A Comparison of Volumetric Differences of the Velopharyngeal Airways in Patients with Cleft Palate: Implications for Palatoplasty Techniques

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INTRODUCTION

According to the NIH, 1 in every 2,000 children worldwide is affected by cleft palate (Kosowski et al., 2012). Many of these children, around 20-50%, will additionally develop velopharyngeal insufficiency (VPI), either due to a short soft palate or a non-functional levator veli palatini which results in the failure of the soft palate to create a seal between the oral and nasal cavities (Kao et al., 2008; Kurnik et al., 2020). This inadequacy allows air to escape through the nose as opposed to the mouth during oralized speech sounds, negatively impacting the ability to communicate (Sainsbury et al., 2019). Despite years of research into cleft palate surgical approaches, there is no universal procedure due to anatomical variances within those affected by cleft palate. Recently published articles (Chauhan et al., 2020; Haenssler et al., 2023; Mann et al., 2011) suggest that palatal lengthening by double opposing buccinator myomucosal flap ("the buccal flap approach") may provide a more effective means to preventing VPI.

STUDY AIM

In this study, the aim is to evaluate this promising approach with 3D MRI data to determine volumetric measurements of the velopharyngeal airways to better understand which surgical techniques can be used to improve speech outcomes. Data from this study will provide quantitative details about the anatomic and physiologic impact of the use of buccinator myomucosal flap during primary palatoplasty. We hypothesize that subjects with cleft palate repaired via Buccal Flap will demonstrate anatomical similarities in the volume of the velopharyngeal airways to that of the control group, whereas subjects with cleft palate repaired traditionally with intravelar veloplasty (IVV) or Furlow palatoplasty will exhibit larger airways.

MATERIALS & METHODS

Participants. *Data was collected from 30 male age-matched adult subjects. The study group consisted of 15 male adults with cleft palate that were repaired via Buccinator myomucosal flap during primary palatoplasty at 12 mo. of age, and no history of secondary speech surgery or orthognathic surgery, and the control group consisted of 15 male adults with normative non-cleft anatomy.*

Imaging. *Our study has built upon published static MRI protocols for assessing velopharyngeal (VP) structure among adults (Kotlarek et al., 2017; Perry et al., 2014a; Perry et al., 2014b), children (Kollara & Perry, 2014; Perry et al., 2014b; Perry et al., 2014c), and infants (Perry et al., 2011; Schenck et al., 2016).*

Surgical Approach. *All repairs for study subjects were performed by the same surgeon, Dr. Robert J. Mann. An incision posterior to the hard palate was made to separate it from the soft palate and expose the nasal and oral mucosa. A lateral incision anterior to the palate defect will be performed to create the buccal flap. Oral mucosa of each cheek is then exposed, allowing for the buccal flaps to be raised. The flaps will contain parts of the buccinator muscle and its vasculature, which will then be sutured over the gap that was formed between the hard and soft palate to cover both the nasal and oral sides of the defect (Varghese et al., 2015).*

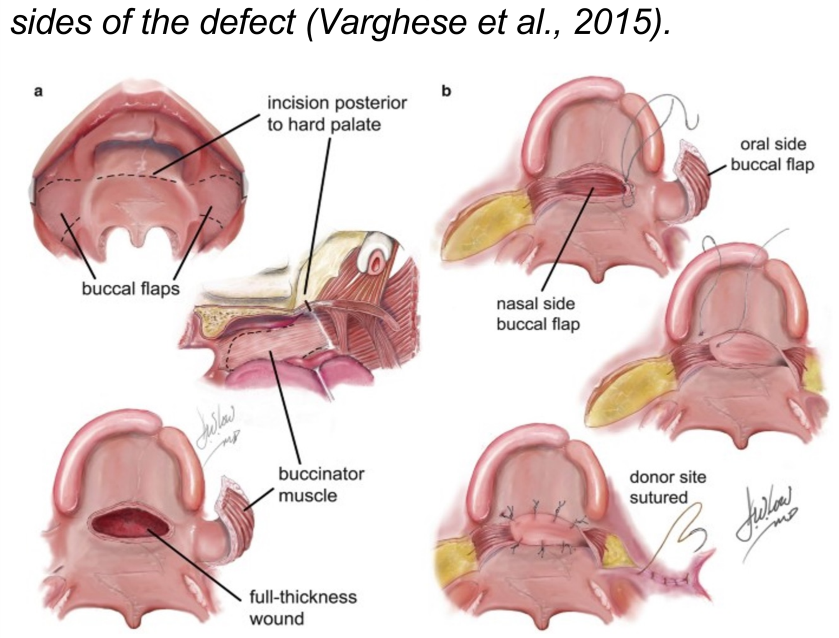


Figure 1. Buccal flap procedure implemented in the current study. The figure depicts the various steps throughout the surgery (Jackson et al., 2020).

METHODS (CONT.)

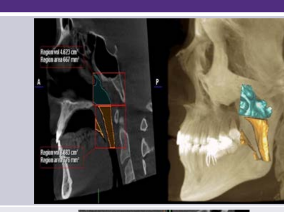
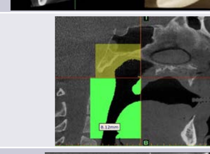
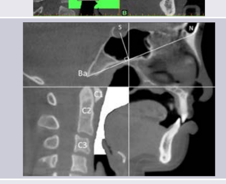
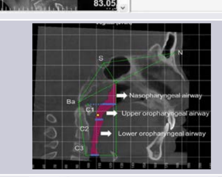
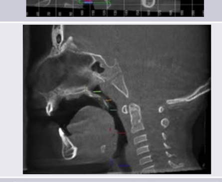
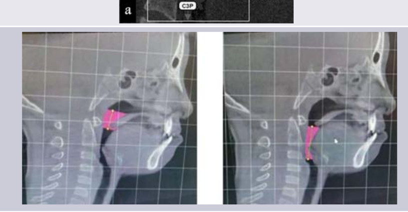
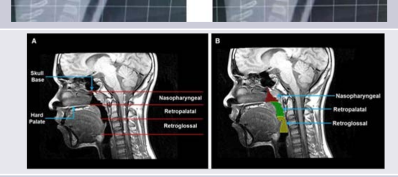
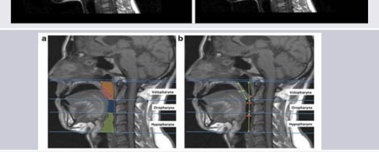
Previous Studies	Airway Definitions	
Comparison of Nasopharyngeal Airway Volume in Cleft Lip and Palate Patients With Normal Individuals Using Cone Beam Computed Tomography	nasopharynx (superior pharynx)= superior border: frankfurt plane, inferior border: horizontal line through PNS, anterior border: vertical line through PNS; oropharynx= superior border: horizontal line through PNS, inferior border: horizontal line at end of velum/soft palate	
Three-dimensional assessment of airway volumes in patients with unilateral cleft lip and palate	anterior border: vertical line from nasion-basion sella intersection, posterior border: posterior wall of pharynx, inferior border: horizontal line through bottom edge of C3, superior border: nasal floor	
Comparative Evaluation of the Pharyngeal Airway Space in Unilateral and Bilateral Cleft Lip and Palate Individuals With Noncleft Individuals: A Cone Beam Computed Tomography Study	anterior border: vertical line from nasion-basion sella intersection, posterior border: posterior wall of pharynx, inferior border: horizontal line through bottom edge of C3; division between nasopharynx and oropharynx= horizontal line through top edge of C1	
Assessment of pharyngeal airway volume in adolescent patients affected by bilateral cleft lip and palate using cone beam computed tomography	anterior border: vertical line from nasion-basion sella intersection, posterior border: posterior wall of pharynx, inferior border: horizontal line through bottom edge of C3; division between nasopharynx and oropharynx= horizontal line through top edge of C1	
Three-Dimensional Analysis of the Pharyngeal Airway Volume and Craniofacial Morphology in Patients With Bilateral Cleft Lip and Palate	anterior border: vertical line from nasion-basion sella intersection, posterior border: posterior wall of pharynx, inferior border: horizontal line through bottom edge of C3; division between upper and lower oropharynx= horizontal line through tip of soft palate	
Three-dimensional evaluation of the airway spaces in patients with and without cleft lip and palate: A digital volume tomographic study	oropharynx= superior border: palatal plane, inferior border: epiglottis plane; oropharynx was further divided-> PNS to middle of soft palate, middle of soft palate to tip of soft palate, tip of soft palate to base of tongue, base of tongue to base of epiglottis	
3-Dimensional Computed Tomographic Analysis of the Pharynx in Adult Patients With Unrepaired Isolated Cleft Palate	volumes measured= total volume, volume above palatal plane, volume between palatal plane and anterior bottom edge of C2, volume between C2 and anterior bottom edge of C3 planes	
Cone Beam Computed Tomography Analysis of Oropharyngeal Airway in Preadolescent Nonsyndromic Bilateral and Unilateral Cleft Lip and Palate Patients	division between superior and inferior oropharynx= horizontal line at the level of tip of soft palate; superior border: nasal floor, inferior border: anterior bottom edge of C3	
The study on the morphological changes of oropharynx in patients with complete unilateral cleft lip and palate after palatopharyngeal closure	Palatopharyngeal= superior border: horizontal line at level of hard palate, inferior border: horizontal line at the level of the tip of the soft palate/velum; glossopharyngeal= superior border: horizontal line at level of soft palate tip, inferior: horizontal line at level of bottom anterior edge of C3	
Understanding the Anatomic Basis for Obstructive Sleep Apnea Syndrome in Adolescents	Nasopharyngeal= skull base to level of hard palate; retropalatal= hard palate to bottom tip of soft palate; retroglossal= bottom tip of soft palate to base of tongue.	
Effect of mandibular advancement splint treatment on tongue shape in obstructive sleep apnea	Velopharynx= hard palate to tip of velum; oropharynx= tip of velum to tip of epiglottis; hypopharynx= tip of epiglottis to vocal chords	

Table 1. Variances Across Airway Definitions. *This table demonstrates the variability of definitions established for airway sections. Table information was collected during this study's literature review.*

Literature Review. *Studies involving the VP airways in subjects with cleft palate have obtained linear or volumetric measures by segmenting different sections of the airways. Each section has been determined based on certain anatomical landmarks. However, given the anatomical variances in subjects with cleft palate, methods for determining airway borders differ greatly across studies. Additionally, studies that have explored VP airways more commonly implement the use of CT imaging, which proves beneficial for examining bone. Nevertheless, this method of imaging is significantly less effective than MRI for capturing VP musculature and airways important in producing speech (Kao et al., 2008; Perry et al., 2024)*

Segmentation. *MRI data was imported into Amira 6.0.3 Visualization and Volume Modeling Software (Mercury Company Systems, Inc., Chelmsford, MA) and 3D volumetric measurements were taken in the segmentation editor workroom. The VP airways were divided into 4 separate sections defined by different borders, the nasopharynx, velopharynx, oropharynx, and hypopharynx. Airway borders were adapted from Ogawa's (2015) MRI study, given that the study's methods fully captured the area in question which is behind the palate and tongue.*

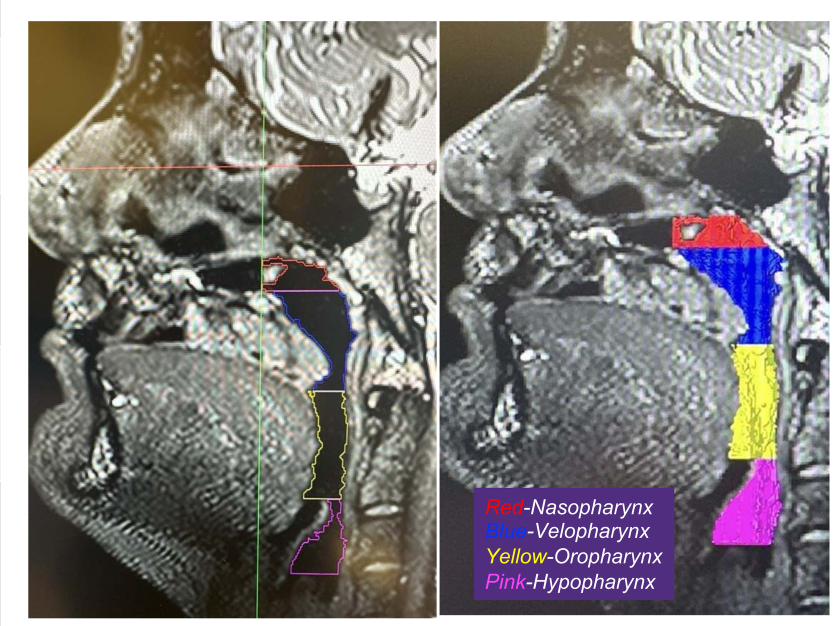


Figure 1. Segmentation procedure implemented in the current study. The figure depicts the 4 separate airway divisions. Borders were adapted from Ogawa's (2015) MRI study.

Statistical Analyses. *Volumetric measurements obtained by Amira were imported into Excel Spreadsheets to calculate the average volume among the different sections of airways for each group and to compare across control values obtained in previous studies. An Analysis of Variance (ANOVA) will be used to compare the values obtained across the two groups.*

PRELIMINARY DATA

Buccal Flap Subject ID	Airway Section Volume (mm³)				Total Airway volume (mm³)
	Nasopharynx	Velopharynx	Oropharynx	Hypopharynx	
003	3520.9	4529.2	2507	2080.3	12637.4
004	1521.9	4730.3	4352.6	2940.4	13545.2
006	2991.2	6248.9	3713.9	4221.1	17175.1
007	5625.3	2964.6	8911.9	56.6	17558.4
008	5093.1	7729.3	4022.2	1912	18756.6
010	5709.3	4275.9	4250	3225	17460.2
011	4127.5	4023.7	2565.2	4621.3	15337.7
012	3324.5	5117.9	2763	1493	12698.4
013	3269.4	4079.2	2998.6	996.5	11343.7
014	3420.9	3262.7	1281.5	3129.1	11094.2
015	5157.2	6245.4	2820.8	2588.5	16811.9
016	4114.3	3603.8	3335	1856.1	12909.2

Table 2. *The results of volume segmentation in Amira. This table displays the different volumes within each section of the airways, the nasopharynx, velopharynx, oropharynx, and hypopharynx, for subjects with cleft palate repaired via the buccal flap approach.*

Airway Section	Average Volume mm³ (SD)
Nasopharynx	3989.625 (1237.260256)
Velopharynx	4734.241667 (1396.632513)
Oropharynx	3626.808333 (1877.336631)
Hypopharynx	2426.658333 (1303.909898)
Total Airway	14777.33333 (2700.742121)

Table 3. *The average volume and standard deviation of each airway section. This table displays the volumes obtained from subjects with cleft palate repaired via the buccal flap approach.*

ANTICIPATED RESULTS AND DISCUSSION

- *Preliminary data from this study demonstrates that subjects with a history of cleft palate repaired via buccinator myomucosal flap during primary palatoplasty have VP airway dimensions similar to that of controls, when compared to data from previous studies.*
- *Given that previous studies have also shown that unrepaired cleft palate subjects exhibit significantly larger volumes in VP airways when compared to controls, smaller airways indicate a surgical outcome more similar to that of normative non-cleft anatomy, and thus, could produce better speech outcomes (Xu et al., 2015, 2020). However, the significance of the current study's results have yet to be determined.*
- *We anticipate that there will be no difference to controls in airway volume, and this will be found significant following the completion of control subject airway segmentation with Amira and an ANOVA to compare values between the study and control group.*
- *We will compare the results of the current study to subjects with cleft palate repaired traditionally via IVV and Furlow palatoplasty and hypothesize that this group will demonstrate airways larger than that of controls and subjects with cleft palate repaired via the buccal flap approach. We predict that this comparison will aid in surgeons being more informed as to which surgical variances result in the most functional VP anatomy, improving speech outcomes in cleft palate surgery.*
- *Given the importance of speech in communication with others, we predict that the results of the study will enhance the development of interpersonal skills in cleft palate patients affected by VPI.*

LIMITATIONS AND FUTURE DIRECTIONS

- *From our literature review, we found that previous studies examining the VP muscles and airways have been limited to CT image data and linear measures of muscle and airway variations (George et al., 2018; Perry et al., 2018).*
- *Moreover, the few studies that have attempted to examine the VP airways differ in their methods of airway segmentation, proving difficult to compare data (Miller et al., 2020).*
- *Future studies will need to establish standardized methods to better compare results and draw additional conclusions.*
- *The current study was limited by a relatively small sample size in the subject population, specifically cleft palate patients repaired via the buccal flap approach with no history of VPI. Thus, these results may not be applicable to all types of cleft palate patients, such as those requiring a second speech surgery. Additionally, the sample population differed in terms of demographics. Subjects also presented with a variety of cleft types, such as bilateral and unilateral cleft palate.*
- *As such, future studies with larger sample sizes will be required to aid in the generalization of results across greater populations.*

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