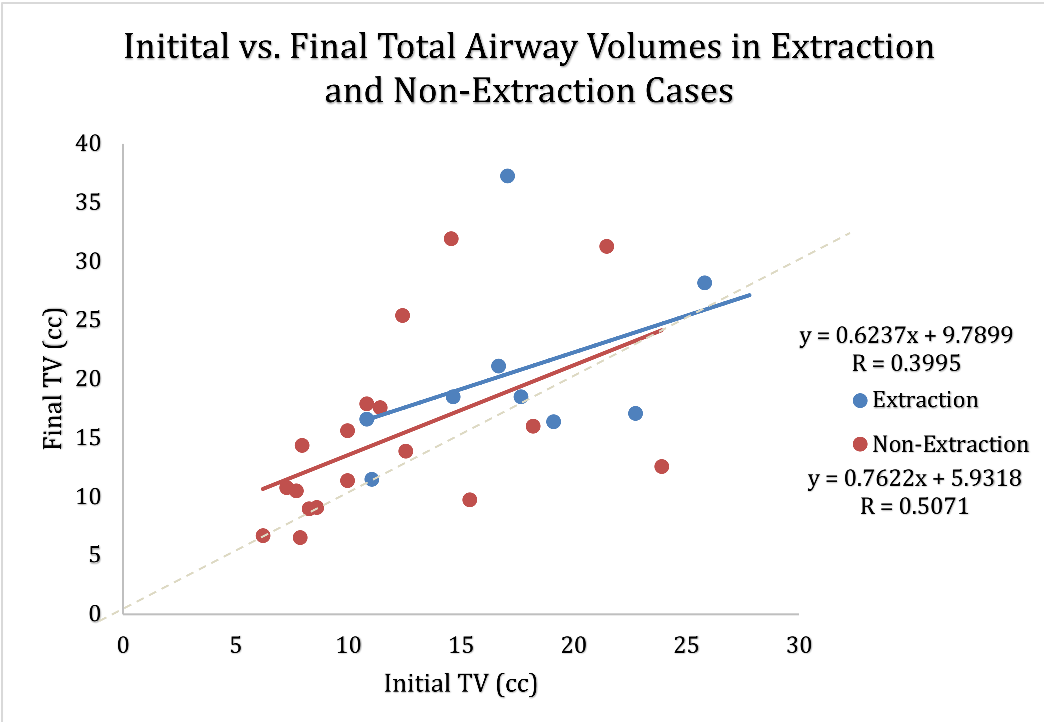
Intra-rater Reliability:

To determine intra-rater reliability, all measurements were repeated by the same investigator, the author of the present study, after one week. The correlation between the two sets of measurements was calculated using a Spearman Rho test. In the table available in the appendix, the difference in the two measurements for total volume at the initial time point for the extraction group was calculated, and the resulting Spearman Coefficient was 0.99, indicating that both measurements were highly related. After a high reliability was determined, the two measurements were averaged, and this data is available in Tables 3a-4b.

Initial vs. Final Total Airway Volume Correlation:

As demonstrated in Figure 4, there are several outliers in each group. Of the extraction group, Patient 9 experienced a considerably larger increase in airway volume as compared to other subjects in the group. Patients 1, 2, and 3 fell below the trend line for airway volume change. Patients 10, 11 fell well below the trend line of the non-extraction group, and Patients 20, 26, and 27 fell substantially higher than the trend line for the non-extraction group.

Figure 4: Initial vs Final Total Airway Volume Correlation



A Spearman Rho correlation test was done to determine if there was a relationship between each subject's initial and final total airway volume (Tables 2a and 2b). This test showed that there was no significant pairing between initial and final airway volumes in the extraction group, however; the initial and final airway volumes of the non-extraction group were correlated with a Spearman coefficient of 0.61.

Table 2a: Extraction Group Correlation Test

Patient ID	Initial TV (cc)	Final TV (cc)	Spearman Coefficient
1	22.75	17.1	0.34
2	19.1	16.35	
3	11.05	11.5	
4	17.65	18.5	
5	25.8	28.2	
6	14.65	18.5	
7	16.65	21.1	
8	10.8	16.6	
9	17.05	37.25	

Table 2b: Non-Extraction Group Correlation Test

Patient ID	Initial TV (cc)	Final TV (cc)	Spearman Coefficient
10	23.9	12.55	*0.61
11	15.4	9.75	
12	7.85	6.55	
13	18.2	16	
14	8.6	9.1	
15	6.2	6.7	
16	8.25	9	
17	12.55	13.85	
18	9.95	11.35	
19	7.7	10.5	
20	21.45	31.3	
21	7.25	10.75	
22	11.4	17.55	
23	9.95	15.6	
24	10.8	17.9	
25	7.95	14.35	
26	12.4	25.4	
27	14.55	31.95	

Asterisk indicates statistically significant result

Figure 5 presents each individual extraction subject's change in total volume, represented as a percent change. Patient 9 experienced a 118% increase in total volume, which was substantially larger of a difference as compared to all other extraction patients. Patients 1 and 2 were the only two subjects of the extraction group that experienced a decrease in total airway volume. Figure 6 presents each individual non-extraction subject's change in total volume, represented as a percent change. Four subjects experienced a decrease in total airway volume ranging from a 12% decrease to a 47.5% decrease from initial to final.

Figure 5: Percentage change of total airway volume in extraction cases

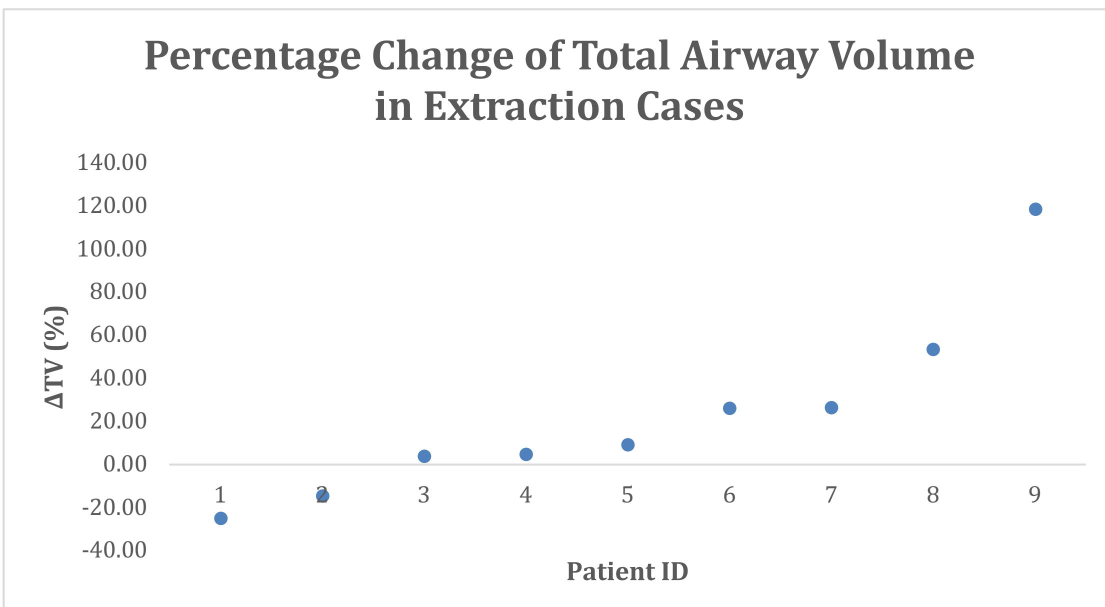
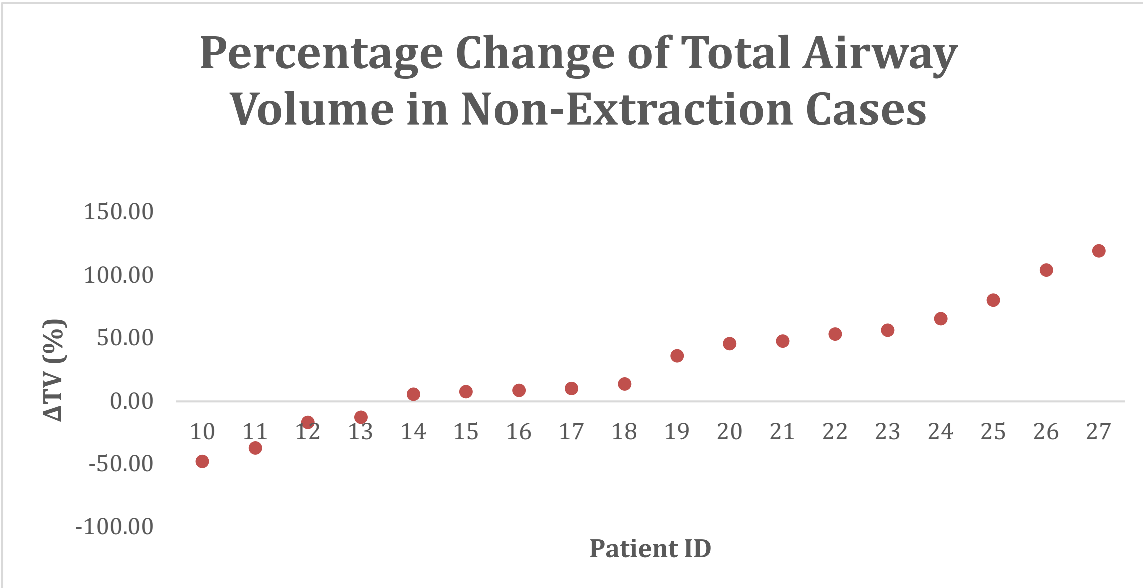


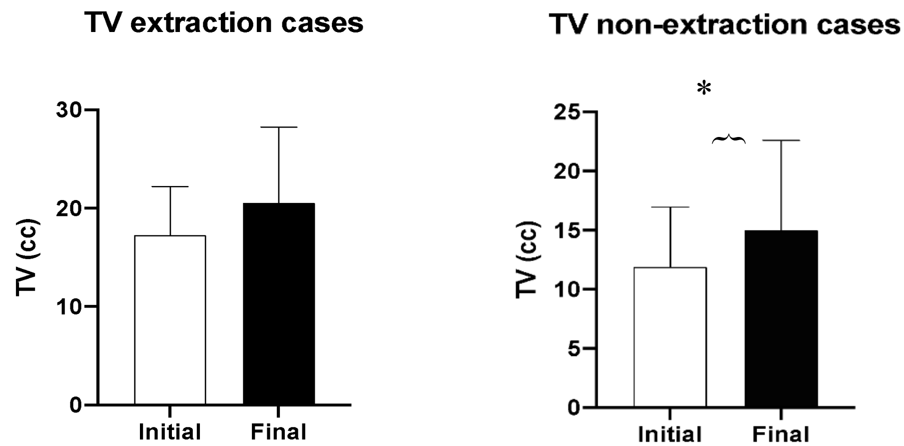
Figure 6: Percentage change of total airway volume in non-extraction cases



The changes in total airway volume and minimum area of constriction from initial to final in each group were compared with a Wilcoxon test (Figures 7a,7b). The total airway volume in the non-extraction cases showed a significant increase ($p = .037$). All other results of the Wilcoxon tests were non-significant.

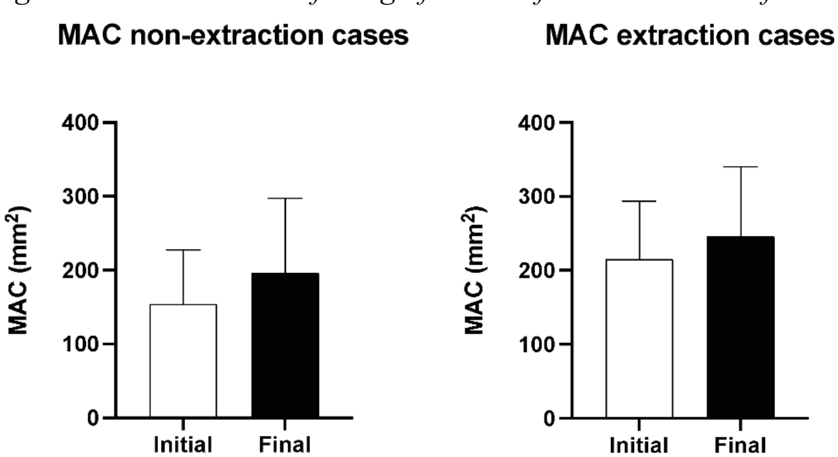
The average initial and final measurements for TV in the extraction and non-extraction groups, and the change in TV, represented by both the numerical value and a percent change, are presented in Tables 3a and 3b below. The average initial and final measurements for MAC in both extraction and non-extraction groups, and the change in MAC is presented in Tables 4a and 4b below.

Figure 7a: Wilcoxon test for significance of total airway volume.



There was a significant increase in the total airway volume of the non-extraction subjects (p=0.037). The change from initial to final airway volume in the extraction group was not significant.

Figure 7b: Wilcoxon test for significance of minimum area of constriction.



There was no significant change between initial and final minimum area of constriction in either group.

Table 3a: Total Airway Volume (TV): Extraction Patients

Patient ID	Initial TV (cc)	Final TV (cc)	ΔTV (cc)	ΔTV (%)
1	22.75	17.1	-5.65	-24.8
2	19.1	16.35	-2.75	-14.4
3	11.05	11.5	0.45	4.1
4	17.65	18.5	0.85	4.8
5	25.8	28.2	2.4	9.3
6	14.65	18.5	3.85	26.3
7	16.65	21.1	4.45	26.7
8	10.8	16.6	5.8	53.7
9	17.05	37.25	20.2	118.5

Table 3b: Total Airway Volume (TV): Non-Extraction Patients

Patient ID	Initial TV (cc)	Final TV (cc)	ΔTV (cc)	ΔTV (%)
10	23.90	12.55	-11.35	-47.50
11	15.40	9.75	-5.65	-36.70
12	7.85	6.55	-1.30	-16.60
13	18.20	16.00	-2.20	-12.10
14	8.60	9.10	0.50	5.80
15	6.20	6.70	0.50	8.10
16	8.25	9.00	0.75	9.10
17	12.55	13.85	1.30	10.40
18	9.95	11.35	1.40	14.10
19	7.70	10.50	2.80	36.40
20	21.45	31.30	9.85	45.90
21	7.25	10.75	3.50	48.30
22	11.40	17.55	6.15	53.90
23	9.95	15.60	5.65	56.80
24	10.80	17.90	7.10	65.70
25	7.95	14.35	6.40	80.50
26	12.40	25.40	13.00	104.80
27	14.55	31.95	17.40	119.60

Table 4a: Minimum area of constriction (MAC): Extraction Patients

Patient ID	Initial MAC (mm²)	Final MAC (mm²)	ΔMAC (mm²)	ΔMAC (%)
1	254	158	-96	-37.8
2	262.95	236.7	-26.25	-10
3	85	75.5	-9.5	-11.2
4	338.5	313	-25.5	-7.5
5	269.5	337.5	68	25.2
6	149.5	190	40.5	27.1
7	246.6	288.5	41.9	17
8	169	245.5	76.5	45.3
9	163	372	209	128.2

Table 4b: Minimum area of constriction (MAC): Non-extraction Patients

Patient ID	Initial MAC (mm²)	Final MAC (mm²)	ΔMAC (mm²)	ΔMAC (%)
10	331.80	127.70	-204.10	-61.50
11	243.75	135.35	-108.40	-44.50
12	143.40	94.50	-48.90	-34.10
13	271.65	282.45	10.80	4.00
14	169.65	188.55	18.90	11.10
15	117.95	74.20	-43.75	-37.10
16	141.80	97.55	-44.25	-31.20
17	153.20	191.25	38.05	24.80
18	128.20	158.20	30.00	23.40
19	59.20	74.90	15.70	26.50
20	252.90	410.65	157.75	62.40
21	118.65	139.45	20.80	17.50
22	82.80	184.35	101.55	122.60
23	114.10	230.65	116.55	102.10
24	118.60	258.25	139.65	117.70
25	84.85	171.30	86.45	101.90
26	125.55	329.80	204.25	162.70
27	125.15	380.65	255.50	204.20

Discussion:

Total Oropharyngeal Airway Volume

In the present study, there was no significant change in oropharyngeal airway volume in patients that underwent orthodontic treatment with four premolar extractions, similar to the findings of Zhang and colleagues in 2015. While there was a significant increase in total airway volume in the non-extraction group, the small sample size, similar means and small standard deviations suggest that this may not be a clinically significant difference.

Most individuals observed in this study experienced an increase in total oropharyngeal airway volume which can be accounted for by many factors. The average age of the subjects in the extraction group was 19 years and 4 months, whereas the average age of subjects in the non-extraction group was 13 years and 2 months. The extraction group, with a higher average age, likely did not experience as much growth as the non-extraction subjects. Despite all subjects having a cervical vertebral maturation stage of 4 or 5, the non-extraction group was on average younger, and subjects in this group may have experienced some growth over the course of their orthodontic treatment. If the initial CBCT image was acquired before skeletal growth and maturation was complete, the mandible may have been in a more retrusive position than in the final CBCT image. This may have contributed to a smaller initial airway and more sizeable increase in airway over the course of treatment. As the patient's mandible grew and was displaced more anteriorly, this led to an increase in oropharyngeal airway volume. In a study by Silva et al. in 2015, it was concluded that "short mandibular length is related to a decrease in upper airways measurements", and "anteroposterior positioning of the mandible exerts influence on airways measurements” (Silva et al., 2015). It was also found that there was a tendency of facial growth pattern with a positive but weak correlation with the size of the airway (Silva et al., 2015). The authors emphasize the importance of mandibular advancement by way of orthopedic appliances or orthognathic surgery when possible to promote airway enlargement. Mandibular position as a result of growth may have been a contributing factor to the significant increase in total oropharyngeal airway volume in the non-extraction group.

In addition to growth influences on the airway, tongue posture and subject’s head position may also be a contributing factor to the significant increase in oropharyngeal airway volume. According to Ono et al., the volume and the cross-sectional areas of the oropharynx increase in response to head extension, head rotation, and jaw protrusion (Ono et al., 2000). If a patient extended their head, protruded their mandible or rotated their head in the final CBCT image, then final airway may have been measured as larger than initial airway and would not be a true representation of their resting oropharyngeal airway dimensions. By the same token, if the subject lifted their tongue or postured their tongue more anteriorly in the final CBCT image, the final airway volume may have been recorded as larger than the true resting airway volume. Posterior positioning of the tongue and the soft palate may encroach on the pharynx and cause a constriction in airway.

Minimum Area of Constriction

In regard to cross-sectional area of minimum constriction, our results differed from those of Chen and colleagues in that, in the present study, the MAC did not significantly change in either group (Chen et al, 2012). In an MRI study of twenty-eight obese adult subjects with severe OSA, the cross-sectional area of minimum constriction was reported to be 35±16 mm^2 (Cosentini et al., 2004). Each of the subjects in the present study, regardless of extraction or non-extraction groupings, had significantly greater MAC measurements both in the initial and final CBCT images with an average of 246mm^2 in the extraction group and a MAC of 196mm^2 in the non-extraction group. This suggests that the airway of the subjects included in this study are likely not constricted to the same degree as an individual with severe OSA, even including those subjects that experienced a decrease in MAC from initial to final. Nine of the twenty-eight subjects experienced a decrease in MAC ranging from a -7.5% to a -61%, however; the smallest of these cross-sectional areas was 74mm^2, significantly greater than the average cross-sectional area of constriction found in OSA patients by Cosentini. In the present study, Subject 19 of the non-extraction group had a considerably smaller initial MAC as compared to all other subjects in either group, with an initial measurement of 59mm^2 that increased to 74mm^2 after orthodontic treatment. Despite the patient having undergone extractions, the minimum area of constriction increased by 26.5% which contradicts the conclusions of Chen in his 2012 study.

Case Studies and Subject Anomalies

The intra-rater reliability is of utmost importance in this study, as there was very little variation in the tracings of the airway limits. This eliminates the variable of inconsistency in the 3-dimensional airway measurements being evaluated. As such, the subjects that experienced changes that deviated from the trendlines in Figure 4 provide a notable point of discussion.

Of the extraction group, two subjects experienced a decrease in total oropharyngeal airway volume. At the time of initial CBCT acquisition, Subject 1 was 14 years old and had a 24.8% decrease in oropharyngeal airway volume, and Subject 2 was 32 years old and had a decrease in airway volume of 14.4%, thus the growth cannot be the only factor influencing airway changes. In contrast to Subject 1, Subject 9 who was 13 years old at the time of initial image acquisition, experienced the largest increase in oropharyngeal airway volume at 118.5% increase. These two patients were of similar age, however experienced drastically different changes to total airway volume after undergoing the same orthodontic treatment. It is also interesting to note that Subject 5, who was 46 years old at the time of initial image acquisition, experienced an increase in total airway volume of +9.3%. While growth may be a factor in changes observed in oropharyngeal airway in the growing subjects in this study, there were also considerable changes in airway volume in non-growing subjects.

Both Subject 2 and Subject 5 are non-growing adults and any changes observed in the airway cannot be explained by differential growth. One possible reason for this difference could be the orthodontic mechanics used to close the extraction spaces. Subject 2 may have had more retraction of the anterior teeth to achieve orthodontic space closure, possibly as a result of more anterior crowding. Retraction of the anterior teeth may have caused a decrease in arch length, and therefore a decrease in space available for the tongue within the oral cavity, forcing it to rest lower and more posteriorly towards the pharynx. It is possible that Subject 5 may have had less anterior crowding, and space closure was achieved by protraction of the posterior teeth or even reciprocal closure of the space, leading to a smaller decrease in arch length and more room for the tongue to rest in the oral cavity. Another potential contributing factor to the differing airway changes could be a difference in patient head and tongue position at the time of image acquisition as discussed by Ono and colleagues.

Also of note are Subjects 3 and 4 who both experienced an increase in total oropharyngeal airway volume but had a decrease in minimum area of constriction after orthodontic treatment. There may be a change in the shape of the airway resulting in the change in volume. Further studies are necessary to see if there is a lengthening of the airway that leads to increase in oropharyngeal airway volume could explain a simultaneous increase in volume with a decrease in cross-sectional area.

Limitations and Future Directions

During data collection, the goal was to collect data from 60 or more subjects based on other similar studies by Galeotti and colleagues and Dalmau and colleagues. (Galeotti, et al., 2019) (Dalmau et al., 2015). However, due to limitations related to the COVID-19 Pandemic, we were able to collect images and demographic data for twenty-seven subjects. While this number of subjects was similar to studies by Korayem et al. and Ogawa et al., future studies with a larger sample size are necessary to confirm the conclusions of the present study.

Long-term follow up is necessary to observe post-treatment changes to the airway, position of the tongue, and any possible development of OSA symptoms. The subjects in the present study were not asked about breathing or sleep habits, nor were any potential OSA symptoms recorded.

Conclusions:

There was no significant change in oropharyngeal airway volume in Class II patients that underwent orthodontic treatment with four premolar extractions. Class II patients that did not have premolars extracted for their orthodontic treatment had a significant increase in oropharyngeal airway volume. There was no significant change in cross-sectional area of minimum constriction in either group. However, due to the small sample size, the results of the present study serve as preliminary insight to changes in airway in Class II individuals, and further studies are necessary to support these conclusions.

Appendix

Raw Data for Inter-Rater Reliability Measurements:

Total Volume Measurements			
First Measurement (cc)	Second Measurement (cc)	Difference in Measurements	Spearman Coefficient
10.9	10.7	-0.2	0.99
17.7	17.6	-0.1	
14.8	14.5	-0.3	
16.9	17.2	0.3	
11.2	10.9	-0.3	
17.1	16.2	-0.9	
22.5	23	0.5	
25.7	25.9	0.2	
19	19.2	0.2	
16.9	16.3	-0.6	
18.3	18.7	0.4	
19.8	17.2	-2.6	
37.2	37.3	0.1	
11.4	11.6	0.2	
21	21.2	0.2	
16.8	17.4	0.6	
28.1	28.3	0.2	
15.6	17.1	1.5	
8.2	7.7	-0.5	
12.7	12.4	-0.3	
9.8	10.1	0.3	
21.4	21.5	0.1	
15.3	13.8	-1.5	
8.2	7.5	-0.7	
7.7	6.8	-0.9	
23.3	24.5	1.2	
6.2	6.2	0	
10	9.9	-0.1	
11.5	13.3	1.8	
18.3	18.1	-0.2	
11.3	11.5	0.2	
10.1	11.5	1.4	
15.6	15.2	-0.4	
7.8	7.6	-0.2	
8.4	8.1	-0.3	
9.1	8.1	-1	
14.8	13.9	-0.9	
13.4	14.3	0.9	
15.7	15.5	-0.2	
31.3	31.3	0	
31.3	32.6	1.3	
6.6	6.5	-0.1	
10.5	11	0.5	
12.5	12.6	0.1	
6.5	6.9	0.4	
11.8	10.9	-0.9	
25.5	25.3	-0.2	
16	16	0	
17.4	17.7	0.3	
17.7	18.1	0.4	
10	9.5	-0.5	
10.3	10.7	0.4	
9.3	8.7	-0.6	
9.3	8.9	-0.4	

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