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Retrospective Evaluation of the Changes in the Nasal and Pharyngeal Airway Volume After Miniscrew Assisted Rapid Palatal Expansion (MARPE) Appliance

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Retrospective Evaluation of the Changes in the Nasal and Pharyngeal Airway Volume After Miniscrew Assisted Rapid Palatal Expansion (MARPE) Appliance

Joanna Song, D.M.D.

Thesis submitted
to the School of Dentistry
at West Virginia University
in partial fulfillment of the requirements for the degree of

**Master of Science in
Orthodontics**

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2020

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pharyngeal airway, CBCT

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ABSTRACT

Retrospective Evaluation of the Changes in the Nasal and Pharyngeal Airway Volume After Miniscrew Assisted Rapid Palatal Expansion (MARPE) Appliance

Joanna Song, D.M.D.

Background and Objectives: A transverse deficiency of the maxilla is a pervasive skeletal problem that can affect almost a quarter of the primary dentition population. The interesting relationship between rapid maxillary expansion (RME) and its effects on the surrounding airway is not well described in the literature. For today's contemporary orthodontist, there are a variety of rapid palatal expanders (RPE) and expansion protocols to prescribe for patient treatment. Of late, the miniscrew-assisted RPE (MARPE) has been receiving attention by clinicians because of its increased orthopedic effects when compared to conventional RPE while avoiding the surgical procedure needed with SARPE. As MARPE treatment becomes increasingly popular, scientific evidence regarding its effects on the upper airway is limited. The orthopedic effects of RME could extend to alleviating obstructive sleep apnea symptoms with a hypothesized change in nasal and upper pharyngeal airway. The purpose of this study is to assess the volumetric changes in the nasal and pharyngeal airway volume after MARPE treatment with the use of CBCT imaging.

Experimental Design and Methods: IRB approval was granted by West Virginia University Office of Research Integrity & Compliance (#1908679933). Twenty subjects who underwent MARPE with the maxillary skeletal expander (MSE) as part of their orthodontic treatment were retrospectively studied. CBCT scans pre-expansion and immediately post-expansion with MARPE were collected from the patient archives of West Virginia University Department of Orthodontics (Morgantown, WV) and Wuhan University Department of Orthodontics (Wuhan, China). Thirteen subjects were patients of Wuhan University and seven subjects were patients of West Virginia University. Pre- and post-expansion airway volume measurements of the nasal cavity, nasopharynx, and oropharynx were measured to assess any significant changes following MARPE expansion and the resulting volumetric change in percentage. Linear measurements of the skeletal structures surrounding the nasal cavity before and after expansion were measured to assess the pattern of expansion of the airway. Statistical analysis of paired t-test and independent sample t-test ($\alpha = 0.05$) were performed.

Results: When separating the subjects into those who experienced a successful orthopedic split, there was a significant increase in nasal (14.1%) and nasopharyngeal (20.4%) airway volume post-MARPE expansion. The successful split group also saw a statistically significant increase in the linear measurement of the nasal cavity base width in the frontal plane (8%), and both the anterior and posterior widths in the transverse dimension (11% and 4.2% respectively). There were no statistically significant changes for airway volume or nasal skeletal measurements for the group who did not experience an orthopedic split.

Conclusions: The post-expansion effects of MARPE treatment include an increase in nasal cavity and nasopharyngeal volume, but no evidence that MARPE expansion can enlarge the oropharyngeal airway volume. The nasal cavity expands in a triangular pattern in both the frontal and transverse dimension following orthopedic expansion with MARPE.

DEDICATION

This thesis is dedicated to my parents, Steven and Cindy, for encouraging me to find passion in science and academics. The countless fights and arguments we had over report cards and homework must have been challenging for you, but I can see now that it was your way of pushing me to be my very best. The future I have in front of me is only because of you and your support. I love you both for all the sacrifices you've made for me and Kimberly, so that we could have a better life than yours. Thank you for being my biggest critic and loudest cheerleader, and I hope I've made you proud!

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Chapter 1: Introduction

BACKGROUND:

A transverse deficiency of the maxilla is a pervasive skeletal problem that can affect almost 25% of the primary dentition population³. Most clinicians recognize a transverse deficiency when it manifests as a posterior dental crossbite where the posterior maxillary dentition occludes lingually to the mandibular dentition. However, a transverse skeletal imbalance of the maxilla can also present in more nuanced ways, such as dental crowding, abnormal incisor inclination due to a short arch perimeter line, the presence of soft tissue buccal corridors, and can even be related to anterior-posterior malocclusions where a narrow maxilla is unable to accommodate the mandibular dentition. Once a proper diagnosis is made, the treatment goal is typically to orthopedically expand the maxilla. In pre-pubescent patients, the circummaxillary sutures are still patent and a rapid palatal expander (RPE) is the treatment of choice. As the patient ages, the cranial sutures surrounding the maxilla become increasingly interdigitated which increases the resistance to orthopedic expansion. In adults, the surgically assisted RPE (SARPE) is the gold standard for orthopedic expansion. However, many clinicians and patients shy away from treatment with a SARPE since it necessitates all the surgical cuts of a LeFort I in order to allow for separation of the maxillary palatal halves. In recent years, the mini-screw assisted RPE (MARPE) has become increasingly popular due to its increased orthopedic effect with the addition of temporary anchorage devices (TADs) incorporated in the expander design. The MARPE can be inserted by the orthodontist chairside, which avoids the invasiveness of a SARPE while providing increased orthopedic force that a tooth-borne RPE lacks. Due to the relative novelty of the MARPE appliance, the literature studying its effects on expansion are scarce.

As the role of the orthodontist changes today, the orthodontic community is increasingly focused on the importance of diagnosing obstructive sleep apnea (OSA) as part of routine treatment. OSA prevalence has been reported in the literature to be as high as 37% in men and 50% in women⁹, and 7.45% in the pediatric population¹⁵. In addition to the large array of morbidities associated with pediatric OSA, the long-term effects can persist into adulthood. Studies have shown that adults with OSA have an increased risk of developing serious medical issues, such as stroke, hypertension, coronary artery disease, and risk of early death. Pediatric patients diagnosed with both a maxillary transverse discrepancy and OSA have demonstrated improvements in in apnea-hypopnea index (AHI)¹⁷ and clinical symptoms such as nocturnal enuresis, snoring, excessive daytime sleepiness, and school related problems after being treated with rapid maxillary expansion (MRE)²⁷. With the intimate relationship of maxillary expansion on the upper airway, it would behoove the profession to determine if a commonly performed orthodontic procedure has an impact on the surrounding upper airway.

STATEMENT AND PURPOSE OF STUDY:

There are few studies published in the literature that study the effects of MARPE appliances on airway volume changes. The purpose of this study was to investigate the volumetric changes in the nasal and upper pharyngeal airway after MARPE treatment using CBCT imaging. The volumetric changes of the upper airway were divided into three anatomical compartments: nasal airway, nasopharynx, and the oropharynx. In addition, this study aims to investigate the pattern of expansion the nasal cavity experiences following MARPE treatment.

NULL HYPOTHESIS:

1. There is no significant difference in nasal airway volume pre-expansion and immediately post-expansion.
2. There is no significant difference in nasopharynx volume pre-expansion and immediately post-expansion.
3. There is no significant difference in oropharynx volume pre-expansion and immediately post-expansion.
4. There is no significant difference in skeletal nasal superior width in the frontal dimension pre-expansion and immediately post-expansion.
5. There is no significant difference in skeletal nasal inferior width in the frontal dimension pre-expansion and immediately post-expansion.
6. There is no significant difference in skeletal nasal anterior width in the transverse dimension pre-expansion and immediately post-expansion.
7. There is no significant difference in skeletal nasal posterior width in the transverse dimension pre-expansion and immediately post-expansion.

ALTERNATIVE HYPOTHESIS:

1. There is a significant difference in nasal airway volume pre-expansion and immediately post-expansion.
2. There is a significant difference in nasopharynx volume pre-expansion and immediately post-expansion.
3. There is a significant difference in oropharynx volume pre-expansion and immediately post-expansion.

4. There is a significant difference in skeletal nasal superior width in the frontal dimension pre-expansion and immediately post-expansion.
5. There is a significant difference in skeletal nasal inferior width in the frontal dimension pre-expansion and immediately post-expansion.
6. There is a significant difference in skeletal nasal anterior width in the transverse dimension pre-expansion and immediately post-expansion.
7. There is a significant difference in skeletal nasal posterior width in the transverse dimension pre-expansion and immediately post-expansion.

ASSUMPTIONS:

1. Pre-treatment CBCT scans were taken prior to any orthodontic or orthopedic intervention, and post-treatment scans were taken immediately at the end of MARPE appliance activations.
2. CBCT scans were of diagnostic quality and the scan resolution can accurately detect skeletal and airway landmarks. Scans are free of distortion from patient movement and minimal radiographic artifacts.
3. All CBCT scans were taken in centric occlusion.
4. Operators of the CBCT equipment and imaging software are calibrated and understand how to use the technology appropriately.
5. CBCT scans are in a 1:1: ratio to allow for precise evaluation of linear measurements.

LIMITATIONS:

1. Small sample size.

2. Patient variability in terms of gender, age, ethnicity, skeletal maturity, craniofacial anatomy, and bone anatomy and physiology.
3. Treatment for each patient was variable in terms of:
 - a. The amount of appliance activation needed to resolve transverse jaw disharmony.
 - b. The anterior-posterior positioning of the appliance along the palate.
 - c. The number of mini-implants used to anchor and fixate the appliance to the palate.
4. Intra-operator variability exists in the investigator's ability to manipulate 3D imaging software to accurately orient pre- and post-expansion CBCT scans, determine landmarks, and obtain linear measurement for reliable comparison.
5. The resolution of CBCT in Dolphin imaging software, and noise and scatter produced by the metal of the expander and mini-implants make it difficult to precisely identify landmarks in post-expansion scans.

DELIMITATIONS:

1. Subjects selected from an age range starting from 8 years old and older.
2. Subjects selected based on MARPE treatment with the specific maxillary skeletal expander (MSE).
3. Subjects selected if diagnostic, full field of view (17x13 cm) baseline scans were available for both timepoints.
4. Subjects selected if there was no history of previous orthodontic or orthopedic treatment, and any craniofacial syndrome or deformities due to abnormal development or trauma.

Chapter 2: Review of the Literature

HISTORY OF EXPANSION

Rapid maxillary expansion (RME) was first proposed by E.C. Angell in 1860, but was quickly discredited by his peers for being impossible²⁶. Almost a century later, Andrew Haas repopularized expansion in the 1960's with his Haas style expander. Maxillary expansion today is generally accepted as a simple and predictable treatment modality for treatment of dental and skeletal transverse deficiencies.

The success of maxillary expansion historically was limited based on the patient's skeletal maturity. As the circummaxillary sutures of the head increasingly interdigitate with age, the resistance of the surrounding cranial structures prevents true orthopedic separation at the mid-palatal suture. If using a tooth-borne RPE, the transmitted lateral forces with appliance activation results in dental tipping which can cause adverse periodontal defects of the buccal mucosa and stability issues post-orthodontic treatment. Thus, RME was reserved for treatment of younger patients that in the clinician's judgement would successfully experience an orthopedic split. Today, there are a variety of expander appliances and development of new protocols, such as slow expansion, in attempt of increasing the success of RME in post-pubescent patients.

EXPANSION PATTERN

The expansion pattern following RME has been described as "triangular" or "V" shaped in both the frontal and transverse dimension. In the frontal dimension, there is less width change at the fronto-nasal sutures and increases inferiorly to the palate in the pattern of a right side up triangle. In the transverse dimension, there is less change observed at the level of the maxillary

permanent first molars compared to the central incisors where routinely a midline diastema develops.

A prospective study done by Ghoneima et al.¹⁰ investigated the effect of RME on the cranial and circummaxillary sutures of pre-pubertal and pubertal patients using CBCT imaging. Ghoneima found that the frontozygomatic, zygomaticomaxillary, zygomaticotemporal, and pterygomaxillary sutures showed no significant width increases following expansion. The other six cranial sutures responded differently depending on their anatomical location and degree of interdigitation, but all showed a significant increase. The amount of width change was greatest at the frontomaxillary, followed by the internasal, nasomaxillary, frontonasal, and frontomaxillary sutures. The mid-palatal suture width change was asymmetric due to a greater increase anteriorly at the central incisor position and decreasing posteriorly towards the posterior nasal spine (PNS).

Figure 1. Triangular expansion pattern with rapid maxillary expansion.

APPLIANCES FOR MAXILLARY EXPANSION

There are several designs of rapid palatal expanders in use today. Clinical preference and treatment goals will dictate which RPE is used in treatment.

- Tooth-borne RPE

A tooth-borne RPE relies on the dentition to hold the jackscrew in place. The lateral force applied should be rapidly and of orthopedic force in order to decrease the effects transmitted to the dentition. Common examples of tooth-borne RPE's include the Hyrax expander or acrylic bonded expander. The tooth-borne expander is commonly used in pre-pubertal and pubertal patients that the clinician reasonably expects a successful mid-palatal suture split.

Figure 2. The Hyrax expander fit with bands on the first permanent molars only, but can incorporate banded premolars into the appliance as well (left). The bonded expander typically has acrylic coverage over the maxillary premolars and first molar occlusal surfaces (right).

- Tooth-tissue-borne RPE

The Hass expander is a common tooth-tissue-borne RPE. In addition to using the dentition to hold the jackscrew in place, palatal acrylic pads are added as reinforcement so that the lateral force is also applied to the palate.

Figure 3. Haas expander with bands on first permanent premolar and molar, with acrylic palatal coverage.

- Hybrid RPE

With the popularization of TADs, RPE's designs have incorporated two or more mini-screws. This hybrid RPE utilizes the dentition to aid in insertion of the appliance, but the jackscrew is inserted against the palate with TADs to increase the orthopedic force directly to the skeletal halves of the maxilla. This expander is useful for maxillary expansion in patients that the clinician judges additional force is required than what a conventional RPE can provide.

Figure 4. Maxillary skeletal expander (MSE) shown above is a specific type of MARPE appliance. Four TADs are placed around the jackscrew through the guide holes, and the number of

teeth banded is variable depending on clinician preference. Anterior-posterior placement can also be variable along the palate.

Zong et al.³⁰ studied the skeletal and dentoalveolar transverse changes following MARPE expansion with the MSE appliance. The pre- and post-expansion CBCT scans of 22 young adolescent patients were retrospectively evaluated to determine the total expansion, skeletal expansion, and angular dental tipping at the first molar region achieved post-expansion. The patient sample included by Zong was a shared sample of patients also used for this thesis. A total expansion of 5.41 ± 2.18 mm was achieved with 59% of the expansion due to skeletal expansion. The remaining expansion was due to dentoalveolar changes in the permanent first molar buccal tipping ($2.56 \pm 2.64^\circ$). The authors concluded that expansion with MARPE appliances can be used to correct transverse maxillary deficiencies in adolescent patients with minimal dentoalveolar side effects.

- *Bone-borne RPE*

A bone-borne RPE is inserted into the maxillary palatal halves with TADs and does not incorporate the dentition in its design. This is to minimize the unwanted side effect of dental tipping. This design requires CBCT imaging to determine the bone depth for TAD placement and subsequent specialized laboratory fabrication of the expander.

Figure 5. A pure bone-borne expander using TADs solely to hold the jackscrew in place.

AIRWAY CHANGES WITH EXPANSION

There are studies describing upper airway changes seen post-expansion with different expanders and expansion protocols. The literature varies in which upper airway compartments were included for analysis, the patient age group, and the type of expansion studied. The purpose of this research was to evaluate the effects that MARPE has on the surrounding airway and if the post-expansion changes agree with the current literature.

Tooth-borne conventional MRE on upper airway volume

Zhao et al.²⁹ retrospectively studied the oropharyngeal volume change following expansion using CBCT imaging. Twenty four growing patients (mean age 12.8 ± 1.88 years old) were treated with Hyrax expansion, and compared to a control group consisting of patients who received orthodontic treatment only. The oropharynx was defined superiorly at the posterior nasal spine (PNS) and extended inferiorly to the most superior point of the epiglottis. The oropharynx was further divided into the retropalatal airway volume and the retroglossal airway volume, where the split was defined at the inferior point of the uvula (Figure 6).

Figure 6. Midsagittal plane section showing the oropharyngeal airway volume in red. The retropalatal airway volume is shown in green, and the retroglossal volume is shown in purple.

The results of this study showed that only the baseline retropalatal airway volume was significantly different between the two sample groups before any treatment was started, specifically that the control group started out with a larger volume. There were no significant differences observed between the control and experimental group in oropharyngeal volume following expansion and orthodontic treatment. The authors concluded that patients with

maxillary constriction have narrower oropharyngeal airways prior to treatment, and that there is no evidence that RPE treatment will enlarge the oropharyngeal airway.

Smith et al.²² repeated a similar study to Zhao et al. but incorporated the nasal cavity in their study design. The authors retrospectively studied twenty adolescent patients (average age 12.3 ± 1.9 years old) treated with Hyrax expanders and compared the change in airway volumes pre- and post-expansion. This study found there were significant increases in nasal cavity and nasopharyngeal volumes post-expansion and agreed with Zhao that no significant differences were observed for the oropharynx and hypopharynx volumes.

Figure 7. Boundaries of the upper airway compartments: A, nasal cavity; B, nasopharynx; C, oropharynx; D, hypopharynx.

SARPE on upper airway volume

SARPE expansion yields predictable results in adult patients requiring surgical intervention to separate the maxillary palatal halves due to increased sutural maturation. Despite

requiring all the surgical cuts of a LeFort I except the final down fracture, the pattern of expansion with SARPE is similar to the conventional RPE.

Pereira-Filho et al.²⁰ studied fifteen adult patients (30.2 ± 7.4 years old) who were treated with SARPE and Hyrax expanders and evaluated the change in oropharyngeal volume. Three timepoints were included to assess changes: pre-expansion, immediately after expansion, and six months post expansion. The results showed no significant differences in either cross-sectional area or volumetric measurements between the three time points. The authors noted the smallest transverse section moved inferiorly with treatment and there was a tendency for relapse in oropharyngeal volume after expansion.

Figure 8. Oropharyngeal volume construction shown in pink (top) and the smallest transverse cross section in the oropharynx (bottom, yellow ring).

Deeb et al.⁸ and Nada et al.¹⁸ investigated the volumetric change of the nasal airway following SARPE, and both studies concluded there is a statistically significant increase in nasal volume following expansion. Deeb reported an increase of 5.1% nasal airway volume, and Nada

reported 12.9% increase in nasal airway volume. The study by Nada compared the nasal airway volume pre-SARPE to a second time point 22 months post-expansion. The authors noted the change in airway volume was still significant even after almost two years had passed since the expansion was terminated, indicating a relatively stable change.

MARPE on airflow dynamic studies

Hur et al.¹³ published a case report on the effect of MARPE expansion and the upper airway airflow using 3D-computational fluid dynamics/fluid-structure interaction. The patient was an 18.7 year old male diagnosed with OSA. The study showed after expansion with MARPE, the cross-sectional airway area was significantly larger in the anterior nasal cavity compared to the posterior nasal cavity. These effects extended below to the oropharynx (Figure 9C, planes 1, 2, 3) and the upper part of the laryngopharynx (planes 4 and 5). There were additional changes in the airflow pressure and velocity due to a pressure drop in the upper airway, and a decrease in airflow velocity. The total resistance in the upper airway during the entire respiratory cycle decreased. The authors concluded that MARPE treatment can improve the airflow and decrease resistance in the upper airway, which may ultimately be an effective treatment modality for adult patients with moderate OSAS.

Figure 9. Three-dimensional models of the upper airway: initial (A), post-expansion (B), superimposition of models (C). The superimposition was done using the anterior cranial base as a reference structure (not shown in figure).

Bone-borne expander on upper airway volume

Kavand et al.¹¹ studied the airway volume change of 36 adolescents (average age 14.4 years old) treated with either a tooth-borne Hyrax expander, or a purely bone-borne expander. The initial CBCT was compared to a second timepoint taken three months post-expansion. Both experimental groups showed a significant increase in the nasal cavity and nasopharynx volume, but no significant increases in the oropharynx or maxillary sinus volumes. The results of this study suggest there may not be a requirement to use bone-borne expanders in younger patients for the purpose of achieving increased upper airway development as there were no significant differences between the tooth- and bone-borne expanders.

Figure 10. Tooth-borne and bone-borne expanders used.

MARPE expansion on upper airway volume

A recently published paper by Yi et al.²⁸ studied nineteen patients (average age 19.95 ± 4.39 years old) treated with MARPE. CBCT scans were taken pre-treatment and three months post MARPE expansion. The authors concluded that there was an 8.48% significant increase in nasopharyngeal volume, and no significant change in the oropharyngeal, palatopharyngeal, glossopharyngeal, and airway total volume. The study also concluded that nasal lateral width was greater post-expansion.

Chapter 3: Materials and Methods

IRB APPROVAL

Approval for exempt research was obtained from the Institutional Review Board of West Virginia University (# 1908679933) prior to the start of this study. See Appendix A.

SAMPLE DESCRIPTION

Twenty subjects who underwent MARPE as part of their orthodontic treatment were included in this study. Patient scans were collected and retrospectively analyzed from the patient archives of West Virginia University Department of Orthodontics (Morgantown, WV) and Wuhan University Department of Orthodontics (Wuhan, China). Thirteen subjects were patients of Wuhan University and seven subjects were patients of West Virginia University.

The patient sample included both growing and non-growing patients. After applying the exclusion criteria, the youngest patient was 8 years old and the oldest patient was 22 years old. The cervical vertebral maturation (CVM) ranged from stage two to six to assess skeletal maturation.

Inclusion Criteria

- No criteria for patient age.
- MARPE treatment with Maxillary Skeletal Expander (MSE) to correct maxillary transverse discrepancy.
- Full field of view (17x13 cm) CBCT scans of diagnostic quality, including all pertinent anatomy. Scans were captured before and immediately after expansion.
- No history of previous orthodontic or orthopedic treatment.

- No history of craniofacial syndrome or deformities due to abnormal development or trauma.

Exclusion Criteria

Subjects were excluded based on the following criteria:

- Lack of full field of view CBCT at either initial or post-expansion
- Scans with distortion due to patient movement

Pre-treatment and immediate post-expansion CBCT scans were collected for each patient. Each scan was de-identified and coded to protect patient privacy (WVU1, China 1, etc). The WVU CBCT scans were obtained with a Gendex GX-DP-700 cone beam 3-dimensional imaging scanner, and the Wuhan University CBCT scans were obtained with a NewTom VGi 9 cone beam (Imola, Italy). The chosen field of view was 17x13 cm with a 300 voxel size and 16 bit gray scale. Exposure components were pre-adjusted to the selected field of view: 11.30 seconds scan time, 85 KV, and 4.0 mA. All patients were scanned in standing supine position, upright head posture, and in maximum intercuspatation (MI). The data of each patient was reconstructed with 0.0 mm slice thickness, and the DICOM images were assessed using Dolphin imaging software (11.95).

APPLIANCE DESCRIPTION

All patients were treated with the maxillary skeletal expander (MSE) manufactured by BioMaterials Korea, Inc. The MSE consists of a central expansion screw which is held in place against or close to the palate. The design of the appliance may vary from patient to patient, but commonly the maxillary first premolar and first molar are pre-fit with orthodontic bands to allow

for the MSE arms to be soldered to. Four miniscrews are inserted through the guide holes surrounding the expansion screw and seated fully against the metal framework of the MSE (Figure 11). Each screw inserted perpendicular and bicortically through the palate for maximum skeletal anchorage. The miniscrews are 1.5-1.8 mm in diameter, and although the length varies depending on the anatomical thickness of the patient's palate, a length of 11-13 mm was routinely used.

The appliance design can vary depending on:

- Appliance position:
 - Anteriorly along the anterior palate distal to the third rugae. Placement more anteriorly is thought to increase the primary stability of the miniscrews due to the presence of thick palatal bone, and subsequently increase the propagation of forces to the nasomaxillary complex.
 - Along the middle of the palate in the region of the second premolar. Placement in this region may be ideal due to the presence of a flat palatal surface ensuring close contact with the jackscrew, but the palatal bone is thinner and bicortical insertion is likely to result in penetration through the nasal cavity.
 - Posteriorly on the hard palate, just anterior to the soft palate in the region of the permanent first molar. More posterior placement is thought to increase the orthopedic effect as the appliance activation is close to the resistant pterygoid plates.
- Appliance activation:
 - Depending on the amount of transverse correction needed, the number of jackscrew turns varied between patients. When the lingual cusps of the maxillary

first molars were in edge-edge contact with the buccal cusps of the mandibular first molars, appliance activation was terminated.

Figure 11. Typical design of MSE used for MARPE expansion in this study.

CBCT IMAGE ANALYSIS

1. Intra-Examiner Reliability

All landmark identification and measurements were done by one examiner (J.S). Ten randomly selected patients were re-measured by the examiner 2 weeks later to determine the intraclass correlation coefficient.

2. CBCT Image Orientation

To standardize the image analysis procedure, all CBCT scans were oriented in three planes of space (sagittal, coronal, and transverse). Image orientation was done with the use of Dolphin imaging software (11.95).

- Sagittal orientation was determined with a line of best fit down the skeletal midline.

Figure 12. CBCT head orientation in the mid-sagittal plane.

- Coronal orientation was based on Frankfort horizontal plane from the right lateral perspective.
- Transverse (axial) orientation was based on a line passing through the furcation of the permanent first molar from the right lateral perspective

Figure 13. CBCT head orientation in the coronal and transverse planes.

3. Defining the Nasal and Upper Airway Compartments

Definition of the airway compartments was adopted from Kavand et al. to allow for comparison of results. The upper airway was divided into three compartments in the mid-sagittal plane:

1. Nasal cavity:

- a. From the sagittal view, the nasal cavity was defined as the airway space bound by the lines connecting sella (S), nasion (N), the tip of the nasal bone, anterior nasal spine (ANS), posterior nasal spine (PNS), and back to sella.
- b. From the frontal view, the nasal cavity was outlined avoiding the surrounding maxillary, ethmoidal, and sphenoid sinuses.

Figure 14. Boundaries of the nasal cavity in the sagittal and frontal view.

2. Nasopharynx: the airway space bound by the lines connecting S, PNS, to the tip of the odontoid process, and back to S.
3. Oropharynx: the airway space bound by the lines connecting the tip of the odontoid process, PNS, menton, the most anterior-inferior point of the third cervical vertebrae, and back to the tip of the odontoid process.

Figure 15. Boundaries of the nasopharynx (A) and oropharynx (B).

4. Determining Airway Volume

With Dolphin imaging, the airway boundary was defined on the CBCT as specified above (green points and lines in Figure 16). Seed points (yellow dots) were then added to the negative space on each draft slice to calculate the airway volume (shown in pink). An airway sensitivity ranging from 20-50 was determined based on the examiner's judgement to best fill the negative spaces of the specific airway compartment in question while avoiding any of the surrounding cranial sinuses and hard bony structures.

Figure 16. Example of airway volume creation for the nasal cavity.

5. Measurement of the Skeletal Changes of the Nasal Airway

To determine the pattern of expansion for the nasal cavity following MARPE treatment, skeletal landmarks of the nasal cavity were defined in the frontal and transverse dimensions. The landmarks chosen for this study were based on easily identifiable and repeatable structures but not currently used in the literature as cephalometric landmarks.

- Frontal view (Figure 17): orient CBCT to view a coronal slice through the landmark of the furcation of the permanent first molar.
 - Superior landmark is defined as the widest point of the fronto-ethmoid suture.

- Inferior landmark is defined as the widest point of the wall of the nasal cavity passing through the tip of the vomer.

Figure 17. Frontal dimension showing measurements for superior and inferior nasal cavity width. Green line showing measurement, and blue line delineating the tip of the vomer bone.

- Transverse view (Figure 18): orient CBCT axially through the superior tip of the vomer bone.
 - Anterior landmark is defined as the widest point of the nasal cavity anteriorly.
 - Posterior landmark is defined as the widest point between the walls of the pterygoid plates

Figure 18. Transverse dimension showing measurements for anterior and posterior nasal cavity width at the level of the vomer tip.

STATISTICAL ANALYSIS

All statistical analyses were conducted using SAS (version 9.4, 2013, SAS institute Inc., Cary, NC). Paired t-tests were performed to evaluate nasal and pharyngeal airway volume changes between pre- and post-measurements with treatment of MARPE appliances. To examine the difference between successful orthopedic split and non-split patients in nasal and pharyngeal airway volume changes, we conducted two independent sample t-test. Intra-class correlation coefficients were calculated to evaluate the reliability of the measurements. Pearson correlation test was utilized to assess the relationship between nasal and pharyngeal volume changes. All statistical tests were two-sided and $p\text{-value} < 0.05$ was considered statistically significant.

Chapter 4: Results

INTRA-RATER RELIABILITY ANALYSIS

In order to assess the accuracy of the measurements done by one evaluator, pre-expansion and post-expansion measurements for ten randomly selected subjects were repeated two weeks apart. The intraclass correlation coefficient was high for all measurements, indicating a high level of agreement between the two sets of measurements done by the evaluator (Table 1).

Variables	Intra-class correlation coefficient
Nasal volume pre	0.991
Nasal volume post	0.993
Nasopharynx pre	0.989
Nasopharynx post	0.993
Oropharynx pre	0.999
Oropharynx post	0.998
Nasal width tip pre	0.986
Nasal width tip post	0.993
Nasal width base pre	0.993
Nasal width base post	0.989
Nasal transverse anterior pre	0.996
Nasal transverse anterior post	0.997
Nasal transverse posterior pre	0.985
Nasal transverse posterior post	0.986

Table 1. Reliability coefficient of each measurement.

COMPARISON OF PRE-EXPANSION AND POST-EXPANSION MEASUREMENTS

Due to a small sample size of twenty patients, a paired-test was run for three scenarios.

1. All samples included (n=20):

To account for a small sample size, a paired t-test was run for all patients regardless whether they experienced an orthopedic split with expansion or not. Paired t-test results showed

significant changes in an increase of nasal cavity volume, frontal dimension inferior nasal width, transverse dimension nasal anterior width, and transverse nasal posterior width following MARPE expansion (Table 2). No significant changes were seen for volume changes of the nasopharynx, oropharynx, and frontal nasal superior width.

	Pre-treatment		Post-treatment		T (df=19) ^a	P ^b
	Mean	SD	Mean	SD		
Nasal volume	16181.9	3257.8	18122.1	4915.7	2.98	.008**
Nasopharynx	5238.5	2331.8	5926.2	2185.0	1.65	.12
Oropharynx	16361.2	7249.4	17325.2	7594.1	0.95	.35
Nasal width tip	7.6	1.5	7.7	1.4	1.43	.17
Nasal width base	32.5	3.2	34.8	3.0	6.86	<.0001***
Nasal transverse anterior	28.6	4.4	31.3	4.6	6.10	<.0001***
Nasal transverse posterior	26.5	2.1	27.4	1.8	3.74	.001**

^a T-value from paired t test. df= degree of freedom

^b P-value from paired t test. *p<.05, **p<.01, ***p<.001

Table 2. Comparison of pre- and post-expansion measurements for all subjects.

2. Isolating subjects who experienced a successful orthopedic split (n=17):

One of the variables studied was whether clinically a successful orthopedic separation was observed at the mid-palatal suture. When isolating the measurements into those who experienced a successful split, the paired t-test results showed significant changes in an increase of nasal cavity volume, nasopharynx volume, frontal dimension inferior nasal width, transverse

dimension nasal anterior width, and transverse nasal posterior width following expansion (Table 3). No significant changes were seen for oropharyngeal volume and frontal nasal superior width distance.

	Pre-treatment		Post-treatment		T (df=16) ^a	P ^b
	Mean	SD	Mean	SD		
Nasal volume	15892.7	3025.0	18131.9	4814.1	2.89	.01*
Nasopharynx	4879.2	1847.6	5874.6	2172.6	2.31	.03*
Oropharynx	15914.2	7137.3	17855.4	7806.0	1.94	.07
Frontal nasal superior width	7.5	1.6	7.7	1.5	1.90	.08
Frontal nasal inferior width	32.4	3.3	35.0	2.7	7.49	<.0001***
Transverse nasal anterior	29.2	4.5	32.4	3.9	7.73	<.0001***
Transverse nasal posterior	26.1	2.0	27.2	1.8	4.09	.0009***

^a T-value from paired t test. df= degree of freedom|

^b P-value from paired t test. *p<.05, **p<.01, ***p<.001

Table 3. Comparison of pre- and post-expansion measurements for subjects with successful split only (n=17).

The nasal cavity volume increased by 14.1% and the nasopharynx volume increased by 20.4% following MARPE expansion. The percent change of linear measurement of the nasal cavity is useful to describe the pattern of expansion. In the frontal plane, the superior nasal width increased by 2.7% and the inferior nasal width increased by 8.0% post-MARPE expansion. In the transverse plane, the anterior nasal width increased by 11.0% and the posterior nasal width increased by 4.2% post-MARPE expansion.

3. Isolating subjects who did not experience a successful orthopedic split (n=3):

Three patients did not experience a successful orthopedic split following MARPE expansion: two patients had a CVM of 5, and the other patient had a CVM of 6. All three patients were skeletally mature.

When isolating the patients who did not experience a successful orthopedic split, the paired t-test results showed no significant changes in any of the measurements (Table 4).

	Pre-treatment		Post-treatment		T (df=2) ^a	P ^b
	Mean	SD	Mean	SD		
Nasal volume	17311.0	5036.9	18066.3	6644.1	0.72	.54
Nasopharynx	7274.3	4127.2	6218.7	2728.2	-1.21	.35
Oropharynx	18893.7	8967.0	14320.7	6668.8	-3.28	.08
Frontal nasal superior width	8.0	1.2	7.8	1.1	-1.73	.23
Frontal nasal inferior width	32.9	5.1	33.6	4.7	2.77	.11
Transverse nasal anterior	24.9	1.3	24.9	2.0	-0.15	.89
Transverse nasal posterior	28.7	1.9	28.6	1.8	-1	.42

^a T-value from paired t test. df= degree of freedom

^b P-value from paired t test. *p<.05, **p<.01, ***p<.001

Table 4. Comparison of pre- and post-expansion measurements for subjects with unsuccessful split only (n=3).

COMPARISON OF THE DIFFERENCE BETWEEN SUCCESSFUL & UNSUCCESSFUL ORTHOPEDIC SPLIT GROUPS

A two independent sample t-test was performed to evaluate any significant differences in each measurement between the group with successful orthopedic split and the unsuccessful orthopedic split. The results showed there were significant differences between successful split patients and unsuccessful split patients on changes (post minus pre values) in the oropharynx volume, the frontal dimension inferior width, and the transverse dimension anterior nasal width. None of the other measurements showed a significant difference between the two patient groups.

	Successful Split (n=17)		Unsuccessful Split (n=3)		T (df=18) ^a	p ^b
	Mean	SD	Mean	SD		
Nasal volume	2149.3	3062.9	755.3	1809.4	0.75	.46
Nasopharynx	995.4	1777.3	-1055.7	1512.7	1.87	.08
Oropharynx	1941.2	4114.3	-4573.0	2417.2	2.63	.02*
Frontal nasal superior width	0.2	0.4	-0.2	0.2	1.58	.13
Frontal nasal inferior width	2.7	1.5	0.7	0.4	2.29	.03*
Transverse nasal anterior	3.2	1.7	-0.1	0.8	3.2	.005**
Transverse nasal posterior	1.1	1.1	-0.1	0.1	1.78	.09

^a T-value from two independent sample t test. df= degree of freedom

^b P-value from paired t test. *p<.05, **p<.01, ***p<.001

Table 5. Comparison of the difference in measurements (post-pre) between successful and unsuccessful split groups.

CORRELATION BETWEEN THE CHANGE IN VARIABLES

Comparison of the difference for each variable (post-expansion minus pre-expansion measurement) showed there were significant positive correlations between measurements of the

nasopharynx and oropharynx volumes, nasopharynx volume and frontal nasal inferior width, oropharynx volume and frontal nasal inferior width, frontal nasal inferior width and transverse nasal anterior width, transverse nasal posterior width and frontal nasal inferior width, and transverse posterior nasal width and transverse anterior nasal width.

Change variable s ^c	d_nasal	d_nasop	d_orop	d_nwtip	d_nwbs	d_ntant	d_ntpos
	r ^a	r ^a	r ^a	r ^a	r ^a	r ^a	r ^a
	p ^b	p ^b	p ^b	p ^b	p ^b	p ^b	p ^b
d_nasal		0.33 .15	0.40 .08	0.03 .87	0.14 .56	-0.07 .77	-0.18 .44
d_nasop			0.63 .003**	-0.06 .79	0.55 .01*	0.36 .12	0.31 .18
d_orop				0.11 .63	0.49 .03*	0.32 .17	0.36 .11
d_nwtip					0.06 .81	0.08 .75	-0.02 .92
d_nwbs						0.63 .003**	0.46 .04*
d_ntant							0.77 <.0001***

^a Pearson correlation coefficient

^b p-value from Pearson correlation test. *p<.05, **p<.01, ***p<.001

^c d_nasal = post nasal volume - pre nasal volume

d_nasop = post nasopharynx - pre nasopharynx

d_orop = post oropharynx - pre oropharynx

d_nwtip = frontal post nasal width superior - pre nasal width superior

d_nwbs = frontal post nasal width inferior - pre nasal width inferior

d_ntant = transverse post nasal transverse anterior - pre nasal transverse anterior

d_ntpos = transverse post nasal transverse posterior - pre nasal transverse posterior

Table 6. Statistical correlation coefficient between change variables.

Chapter 5: Discussion

This retrospective analysis assessed the volumetric changes of the upper airway following expansion therapy with the MARPE appliance with CBCT scans. This study aimed to describe the expansion pattern of the nasal cavity with an orthopedic split of the mid-palatal suture due to MARPE expansion.

EFFECT OF EXPANSION WITH MARPE ON EACH AIRWAY COMPARTMENT

The group of subjects who experienced an orthopedic mid-palatal sutural separation showed significant differences between the pre-treatment and immediately post-treatment airway volumes for the nasal cavity (14.1% increase) and nasopharynx (20.4% increase). This agrees with previous studies done by Smith et al. and Kavand et al. No statistically significant changes were observed for the oropharynx volume following MARPE expansion, which agrees with studies done by Zhao et al., Smith et al., Kavand et al. and Pereira-Filho et al.

It's interesting to note the different results observed for the group of patients who did not experience a successful orthopedic split. This group showed no significant differences in any of the measurements pre- and post-expansion. These subjects were meant to serve as a control group where no changes were hypothesized post- MARPE expansion due to the lack of change in anatomy or function. However, with a sample size of three patients, the results obtained are not a reliable representation of the population. Future studies should aim to increase the sample size to increase the confidence of these initial results.

EXPANSION PATTERN OF THE NASAL CAVITY

RME with conventional tooth-borne RPE and SARPE has been previously shown to follow a triangular or “V” pattern of expansion. In the frontal plane, the split is greater at the mid-palatal suture than at the front-nasal suture and fans out with the base of the triangle positioned inferiorly near the palate. In the transverse plane, the fan shaped split is greater anteriorly along the mid-palatal suture at the maxillary incisors than posteriorly at the posterior nasal spine.

The expansion pattern with the MARPE appliance varies. It's thought that since the MARPE jackscrew is closer to the center of resistance of the maxilla, the lateral forces applied with appliance activation promotes a greater parallel sutural opening in the coronal view. Additionally, if the MARPE is placed more posteriorly along the palate the lateral forces are applied closer to the pterygoid plates. Since the pterygoid plates are an area of high resistance to expansion, and a posteriorly placed MARPE can promote more parallel sutural opening compared to a more anteriorly placed tooth-borne RPE. Thus, sutural pattern with MARPE appliances can vary between patients (Figure 19).

Figure 19. Showing patterns of sutural separation following MARPE. A) “V” pattern, B) paralleled pattern, and C) reverse “V” pattern.

The effect of RME on the surrounding nasal structure is not as widely studied. Tausche et al.⁴⁴ studied the change in nasal volume following SAPRE and concluded that greatest percent change occurred anteriorly at level of the nasal floor, which matched the “V” shaped opening of the mid-palatal suture. It’s probable that the pattern of nasal expansion is correlated with the shape of the mid-palatal suture opening as the soft tissue anatomy is intimately related to the skeletal structure. With a tendency towards more parallel sutural separation in MARPE patients, this research investigated if nasal cavity changes also tended to be more parallel.

In the group consisting of successful orthopedic split patients, the only nasal width measurement that showed no significant increase was the superior measurement of the frontal view. The other three nasal width measurements indicated a significant increase following MARPE expansion. This strongly supports that the anatomy of the nasal cavity was influenced by orthopedic changes of the palate.

However, the pattern of expansion for the nasal cavity appears to be more triangular than parallel. In the frontal plane the apex of the triangle is situated between the junction of the frontal and ethmoid bones which showed a 2.7% increase in width. The inferior nasal measurement increase is three times that of its corresponding measurement at a width increase of 8%. Similarly, the transverse plane shows a triangular pattern of expansion. The posterior nasal width increased by 4.2%, while a 11% change in anterior nasal width increased almost three times of the posterior width following expansion. This triangular expansion pattern is likely due to the complex boney articulations surrounding the nasal cavity that prevents a parallel separation, unlike what can be observed at the mid-palatal suture. With greater resistance along the cranial base, the change in skeletal nasal width is restricted more superiorly and posteriorly compared to the inferior and anterior portion of the nasal cavity.

DIFFERENCE BETWEEN SUCCESSFUL & UNSUCCESSFUL SPLIT GROUPS

The difference in oropharyngeal volume post-expansion was significantly greater for the group of successful split patients compared to the unsuccessful split patients. Although there was no significant change observed pre- and post-MARPE expansion for the oropharyngeal airway in any of the paired t-tests run, there may be some weak evidence of that MARPE expansion influences the oropharyngeal volume despite being statistically insignificant.

There was also a significant difference observed for the frontal inferior nasal width, and both the transverse anterior and posterior nasal width for the two groups. The successful split group saw an increase in the three variables, indicating that an anatomical and skeletal change occurred as a side effect of RME. However, keeping in mind of the small sample size of three unsuccessful split subjects is too small to draw conclusions on and these results need verification with future studies.

CORRELATION BETWEEN VARIABLES

There are significant positive correlations between the change in nasopharynx and oropharynx volumes, nasopharynx volume and frontal nasal inferior width, oropharynx volume and frontal nasal inferior width, frontal nasal inferior width and transverse nasal anterior width, transverse nasal posterior width and frontal nasal inferior width, and transverse posterior nasal width and transverse anterior nasal width. A positive correlation indicates that both variables increased in volume and/or width with expansion. The other variables were either positively correlated but not statistically significant or had no correlation with an R-value close to zero. None of the variables were negatively correlated as expected.

STUDY LIMITATIONS

Using static 3D reconstruction and head position

The technological advancement of using CBCT imaging to create a three-dimension model of the volumetric airway provides better insight to changes caused by treatment compared to static two-dimensional images, such as lateral and postero-anterior cephalometric radiographs. However, even CBCT scans are subject to inherent problems with head positioning influencing the airway structures. One of the assumptions of this thesis was the operator of the CBCT machine would place the patient in a natural head position during the scan. It was evident during orientation of the scan in Dolphin imaging that the reference landmarks were inconsistent with the patient's head tilt. This is problematic because the anatomy of the pharyngeal airway can change with extension of the head and neck. Better care taken to properly orient the patient head position would be beneficial to minimizing and standardizing the error between operators of the CBCT machine.

Effect of growth

This study included both growing and non-growing patients as part of the sample. This adds a variable in isolating the effect of expansion from natural growth. Transverse growth in children usually is the first dimension to finish and complete by the mid-teens. Since chronological age does not always correlate with skeletal maturity, an assessment of CVM is more accurate in predicting the changes due to growth and due to treatment. Seven patients had a CVM of 2/3, and the remaining sample were non-growing patients with a more mature CVM of 4 or greater. The changes observed in the growing patients must consider that natural growth of the cranial structures can contribute to the differences seen post-expansion. However, the short

duration between the initial CBCT and post-expansion scan should limit the minimal effect of growth and should support grouping all growing and non-growing patients together for analysis. In future studies, limiting the population to just non-growing patients would better isolate the effects of treatment if a larger sample size was available.

Error in accuracies of volumetric measurements

During data collection, there were several factors affecting the accuracy of the volumetric readings:

- Complex anatomy of the nasal cavity:

The complex anatomy of the nasal cavity was more difficult to measure compared to the nasopharyngeal and oropharyngeal compartments. This was primarily due to the curvature of the nasal conchae and proximity to the adjacent cranial sinuses. Since the sinuses of the head are interconnected, the negative space of the nasal cavity often extended into the ethmoid, sphenoid, and maxillary sinuses. The boundary set through Dolphin imaging was not able to accommodate a change in the shape of the nasal cavity as the structure tapers posteriorly in the sagittal dimension. Thus inevitably parts of the surrounding sinuses were included, or parts of the nasal cavity were excluded. The benefit of having only one evaluator perform measurements is that bias can be standardized, and the high intra-class correlation coefficient of this study suggests there is evidence to support the repeatability of the measurements.

- Patient condition and health:

It was evident in select patient scans there were mucous blockages in the nasal cavity. If the scan was taken while the patient was sick or experiencing seasonal allergies, the airway was filled with mucous which limited the sensitivity that seed points could accurately pick up the

negative space. This was problematic for rendering the volumetric measurements of the nasal cavity that already had complex anatomical structures to navigate around.

In the group of patients that did not experience a successful split, it was typical to clinically observe infection around the miniscrews and arms of the expander on the palatal side. Since the TADs extended bicortically through the palatal bone into the nasal cavity, the nasal mucosa likely was inflamed as well. Even after removal of the MARPE appliance, the inflammation may take days to resolve fully. Some CBCT scans at the second time point show mild signs of inflammation in the nasal cavity around the penetrating screw which influences the accuracy of the measured airway. However, no obvious signs of pathology were present, and readings should be affected minimally.

Since this study was retrospectively done, it is impossible to dictate when to expose the patient for a CBCT scan. The health of the patient was not taken into consideration when initial and post-expansion scans were taken, and thus the quality of data available for interpretation is limited. A future prospective study might provide improved records if full head, low dose CBCT scans were taken for initial and progress records.

- Artifacts from metal in post-expansion timepoint scan:

It's logistically difficult to avoid taking post-expansion scans without any metal artifacts. This study utilized CBCT scans taken immediately post-expansion to investigate any anatomical changes experienced by the surrounding airway structures. Popular RPE protocols advise leaving the RPE/MARPE for 3 months post-expansion to help hold the corrected transverse dimension while allowing bone to fill in the space between the separated sutures. In addition, the standard of care is often to begin orthodontic movement before, during, or immediately after expansion by bonding upper and lower orthodontic brackets. Thus, the presence of metal in the post-expansion

scan is almost impossible to avoid unless performing expansion therapies for research purposes only.

The negative space along the floor of the nasal cavity was altered by the radiopaque metal artifacts, which blurred the resolution of the image while also physically decreasing the amount of negative space to be accounted for. The actual volumetric data for each patient's nasal cavity may be larger than reported due to the affected image quality.

CLINICAL IMPLICATIONS

Rapid maxillary expansion may be a useful adjunct for treatment of obstructive sleep apnea in conjunction with comprehensive orthodontic treatment. The increased orthopedic effect of MARPE could be applied to younger, pubertal patients for increased effects on the nasal cavity and nasopharyngeal volume. It would be interesting to compare the volumetric change of conventional RPE's to MARPE expansion to assess if MARPE has increased effects on the upper airway volume.

Although an increase in nasal and pharyngeal airway volume is promising, the orthodontic profession should be aware of the limited changes seen in the oropharynx. The point of greatest restriction (minimum axial area) for an OSA patient can be located anywhere along the upper airway. Expansion therapy is unlikely to alleviate any sleep apnea symptoms if the minimum axial area is in the oropharynx. As expected, the severity of OSAS also plays a factor in the treatment necessary to resolve symptoms. The standard of care for patients with severe OSAS is a double jaw advancement to open the airway and decrease the resistance to airflow. Future studies could investigate the extent that RME has on mild, moderate, and severe OSAS patients, although the likely effect of expansion on the oropharynx will be limited.

As the diagnosis of obstructive sleep apnea is becoming more prominent in the medical and dental field for both pediatric and adult populations, a study investigating the effect of MARPE, or any of the expansion appliances and protocols, on the same sample of OSAS patients will to clarify the cause-effect of RME. This thesis could not study airflow dynamics since we did not have the equipment, but perhaps the most useful method to correlate changes in airway volume and airflow dynamics would be to study a group of OSAS patients prospectively and evaluate both airway volume changes with any observed improvements in airflow with 3D-computational fluid dynamics/fluid-structure interaction. Evaluating if an improvement of clinical symptoms is experienced can also shed light on the effectiveness of RME on OSAS symptoms.

Chapter 6: Conclusion

Orthopedic expansion with MARPE has become an option for clinicians today to treat maxillary transverse deficiencies in older teens and young adults that might otherwise not orthopedically split with a conventional RPE. The potential application of expansion as an adjunct treatment for obstructive sleep apnea has also become a topic of discussion in the orthodontic community. This study determined that the surrounding upper airway and anatomical structures are affected following MARPE expansion.

1. There is a significant increase seen in nasal airway volume following MARPE expansion.
2. There is a significant increase seen in nasopharynx airway volume following MARPE expansion.
3. There is no difference observed in oropharynx airway volume following MARPE expansion.
4. The nasal cavity expansion pattern is more triangular than parallel in both the frontal and transverse dimension.

Chapter 7: Recommendations for Future Research

- This study should be repeated with a larger sample size, particularly for the group of patients who underwent MARPE with no orthopedic split. This may be problematic in practice as clinicians prescribe MARPE with the intent of achieving expansion for the benefit of the patient's malocclusion and the number of failed expansion cases may be limited. Alternatively, patients who had only orthodontic treatment and no expansion could also be used as a control group.
- To assess the long-term stability of the changes seen post-expansion, it would be beneficial to add a third timepoint with a full head CBCT scan after the removal of orthodontic appliances. With the development of low dose CBCT scans, this may become feasible as clinicians incorporate a full head CBCT scans as part of their final records at the end of orthodontic treatment. However currently at West Virginia University, it is unethical to expose patients to a higher dose of radiation for research purposes only without the low dose machines.
- This study showed promising results that the upper airway experiences an increase in airway volume. A study assessing both changes in airway volume and airflow dynamics on the same subject group would shed light on not only the anatomical changes following MARPE expansion but also possible improvement in airflow resistance.

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APPENDIX

Appendix A: IRB Exempt

Acknowledgement of Exemption

10/15/2019

To: Peter Ngan

From: WVU Office of Research Integrity & Compliance

Protocol Type: Exempt

Approval Date: 10/15/2019

Submission Type: Initial

Expiration Date: 10/14/2024

Funding: N/A

WVU Protocol #: 1908679933

Protocol Title: Retrospective Evaluation of the Changes in the Nasal and Pharyngeal Airway after Miniscrew-Assisted Rapid Maxillary Expansion (MARPE) Appliance and Fixed Orthodontic Appliances

The West Virginia University Institutional Review Board has reviewed your submission of Exempt protocol 1908679933. Additional details regarding the review are below:

- This research study was granted an exemption in accordance with Research on existing data, documents, records, pathological specimens, or diagnostic specimens [45 CFR 46.101(4)]. In accordance with the Health Insurance Portability and Accountability Act, a waiver of research authorization has been granted. Please fulfill the subject accounting requirements associated with the granting of this waiver. All exemptions are only good for three years. If this research extends more than three years beyond the approved date, then the researcher will have to request another exemption. The following documents have been acknowledged for use in this study and are available in the WVU+kc system:
- Is the data you are receiving from China identifiable? If so you need to go through the IMport/Exoort department. If not, you may proceed as is.

The following documents were reviewed and approved for use as part of this submission. Only the documents listed below may be used in the research. Please access and print the files in the Notes & Attachments section of your approved protocol.

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Appendix B: Statistics & Raw Data