REDUCTION OF ARCH LENGTH AND ITS EFFECTS ON AIRWAY DIMENSIONS IN ADULT PATIENTS: A SYSTEMATIC REVIEW

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Daniel Chenman, DMD
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Thesis Approval(s):

John V. Moore III, MEd Thesis Advisor, Oral Health Sciences
Jeffrey H. Godel, DDS, MS, Orthodontics
James J. Sciote, DDS, MS, PhD, Orthodontics

ABSTRACT

Objectives: The aim of this systematic review was to collect and review literature that used cone beam computer tomography (CBCT) imaging to study changes in the upper airway of adults who have undergone orthodontic treatment which retracted incisors.

Methods: Pubmed, Mbase, Dentistry and Oral Science Source, and Web of Science databases were searched for relevant articles in English which met the inclusion criteria. Included articles had adult subjects orthodontically treated to retract incisors with pre- and post- treatment CBCT images. Excluded studies were case studies, opinion pieces, studies with adolescent subjects under 18 years old, or subjects with medical conditions or respiratory diseases. Studies were appraised using Joanna Briggs Institute appraisal index for cohort studies. Data collected included the sample size, age, treatment type, changes in airway volume, minimum cross-sectional area, and incisor retraction. Outcomes were analyzed using Forest Plots.

Results: Of the 1,314 studies found through search, 3 retrospective cohort studies were included. These studies represented 229 total participant, 154 extraction and 75 non-extraction. All studies found no significance between incisor retraction and airway dimensions between extraction and non-extraction groups. However, within the extraction group, one study found an increase in oropharyngeal volume, while another found a significant inverse correlation of maxillary distalization and airway volume. One study found significant posterior position of hyoid in the extraction group. The studies had moderate risk of bias.

Conclusion: Included studies have varying results on airway dimensions and volume that are small, and risk of bias cannot be ignored. The latest evidence for changes in arch length and incisor position on the airway with 3D imaging is weak. There is evidence that airway dimensions change in an adaptive manner to compensate for arch length and incisor position changes, which explains lack of significant changes in airway volume.

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CHAPTER 1

INTRODUCTION

There has been interest in connection with the oral cavity and its structures and the upper respiratory tract as they are in close proximity to each other. The upper respiratory tract is subdivided into three regions: nasopharynx, oropharynx, and hypopharynx. The oropharynx has been given attention as its position is posterior to the oral cavity. Its superior and inferior borders are from the soft palate to the epiglottis respectively. The tongue and its many muscles are in intimate connection with the oropharynx as it is part of its anterior border (Isaacs & Sykes, 2002). Tongue positioning has a direct effect of the airway space and can move forward by means of the genioglossus muscle to open the oropharynx (Pierce & Worsnop, 1999). Alternatively, if the tongue has been positioned posteriorly and inferiorly, it can constrict the airspace (Chen, Y. et al., 2012; Germec-Cakan et al., 2010). It is known that surgical setback of the mandible can constrict the airway via posterior and inferior position of the tongue unless there are other surgical procedures such as maxillary advancement (Chen, Y. et al., 2012; Grokce et al., 2014). In that case, a study found that the anterior displacement of the maxilla altered the superior portion of the pharynx to a greater extent than the mandibular setback yielding an overall increase of airway space (Grokce et al., 2014). However, other orthodontic treatments and their effects are beginning to be investigated more deeply.

Historically, extractions in orthodontic treatment have been a topic for contention. Guidelines and philosophies for extractions have shifted in parallel to extractions falling in and out of favor. As diagnosis and treatment planning have evolved through the century, there are additional facets to consider when deciding to extract teeth, but only in the past few decades has the effects of extraction on airway space been studied more closely (Dardengo et al., 2016; Pliska et al., 2016). In addition, retraction of incisors with maximum anchorage to prevent molars form moving mesially to close extractions spaces, as in class I bimaxillary protrusion, decreases the arch length (Germec-Cakan et al., 2010; Wang et al., 2011).

Since certain orthognathic surgeries tend to constrict airway space, it's important to consider how other treatments may affect this structure. Changing the oral cavity volume by means of reducing the arch length may have similar effects on tongue positioning which could alter the airway (Germec-Cakan et al. 2010). Studies have found that extraction cases of four premolars and retraction of incisors with maximum anchorage narrowed the airways space due to narrowing of the tongue space (Germec-Cakan et al., 2010; Wang et al., 2011).

Initial investigations have used lateral cephalograms to analyze the airway space. By using a two-dimensional image, analysis is only possible in the sagittal and vertical dimension. The transverse can be studied using a three-dimensional image generated by Cone Beam Computer tomography (CBCT) thus allowing us to compare the third dimensional value and calculate the area and volume of the airway (Pliska et al., 2016; Dalmau et al., 2015). Recent studies have shown that CBCTs are an effective and accurate method to measure and analyze the airway with greater intra- and inter-examiner reliability for airway volume and soft tissue landmarks (Zimmerman et al., 2016; Chen, H. et al., 2016).

The understanding of the types of orthodontic treatments that may affect tongue positioning and constriction of the airspace is of clinical significance. Since three-dimensional imaging provides more information that previously available to study orthodontic treatment effects, the aim of this study is to compare effects of arch length reduction on the airway space using three-dimensional imaging.

CHAPTER 2

REVIEW OF THE LITERATURE

2.1 Anatomy and Physiology of the Pharynx

The exchange of air, and in some parts, passage of food, is made possible by the pharynx, a musculofascial tube. Superiorly, it connects the nasal cavity and oral cavity to the larynx and connects to the esophagus inferiorly. There are three sections of the pharynx superior-inferiorly: the nasopharynx, the oropharynx, and the hypopharynx also called the laryngopharynx. The nasopharynx is the most superior section which is immediately posterior to the nasal cavity. Its inferior border is shared with the superior border of the oropharynx. This border is formed from a horizontal line extending from the soft palate to the posterior wall of the pharynx. The oropharynx is immediately posterior to the oral cavity. The inferior border is the tip of the epiglottis. The anterior border is composed of the isthmus faucium and the posterior aspect of the tongue. The lateral borders are made up of the lateral pharyngeal walls and the tonsillar fossae. The hypopharynx or the laryngopharynx is the most inferior section of the pharynx. It begins at the border of the epiglottis and has an inferior border at the inferior edge of the cricoid cartilage. It communicates anteriorly with the larynx, and inferiorly with the esophagus (Isaacs & Sykes, 2002).

The pharyngeal tube is composed of soft tissues with a layer of fascia encompassing the pharynx. The muscular components are mainly composed of the three pharyngeal constrictor muscles, superior, middle, and inferior constrictors, which overlap each other (Isaacs & Sykes, 2002; Zhou & Bi, 2021). They play a role in stabilizing the lower posterior and lateral walls of the pharynx (Pierce & Worsnop, 1999).

Another group of muscles are the pharyngeal dilators. They are responsible for maintaining a patient airway in conjunction with the constrictors. Dilators include the palatal muscles, genioglossus, and hyoid muscles. The palatal muscles affect patency in the area of the velopharynx, which resides posterior to the soft palate. The genioglossus muscle is an important dilator of the oropharynx and is responsible for anterior protrusion of the tongue. It attaches to the metal spine, hyoid bone, and the tongue. During inspirations, contraction of the muscle pulls the tongue forward. The genioglossus and position of the mandible also influence resistance and anteroposterior dimensions of the hypopharynx (Pierce & Worsnop, 1999). The oropharynx is mostly supported by soft tissues whereas the nasopharynx and hypopharynx have bony and cartilaginous supports (Chen, Y. et al., 2012).

2.2 Airway Imaging

Cone Beam Computed Tomography (CBCT) generates three dimensional images which is useful in studying volumetric analysis. Using CBCT, linear measurements, area slices, and volumes can be measured. Accuracy of CBCT measurements have been repetitively studied with an overall consensus that there is a high intra-examiner and inter-examiner reliability (Lenza et al., 2010). Soft tissue landmarks are well identified in CBCT images because the differences in densities between air and soft tissues are well visualized (Chen, H. et al., 2016). Unlike medical CTs and MRIs, CBCTs do not differentiate between specific soft tissues which may pose as a limitation in select diagnostic uses. However, this is not a concern for CBCT imaging used for analysis of airway space as the demarcation between the air space and boundaries of the airway is sufficient (Gurani et al., 2016).

Lateral cephalograms also provide a view of the airway space, but there are limitations when compared to CBCT. Since a cephalogram is a two-dimensional image depicting a three-dimensional structure, there are inherent errors that may occur such as superimposition and magnification errors. Additionally with cephalograms, neither cross sectional areas nor volume can be measured. These errors may be overcome with the use of a CBCT resulting in a more reliable analysis (Lenza et al., 2010; Gurani et al., 2016).

CBCTs are not without its limitations either. A major concern in interpreting images of airway space is standardization and reproducibility of images. Some CBCT equipment use natural head position when taking images. Clinically this position may be difficult to reproduce between different time points for the same subject or between different subjects and studies (Gurani et al., 2016). Other CBCT equipment have subjects in a supine position. There is evidence that this position changes the dimensions and morphology in the airway as compared to the natural head position. In a systematic review by Guijarro-Martinez and Swennen (2011), it was noted that ideal positioning for dimensions and morphology of the airway was natural head position. Also noted were discrepancies in reporting conditions of how CBCT images were captured by researchers. By having a standardized reporting and capturing methods for CBCT studies, there would be less bias and confusion when comparing values between subjects and different studies (Guijarro-Martinez & Swennen, 2011).

Measurements may be taken at different levels of the airway and measured as cross-sectional areas, minimum and maximum cross-sectional areas, linear measurements, and volume of the individual sections of the pharynx or the total airway volume. Minimum cross-sectional area can be obtained from CBCT images. This measurement is important as it is the site of airflow limitation. Comparatively, total volume of the airway may be more variable in terms of airway resistance due to the adaptions of other dimensions. As noted from obstructed sleep apnea subjects, improvement of the most constricted portion of the airway is beneficial. Although increase in total volume is important, such general increase may not have an effect on the most constricted portion (Lenza et al., 2010).

2.3 Arch Length, Tongue Position, and Airway Connection

Since the airway is located in close proximity to the oral cavity, many investigators have researched various morphologies and oromaxillofacial treatments and their impacts on this structure. A study found that mandibular position has an effect of the dimensions of the airway as measured with CBCT. The pharyngeal volume was greatest in the mandibular protrusive group, followed by a normal mandibular position, and least in the retrognathic group (Abdelkarim, 2012). The genioglossus muscle forms much of the tongue's mass and attaches to the anterior mental spines of the mandible and the hyoid bone (Pierce & Worsnop, 1999). Its position and function have a role in the patency of the airway. Because of these connections, anteroposterior positioning of the mandible influences the position of the tongue and its base. It has been noted that certain pathological states and syndromes, including anterior mandibular fractures or Pierre Robin syndrome which is characterized by retrognathic mandible, have glossoptosis which restricts the airway (Muto & Takeda, 2007).

Mandibular setback osteotomy procedures have been noted to changes the dimensions of the pharyngeal airway. In a three-dimensional CT study by Kawamata et al. (2000), they found that there was a decrease in both the lateral and frontal dimensions of the airway space. A sequence of adaptions took place after the procedure. It has been noted when the mandible is set back, the tongue will follow the mandible's new posterior position and encroach on the airway space. In order to compensate, there is a downward and backward displacement of the hyoid bone. Kawakami et al. (2005) found that shortly after the surgery, there is little to no changes in the airway dimensions as the hyoid bone has changed to its adaptive position. However, later after surgery the hyoid bone returned to the original position eliminating the adaptive changes of the tissue, and there was a significant reduction in airway space (Kawakami et al., 2005).

Similarly, changes to the space in the oral cavity may have similar effects on the tongue and related tissues as setback surgeries causing displacement into airway space. One such method is reduction of arch length. Arch length is a measure of the anteroposterior dental arch from the central incisors to a perpendicular line connecting the mesial surfaces of the first molars (Proffit & Fields, 2006). Closure of extraction spaces and retracting incisors decrease arch length. When incisors are retracted, the anterior portion of the oral cavity is moved posteriorly and exerts a posterior positional change on the tongue and soft palate. Along with these changes in the soft tissue, a similar down and backward movement of the hyoid bone is seen and is consistent to the finding of Kawakami et al. (2005) (Chen, Y. et al., 2012; Wang et al., 2012).

CHAPTER 3

AIMS OF THE INVESTIGATION

The aim of this investigation is to study the effects of arch length reduction and its associated effects on the airway via soft tissue changes. Being that the oral cavity and its components are in close proximity to and share structures with the airway, it is important to understand the relationship between these structures and any possible effects orthodontic treatment may have on them. In this systematic review, papers that investigated treatment effects of incisor retraction as a way to reduce arch length on the airway space and associated tissues via CBCT will be collected and synthesized.

CHAPTER 4

MATERIALS AND METHODS

4.1 Sources, Search, and Study Selection

Data bases searched included Pubmed, Embase, Dentistry and Oral Science Source, and Web of Science. Search terms included: cone beam computed tomography, adult, malocclusion, Class I, III, and III, upper airway, oropharynx, nasopharynx, hypopharynx, tongue position, hyoid bone, bimaxillary protrusion, arch length, incisor retraction, and orthodontic treatment. A full list of search terms, keywords, and MeSh terms can be found in Table 1 in appendix A. Citations and references were screed to identify any additional relevant papers. Search results were uploaded into Rayyan citation manager for processing (Ouzzani et al., 2016). Results were compiled, screened, and duplicates removed. Titles and abstracts of relevant articles were appraised for relevance as either “yes,” “no,” or “maybe.” For papers with “yes” and “maybe,” full texts were acquired and evaluated based on inclusion and exclusion criteria. Two reviewers (DC and MLF) independently reviewed studies by reading titles and abstracts and compared to eligibility and exclusion criteria.

4.2 Data Collection and Quality Assessment

Data extracted from the selected studies included: year of publication, author, title, study design, sample size, mean age of subjects, gender, dental and skeletal classification of subjects, when possible, orthodontic treatment preformed, mechanics, and CBCT image evaluation and measurements. The patient protocol for CBCT image capture and time points of images were extracted along with methods and techniques for airway assessment.

To assess quality of studies, methodology, and to inform of any possible bias, the Joanna Briggs Institute Critical Appraisal Checklist for Cohort Studies was used (Moola et al. 2020). The JBI appraisal tool has been peer reviewed to be an effective and valid tool for study appraisal (Munn et al., 2014). It has 11 item that can be answered as either Yes, No, Unclear, or Not Applicable. For each item in the checklist, there is a detailed explanation and how it applies to the study. An overall appraisal is generated based on the answers to the individual items in the checklist. Two reviewers (DC and MLF) independently appraised studies and any discrepancies were resolved by discussion between the two reviewers. The tool can be found in Appendix B

4.3 Eligibility

Eligibility of a study was judged on inclusion criteria formulated from the population, intervention, control, and outcomes of this study. Table 2 depicts a summary of the inclusion criteria as a PICOS format. Prospective and retrospective cohort studies published in English using CBCT imaging for analyzing effects of airway change in adult patients over 18 years of age were included. The studies need to have orthodontic treatment, such as extractions, space closure, and retraction of incisors, or any other treatment which decreases arch length with mechanics and anchorage magnitudes defined. A cohort control must be matched to the experimental group as close as possible.

The outcomes measured are amount of incisor retraction, dimensional changes of the oropharynx and/or any of its subdivisions as volume and minimum cross-sectional areas.

Table 1: PICOS inclusion criteria for selected studies

PICOS	Description
Population	Adult patients over 18 years old
Intervention	Orthodontic treatment which reduces arch length by means of extraction, distalization of dentition, or space closure. Maximum anchorage used in mechanics
Control	Orthodontic treatment with non-extraction or no treatment
Outcome	Airway changes: three-dimensional changes such as volume and minimum cross-sectional area of the oropharynx
Study design	Retrospective or prospective cohort studies.

Studies were excluded based on subject samples, study design, and treatments. Studies which included subjects who are medically compromised, have cleft lip and palate, craniofacial deformities, upper respiratory disfunction or disease, or obstructive sleep apnea were excluded. Non-human trials, narrative reviews, case reports, case series, and editorials were not included. Additionally, any studies that did not include mechanics used or protocol of CBCT image acquisition were excluded.

4.4 Statistical Analysis

Extracted data for statistical analysis included continuous variables such as means and standard deviations. T-Tests were used to compare differences in means of pooled data for airway volume, minimum cross-sectional area, sagittal, and transverse dimensions. Confidence intervals of 95% and effect sizes were calculated, and a $p < 0.05$

value was used to determine statistical significance. Forest plots were created to show the individual studies and pooled results. SPSS (v28) and excel, were used to perform the statistical analyses. Funnel plots were not used as there were only a few included papers and may result in misleading information.

CHAPTER 5

RESULTS

5.1 Search Results

An exhaustive search yielded a total of 1,314 studies based on search terms. After duplicates removed, 1,194 studies were screened. Of those, 1,183 were excluded. The remaining 11 studies underwent full text review and three were selected which met the inclusion criteria. After manually screening the 11 study's references, four additional reports were found and went through the same process. Eight studies were excluded based on lack of mechanics mentioned and incorrect study design. Finally, a total of three studies were included in the systematic review and the meta-analysis. The search process is demonstrated the PRISMA diagram in Figure 1.

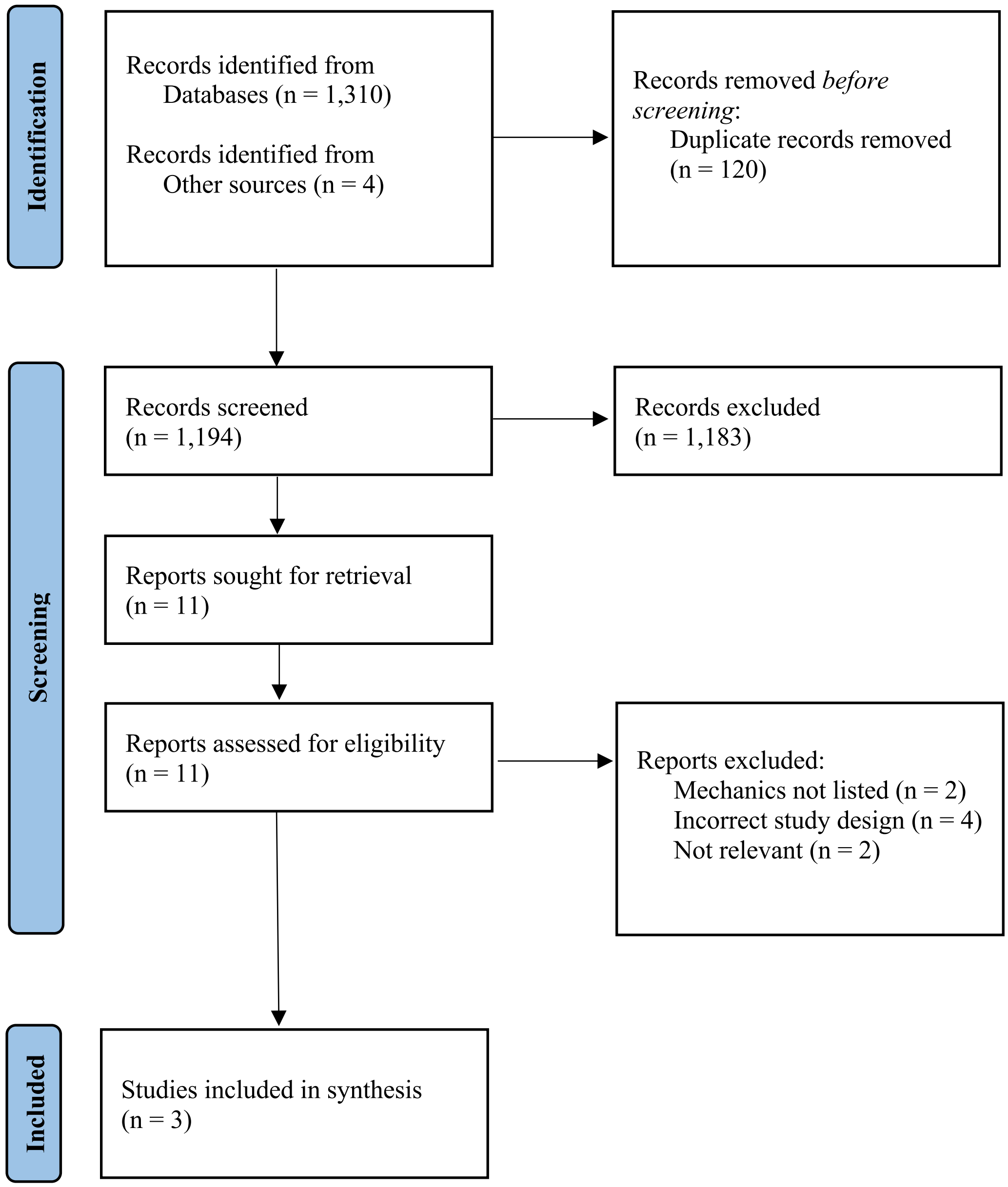

Figure 1: PRISMA Flow Diagram for Study Selection

5.2 Study Characteristics and Quality Assessment

The included studies were published between the years 2015 and 2022. Characteristics of the included studies can be found in Table 3 in the appendix C. All of the studies were retrospective cohort studies and demonstrated a moderate risk of bias. Two of the studies were conducted in China and one study was conducted in Korea. For acquisition of CBCT images, all studies noted at least head positioning and biting in centric occlusion with maximum intercuspation. However, only two studies mentioned breathing and swallowing instructions, and only Zhang et al. noted position of the tongue during image capture (Guo et al., 2022; Zhang et al., 2015). Two studies (Guo et al., 2022; Zhang et al., 2015) differentiated measurements of the airway in sagittal and transverse dimensions at the level of the posterior nasal spine and the epiglottis, which were the only levels that were in common between the studies, in addition to the total volume and minimum cross-sectional area. Zhang et al. (2015) measured sagittal and transverse measurements at additional levels of the airway. The results from JBI appraisal for all studies were rated as moderate risk of bias.

5.3 Airway Volume

Three studies were included in analysis of the airway volume. The meta-analysis showed no statistically significant change in airway volume which enrolled 154 subjects (ES= 0.21, 95% CI = -0.02 to 0.43, p=0.70). Only one study found a significant increase in oropharyngeal volume after extraction of premolars within the experimental group but not when compared to the control (Guo et al., 2022). One study found a significant moderate inverse correlation between the amount of incisor retraction and the airway volume within the extraction group which had a greater amount of incisor retraction than the non-extraction control. However, they did not find any significant in change in airway volume both within the extraction group nor when compared to the control group (Park et al., 2016).

#	Study name	Hedges' g	CI Lower limit	CI Upper limit	Weight
1	Guo	0.28	0.02	0.53	77.17%
2	Park	-0.1	-0.79	0.59	10.77%
3	Zhang	0.08	-0.57	0.73	12.06%
	Overall P = 0.70	0.21	-0.02	0.43	

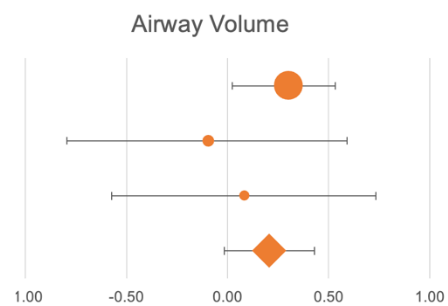

Figure 2: Forest plot showing pooled results for change in airway volume

5.4 Airway Minimum Cross-Sectional Area

Three studies were included in analysis of the airway minimum cross-sectional area. The meta-analysis showed no statistically significant change which enrolled 154 subjects (ES= 0.14, 95% CI = -0.28 to 0.53, p=0.23). One study found that in a subgroup of subjects with incisor retraction less than six millimeters (average 4.1 mm retraction), there was a significant increase in minimum cross-sectional area within the extraction group. However, there was no statistics reported on significance of dental measurements (Guo et al., 2022). Park et al. (2016) found a significant moderate inverse correlation between the amount of incisor retraction and the minimum cross-sectional area within the extraction group but did not find any significant changes within the extraction group nor between extraction and control groups.

#	Study name	Hedges' g	CI Lower limit	CI Upper limit	Weight
1	Guo	-0.2	-0.45	0.05	77.17%
2	Park	0.18	-0.52	0.89	10.77%
3	Zhang	-0.14	-0.81	0.52	12.06%
	Overall P = 0.23	0.13	-0.28	0.53	

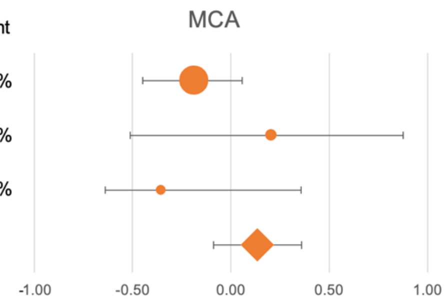

Figure 3: Forest plot showing pooled results for change in minimum cross-sectional area

5.5 Sagittal Dimension at the Posterior Nasal Spine

Two studies were included in analysis of the sagittal dimension at the posterior nasal spine. One study did not measure the values for the sagittal dimensions of the airway (Park et al., 2016). The meta-analysis showed no statistically significant change in the sagittal dimension at the posterior nasal spine between the 2 studies which enrolled 138 subjects (ES=0.12, 95% CI = -0.12 to 0.35, p=0.32).

#	Study name	Hedges' g	CI Lower limit	CI Upper limit	Weight
1	Guo	-0.2	-0.1	0.41	86.48%
2	Zhang	-0.14	-0.65	0.65	13.52%
	Overall P = 0.32	0.13	-0.12	0.35	

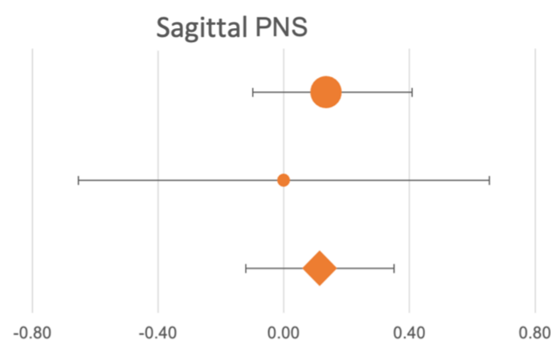

Figure 4: Forest plot showing pooled results for change in sagittal dimension at the level of the posterior nasal spine

5.6 Sagittal Dimension at the Epiglottis

Two studies were included in analysis of the sagittal dimension at the posterior nasal spine. One study did not measure the values for the sagittal dimensions of the airway (Park et al., 2016). The meta-analysis showed no statistically significant change in sagittal dimension at the epiglottis between the 2 studies which enrolled 138 subjects (ES=0.06, 95% CI = -0.29 to 0.18, p=0.64).

#	Study name	Hedges' g	CI Lower limit	CI Upper limit	Weight
1	Guo	-0.2	-0.13	0.67	58.2%
2	Zhang	-0.14	-0.65	0.65	41.8%
	Overall P = 0.83	0.13	-0.17	0.51	

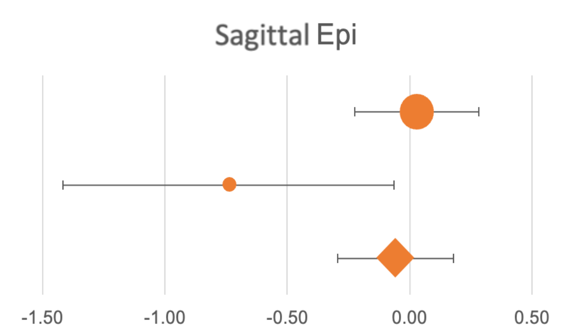

Figure 5: Forest plot showing pooled results for change in sagittal dimension at the level of the epiglottis

5.7 Transverse Dimension at the Posterior Nasal Spine

Two studies were included in analysis of the sagittal dimension at the posterior nasal spine. One study did not measure the values for the sagittal dimensions of the airway (Park et al., 2016). The meta-analysis showed a statistically significant increase in the transverse dimension at the posterior nasal spine between the 2 studies which enrolled 138 subjects (ES=0.33, 95% CI = 0.09 to 0.57, p=0.01).

#	Study name	Hedges' g	CI Lower limit	CI Upper limit	Weight
1	Guo	-0.2	0.09	0.6	86.48%
2	Zhang	-0.14	-0.35	0.96	13.52%
	Overall P = 0.01	0.13	0.09	0.57	

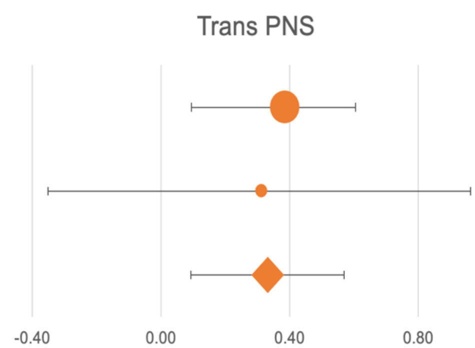

Figure 6: Forest plot showing pooled results for change in transverse dimension at the level of the posterior nasal spine

5.8 Transverse Dimension at the Epiglottis

Two studies were included in analysis of the sagittal dimension at the posterior nasal spine. One study did not measure the values for the sagittal dimensions of the airway (Park et al., 2016). The meta-analysis showed a statistically significant increase in the transverse dimension at the epiglottis between the 2 studies which enrolled 138 subjects (ES= 0.26, 95% CI = 0.02 to 0.4.9, p= 0.03).

#	Study name	Hedges' g	CI Lower limit	CI Upper limit	Weight
1	Guo	0.29	0.09	0.6	86.48%
2	Zhang	0.12	-0.35	0.96	13.52%
	Overall P = 0.03	0.26	0.02	0.49	

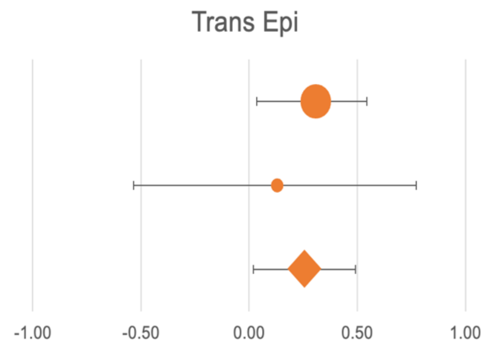

Figure 7: Forest plot showing pooled results for change in transverse dimension at the level of the epiglottis

CHAPTER 6

DISCUSSION

In this systematic review, studies which investigated reduction of arch length via incisor retraction were compared and analyzed for effects on airway dimensions using CBCT images. The inclusion criteria were created to control for effects of growth and orthodontic mechanics by including adult patients and treatment with maximum incisor retraction. After a search of data bases, references of other studies, and raw data from included studies where possible, a total of three studies matched the criteria for inclusion into this review. All studies were retrospective cohort in design with moderate risk of bias. The parameters used for the meta-analysis were airway volume and minimum cross-sectional area, both of which included all three studies. Additionally, both sagittal and transverse dimensions were compared at the levels of the posterior nasal spine and the epiglottis. Only two studies measured these values.

The meta-analysis for airway volume showed no statistically significant change in the volume of the airway. As a result, we cannot rule out that treatments which decrease arch length has an effect on airway volume. The study by Guo et al. (2022) had the largest sample size and was much greater than the other two studies which explains the smaller confidence interval. However, this was the only study that found a significant increase in airway volume. The other two smaller studies found a non-significant decrease in volume. Overall, the effect size in the analysis is small and there is a wide confidence interval causing uncertainty of the result. The meta-analysis for minimum cross-sectional area is the other analysis to use all three studies. This also was an overall nonsignificant change. Similarly to airway volume's analysis, the effect size is small with low level of certainty.

The sagittal dimensional changes at levels of both the posterior nasal spine and epiglottis were not significant. The total sample size of this analysis is smaller since only two studies measured these values, and there is a wide confidence interval with a small effect size resulting in low certainty of evidence. When looking at the transverse dimension for both the posterior nasal spine and epiglottis levels, there is a significant increase for both dimensions. However, both of these results should be interpreted with caution as there is a small effect size, wide confidence interval, and small sample size.

The lack of significant change in airway volume may be explained by a morphological adaptation of the airway when incisors are retracted. There is an increase in the transverse dimensions at two levels of the airway which may cause for an elliptical change in shape. As a result, any change in the sagittal dimension may be masked by enlargements of the transverse dimension. This analysis only used two levels of the airway for each dimension as they were in common between the included studies. Guo et al. (2022) found that there was a significant increase in the sagittal dimension at the posterior nasal spine and not at the epiglottis, but found significant increases for the transverse dimensions at both levels. Zhang et al. (2015) measured the sagittal and transverse dimensions at multiple levels within the airway in addition to the posterior nasal spine and epiglottis. They also measured the cross-sectional areas of each level. They found at each level of the airway there was no significant change in cross-sectional area, but there was a significant decrease and increase of the sagittal and transverse dimensions respectively within the extraction group. This supported the idea that the airway is free to adapt by changing shape (Zhang et al., 2015). The two measurements in common, the posterior nasal spine and epiglottis, are the superior and inferior boarders of the oropharynx respectively, and looking at only the boarders may only reveal a small portion of airway changes.

Dental measurements were measured by all included papers but there were variations between specific measurements used in the studies. Positions of upper incisors and upper molars were measured in all studies. Only one paper additionally studied lower incisors and molars position. One study only listed the amount of incisor retraction but did not use any statistical analysis when addressing the values within and between groups. Overall, the amount of incisor retraction varied. The largest amount of significant incisor retraction within the studies was 7.81mm and smallest was 3.26mm. Park et al. (2016) had the smallest amount of incisor retraction and found no significant changes both within the extraction group and when compared to the control. They did however find a significant moderate inverse correlation to incisor retraction and airway volume and minimum cross-sectional area (Park et al., 2016). Zhang et al. (2015) measured a significant retraction of 7.87mm for upper incisors and also did not find any significant changes in airway volume or minimum cross-sectional area. This study however was the only one to measure the sagittal and transverse dimensions at multiple levels and found the widening in the transverse to adapt for compression in the sagittal dimension (Zhang et al., 2015). It is possible that this amount of incisor retraction is too low to produce significant changes in airway volume that exhaust any possible adaptive changes in the soft tissue walls.

Maximum anchorage was stated in the inclusion criteria so that any decrease in arch length would favor maximal incisor retraction and minimal mesialization of molars. Previous studies comparing extraction and effect on airway demonstrated that extractions with maximum anchorage decreased the middle and inferior sections of the airway. Conversely, when extractions spaces were closed with minimum anchorage, there was an increase in the airway dimensions (Germec-Cakan et al., 2010; Chen, Y. et al., 2012). It was found that molar mesialization may make space for the tongue and decrease amount of incisal retraction which prevents encroachment into the airway space (Germec-Cakan et al., 2010; Wang et al., 2011). Standardizing and reporting mechanics within studies is important to control for these factors. For example, use of Class II elastics exerts a mesial force on the lower molars when used for sagittal correction or as anchorage reinforcement when closing extraction spaces. If that is not accounted for, mechanics become a confounding variable.

Other confounding variables may be present and not accounted for in current studies which may lead to non-significant findings. Transverse dimension changes of the dental arch may play a part in size of airway space and was only measured in one of the included studies (Abdalla et al., 2019). Measurements for molar position was only accounted for in two of the studies. Additionally, palatal morphology may have a role in airway volume but was not measured in any included study. It was found that a smaller palatal volume is associated with smaller airway space and decreased minimum cross-sectional area (Kecik, D., 2017).

Skeletal classifications may predispose smaller airway dimensions and could confound result. Hyperdivergent patients were found to have a larger total airway volume than hyperdivergent patients (Celikoglu et al., 2014). Class II patients were found to have a significantly smaller airway when compared to Class I and III patients in a CBCT study (Tseng et al., 2021). Guo et al. (2022) additionally studied how extractions affected airway in different skeletal classifications. They found that airway volume increased significantly in Class I, and Class II hyperdivergent patients had no significant changes in airway volume. This was the only study included in this systematic review that investigated different skeletal classifications and orthodontic treatment on airway thus incorporation of skeletal pattern into the analysis was not possible.

CBCT image capture may also pose as a confounder. Although all studies included methods for image captured, they varied greatly in their details. A systematic review found natural head position was ideal for measuring dimensions of the airway and for base line measurements, but there was a lack of standardization of image capture in studies using CBCT images. Furthermore, having a standard procedure reduce bias and confusion when comparing measurements between different studies (Guijarro-Martinez & Swennen, 2011). Although natural head position may be the ideal position, it can be difficult to reproduce (Gurani et al., 2016). Guijarro-Martinez & Swennen (2011) reported subject in a supine or seated position can alter the airway morphology for image capture. Subject positioning may be an important factor depending what is being investigated. For example, an obstructive sleep apnea study may use a supine position during image capture for visualization of airway morphology while sleeping. Different degrees of craniocervical angulation also have been shown to alter airway morphology and can make comparison between different studies using CBCT images difficult or may yield misleading results (Guijarro-Martinez & Swennen, 2011).

CBCT images, however, provide critical insight into transverse dimension, which a 2-dimensional lateral cephalogram cannot. It is impossible to measure cross-sectional areas and volume using lateral cephalograms. CBCT images are accurate with soft tissue landmarks that are easily identifiable, and there is good demarcation between soft tissue and air space boundaries which makes CBCT a good choice for 3-dimensional studies of airway (Lenza et al., 2010; Chen, H. et al., 2016; Gurani et al., 2016).

Although this meta-analysis was carefully performed, there are limitations to acknowledge. The analyses show evidence that there may be an adaptive increase of the transverse dimension when incisors are retracted, but the conclusions must be interpreted with caution as the risk of bias and low level of evidence in the studies cannot be ignored. A high level of evidence is a randomized control trial, but it is impossible to preform because the best level of care for a diagnosis cannot be randomized to some patients and not others. Since there is a low number of studies fulfilling the inclusion criteria, the analysis has a small sample size resulting in low power for this review. Due to the small sample size from a population of subjects from China and South Korea, generalizability of these finding is difficult and may not be applicable to other populations. Additionally, there is no long-term follow-up of any subjects within this study. CBCT images taken of the subject in the included studies are varying in the number of instructions given for image capture. There is a lack of standardization for CBCT analyses used and measurements for landmarks to analyze airway dimensions and volumes between included studies. As a result, only limited measurements for the airway can be pooled in this analysis. For this reason, the hyoid bone measurements could not be incorporated since the papers that measured hyoid bone position used different landmarks which could not be combined for analysis.

6.1 Future Direction

Future research within this area would benefit from incorporating tongue measurements to assess posture and positioning. Developing and using a standardize method to capture and measure CBCT images can decrease methodological heterogeneity and bias when comparing different studies. Furthermore, measuring both sagittal and transverse dimensions at multiple levels of the airway with the cross-sectional area would help identify specific 3-dimensional changes that are occurring within the airway. This would be more descriptive than only reporting the volume and minimum cross-sectional area. Since volume is a combination of three different dimensions, changes in one dimension may be masked by changes in a different dimension. Therefore, studying each dimension individually and or multiple cross-sectional areas within each dimension of the air way may provide additional information from the three-dimensional images than volume alone. Including dental measurements would provide information for how orthodontic treatment affects tooth positions which then can be interpreted with any changes of the airway space. This includes movement of molars, amount of incisal retraction, and any transverse changes in the dental arches. Information regarding palatal volume and morphology may also be a factor to consider.

CHAPTER 7

CONCLUSIONS

Conclusions from the review and analysis are:

- There were no significant changes for airway volume, minimum cross-sectional area, nor sagittal dimensions at both levels of posterior nasal spine and epiglottis.
- The transverse dimension at the level of the posterior nasal spine and epiglottis significantly increased.
- There is evidence that airway dimensions change in an adaptive manner by morphological changes to compensate for decreased arch length and retracted incisor positions. This may explain lack of significant changes in airway volume.
- Included studies have varying results on airway dimensions and volume that are small, and the risk of bias and low certainty of evidence cannot be ignored.
- The latest evidence for changes in arch length and incisor position on the airway with 3D imaging is weak.
- There may be unaccounted confounding variables which may also contribute to lack of significant findings.
- Due to these limiting factors, there is low confidence in these findings.

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APPENDIX A

Search Strategy and Terms

Table 2: Search Strategy and Terms

Database	Search completed	Keywords	Total studies retrieved
PubMed	9/17/2022	(airway OR airway space OR airway* OR nasophar* OR orophar* OR laryngophar* OR velophar* OR airway volume OR airway area OR airway measurements OR airway resist* OR breath* OR Upper airway OR upper airway resistance) AND ("Adult"[Mesh] OR non growing OR grow* AND (malocclusion OR angle class* OR Class I OR class II OR Class III OR Hyperdivergent OR normodivergent OR hypodivergent) AND (CBCT OR cone beam CT OR cone beam computer tomography OR 3D OR 3 dimensional OR three dimensional) AND (Arch length OR arch depth OR arch perimeter OR extraction OR retraction OR incisors OR tongue position OR tongue OR distal* OR bimaxillary protrusion OR protr* OR maxil* OR Mandib* OR tooth extract* OR orthodont* OR orthodontic treat* OR braces OR aligner* OR align* OR Invisalign OR teeth OR molar* OR position OR dentoalveolar protrusion OR bimaxillary dentoalveolar protrusion OR proclin* OR bimaxillary proclination OR incisor* proclin*) AND (((((((("Cone-Beam Computed Tomography"[Mesh]) AND "Tooth Extraction"[Mesh]) AND "Airway Resistance"[Mesh]) AND "Overbite"[Mesh]) AND "Orthodontics"[Mesh]) AND "Oropharynx"[Mesh]) AND "Hypopharynx"[Mesh]) AND "Orthodontic Anchorage Procedures"[Mesh])	921

Table 2: (continued)

Embase	9/17/2022	((((((((airway AND space OR airway* OR nasophar* OR orophar* OR laryngophar* OR velophar* OR airway) AND volume OR airway) AND area OR airway) AND measurements OR airway) AND resist* OR breath* OR upper) AND airway OR upper) AND airway AND resistance AND ((adult OR non) AND growing OR grow*) AND (((((malocclusion OR angle) AND class* OR class) AND i OR class) AND ii OR class) AND iii OR hyperdivergent OR normodivergent OR hypodivergent) AND (((cbct OR cone) AND beam AND ct OR cone) AND beam AND computer AND tomography OR (((3d OR 3) AND dimensional OR three) AND dimensional)) AND ((((((((((arch AND length OR arch) AND depth OR arch) AND perimeter OR extraction OR retraction OR incisors OR tongue) AND position OR tongue OR distal* OR bimaxillary) AND protrusion OR protr* OR maxil* OR mandib* OR tooth) AND extract* OR orthodont* OR orthodontic) AND treat* OR braces OR aligner* OR align* OR invisalign OR teeth OR molar* OR position OR dentoalveolar) AND protrusion OR bimaxillary) AND dentoalveolar AND protrusion OR proclin* OR bimaxillary) AND proclination OR incisor*) AND proclin* OR 'tooth extraction'/exp OR 'orthodontics'/exp) AND 'airway'/exp AND 'cone beam computed tomography'/exp OR 'airway resistance'/exp OR 'overjet'/exp OR 'overbite'/exp OR 'oropharynx'/exp OR 'hypopharynx'/exp) AND ('orthodontic anchorage'/exp OR 'tooth arch'/exp OR 'incisor'/exp)	101
DOSS	9/17/2022	cone beam computer tomography AND (dental extraction) OR (orthodontics) AND (airway OR airway space) AND (adult) OR (((((((((DE "DENTAL extraction") AND (DE "AIRWAY resistance")) AND (DE "INCISORS")) AND (DE "HYPOPHARYNX")	121

Table 2: (continued)

Web of Science	9/17/2022	((((CBCT) OR cone beam CT) OR cone beam computer tomography) OR (3D OR 3 dimensional OR three dimensional)) AND (((((((((((((((((((((((((Arch length) OR arch depth) OR arch perimeter) OR extraction) OR retraction) OR incisors) OR tongue position) OR tongue) OR distal*) OR bimaxillary protrusion) OR protr*) OR maxil*) OR Mandib*) OR tooth extract*) OR orthodont*) OR braces) OR align*) OR teeth) OR molar*) OR position) OR dentoalveolar protrusion) OR bimaxillary dentoalveolar protrusion) OR proclin*) OR bimaxillary proclination) OR incisor* proclin*) AND (((adult) OR Non-growing)) AND ((((((airway) OR Airway resistance) OR upper airway) OR hypopharynx) OR oropharynx))	167

APPENDIX B

Joanna Briggs Institute Critical Appraisal Tool for Cohort Studies

JBI CRITICAL APPRAISAL CHECKLIST FOR COHORT STUDIES

Reviewer_________________________________ Date__________________________

Author__________________________________ Year________ Record Number________

	Yes	No	Unclear	Not applicable
1. Were the two groups similar and recruited from the same population?	☐	☐	☐	☐
2. Were the exposures measured similarly to assign people to both exposed and unexposed groups?	☐	☐	☐	☐
3. Was the exposure measured in a valid and reliable way?	☐	☐	☐	☐
4. Were confounding factors identified?	☐	☐	☐	☐
5. Were strategies to deal with confounding factors stated?	☐	☐	☐	☐
6. Were the groups/participants free of the outcome at the start of the study (or at the moment of exposure)?	☐	☐	☐	☐
7. Were the outcomes measured in a valid and reliable way?	☐	☐	☐	☐
8. Was the follow up time reported and sufficient to be long enough for outcomes to occur?	☐	☐	☐	☐
9. Was follow up complete, and if not, were the reasons to loss to follow up described and explored?	☐	☐	☐	☐
10. Were strategies to address incomplete follow up utilized?	☐	☐	☐	☐
11. Was appropriate statistical analysis used?	☐	☐	☐	☐

Overall appraisal: Include ☐ Exclude ☐ Seek further info ☐

Comments (Including reason for exclusion)

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APPENDIX C

Included Study Characteristics

Table 3: Included Study Characteristics

Study, country, and design	Sample size, gender, and age	Dental Class	Skeletal Class	Treatment	Control	Volume	MCA	Sagittal	Transverse	Cross-sectional areas	HB	Dentition	Time points	Findings	JBI
Guo et al. (2022) China Retrospective cohort	n=120 (ext) n=40 (non ext) 120 F 25.4 yr	No Class II Div 2	Class I Normo, Class I Hyper, Class II Normo, Class II Hyper	Extraction of 4 first premolars and retraction of incisors	Non-extraction	Oropharynx	Oropharynx	Level of: PNS and epiglottis	Level of: PNS and epiglottis	Only the MCA	5 linear measurements	U1-SN, L1-MP, U1-X, L1-X	T0= before treatment T1= after treatment	Increase airway volume and MCA within extraction group only. No significant changes when compared to controls. Posterior hyoid bone movement in skeletal Class I	8 (mod)

Table 3: (continued)

Zhang et al. (2015) China Retrospective cohort	n=18 (ext) n=18 (non-ext) 5 M 13 F 24.1 ± 3.8 yr	Class II	n=18 (ext) n=18 (non-ext) 5 M 13 F 24.1 ± 3.8 yr	12 had extraction of 4 first premolars, 6 had extraction of upper first and lower second premolars	Non-extraction	Nasopharynx Velopharynx Hypopharynx	Nasopharynx Velopharynx Hypopharynx	Level of: PNS, Middle of soft palate, Tip of soft palate, Along Go-B line, Epiglottis	Level of: PNS, Middle of soft palate, Tip of soft palate, Along Go-B line, Epiglottis	Level of: PNS, Middle of soft palate, Tip of soft palate, Along Go-B line, Epiglottis	4 linear measurements	U1-SN, U1-VRL (mm), L1-MP, L1-VRL, U6-SN (degrees), U6-PP (degrees), U6_VRL (mm), L6-MP, L6-VRL (mm)	T0= before treatment. T1= after treatment	Changes in volume, MCA, height, cross-sectional area were non-significant. In the extraciton group, there was decrease of sagittal dimensions in middle and inferior parts of airway with unchanged cross-section areas at each level (compressed morphologically but increased transverse dimensions)	7 (mod)

Table 3: (continued)

Park et al. (2016) South Korea Retrospective cohort	n=16 (ext) n=17 (non-ext) 6 M 27 F 22.2±3.99 yr	Class II	Not included	Extraction of 4 premolars and retraction of incisors then whole arch distalization	Whole arch distalization	Oropharynx (total airway) and subdivided into velopharynx and glossopharynx	Oropharynx (total airway) and subdivided into velopharynx and glossopharynx	Not measured	Not measured	Not measured	Not measured	Crown, root, transverse, and axis of U6, U1, U3	T0= before distalization. T1= after distalization	No significant changes in airway volume of MCA between or within groups. There was a significant moderate inverse correlation between the amount distalized and airway volume in only the ext group	6 (mod)