RELATIONSHIP BETWEEN PRE-OPERATIVE NASALANCE SCORES, VELOPHARYNGEAL CLOSURE PATTERNS, AND PHARYNGEAL FLAP REVISION RATE IN PATIENTS WITH VELOPHARYNGEAL INSUFFICIENCY

By

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ABSTRACT

Velopharyngeal insufficiency (VPI) is a disorder that results from the improper contact of the soft palate, lateral pharyngeal walls, and posterior pharyngeal wall. These muscle groups make up the velopharyngeal sphincter. This closure is necessary for the production of oral speech sounds. Improper closure leads to the production of nasal emissions during speech and an inability to produce pressure consonants. VPI is commonly treated surgically. A successful outcome of the surgery is determined by perceptual judgments of a Speech-Language Pathologist and with detailed objective instrumental evaluation (Losken, Williams, Burstein, Malick, & Riski, 2003). It is also necessary to examine the occurrence of surgical revision rates, as this directly relates to the success rate of a chosen surgical technique for a patient with VPI. Past studies have assessed the relationship between patient’s closure patterns with VPI and/or the type of revisions necessary when pharyngoplasty failed (Losken, et. al, 2003; Kasten, Buchman, Stevenson, & Berger, 1997; Witt, Marsh, Marty-Grames, & Muntz, 1995; Amour, Fischbach, Klaiman, & Fisher, 2005; Schultz, Heller, Gens & Lewin, 1973). Fewer studies have systematically studied pre-surgical implications that exist, which could offer valuable information to patients and surgeons. This study investigated if pre-operative oral word and sentence nasometric values and velopharyngeal closure pattern identified patients requiring revision surgery after an initial pharyngeal flap. Fifty-nine patients who were diagnosed with VPI and underwent a pharyngeal flap surgery were included in this study. All patients underwent an evaluation of velopharyngeal function by the craniofacial team at Women’s and Children's Hospital of Buffalo (WCHOB). The evaluation included perceptual and quantitative speech measures, clinical screening of velopharyngeal closure, and an oral peripheral examination. Perceptual ratings of speech were determined through live speech samples of the production of single words, sentences, and conversational speech. Resonance was categorized as hypernasal, hyponasal, mixed, or normal. Patients, who were categorized as having hypernasal speech, hyponasal speech, or nasal air emissions, were evaluated using nasometric instrumentation and multi-view videofluoroscopy/nasoendoscopy. A regression analysis was performed at an alpha level of $\rho \leq 0.05$; indicating pre-operative nasometry scores were significantly higher for those patients who eventually required a revision to the initial pharyngeal flap for alveolar, bilabial, and velar words and affricate sentences. Other comparisons of closure pattern, gap size, diagnosis, age, nasal utterances, low pressure context utterances, and high pressure utterances to revision rate resulted in no significant relationship. Post-operative results were not analyzed. When high nasometric values for oral word and sentence productions are noted pre-operatively, the likelihood of a revision surgery is increased. Nasometry can aid surgeons and Speech-Language Pathologists with preoperative patient counseling.
CHAPTER I

INTRODUCTION

VPI is a disorder that results from the improper contact of the soft palate, lateral pharyngeal walls, and posterior pharyngeal wall. These muscle groups make up the velopharyngeal sphincter. This closure is necessary for the production of oral speech sounds. Improper closure will lead to the production of nasal emissions during speech and an inability to produce pressure consonants, among other speech difficulties.

Cleft palate is one of the leading causes of VPI. Common practice calls for surgical repair of the structures and treatment relies heavily on the type and severity of the cleft. Following surgical repair, it has been found that 20-30% of children have persisting VPI (Abdel-Aziz, El-Hoshy, & Ghandour, 2011). VPI may also occur due to syndromic conditions such as Pierre Robin Syndrome, Treacher Collins Syndrome, Velocardiofacial Syndrome, Apert Syndrome and other procedures such as an adenoidectomy.

In the assessment of VPI, Speech-Language Pathologists often rely on perceptual measures as well as quantitative measures. Quantitative measures are typically collected using a Nasometer as well as direct visualization of the velopharyngeal sphincter using endoscopy. The use of a Nasometer provides valuable objective information and its use was supported in the study by Dalston, Warren, & Dalston (1991). This study found that the sensitivity and specificity of nasometry was 89% accurate when identifying subjects with more than mild hypernasality in their speech.

In assessing the physical parameters of the velopharyngeal sphincter, a multiview videofluoroscopy or flexible endoscopic evaluation of speech/swallowing (FEES) is typically obtained. Multiview videofluoroscopy requires patients to coat the nasal and pharyngeal passages with barium which allows for an x-ray view of the velopharyngeal sphincter and identification of the closure pattern. Closure patterns are categorized as coronal, which is the most common pattern, sagittal, circular, or circular with a Passavant’s ridge (Armour et. al, 2005).

Surgical repair for VPI and/or speech therapy is the recommended course of action. Surgical repair can consist of a superiorly or inferiorly based pharyngeal flap, a sphincter pharyngoplasty (both of which fall under the category of a pharyngoplasty), a double-opposing Z-plasty, or the Furlow Z-plasty. These procedures are all performed for the correction of VPI and aim to decrease the amount of airflow through the nasal cavity.

In an outcome study by Losken et al. (2003), patients who required a revision surgery following a pharyngoplasty (the sphincter pharyngoplasty procedure) for VPI had significantly higher pre-operative oral sentence nasometry percentages than patients who did not require a revision. This statement spurred a further investigation into the use of nasometry as a tool for predicting revisions.

Past studies have assessed the relationship between patient’s closure patterns with VPI and/or the type of revisions necessary when pharyngoplasty failed (Loksen et al., 2003; Kasten et al., 1997; Witt et al., 1995; Amour et al., 2005; Schulz et al., 1973). Fewer studies have systematically studied pre-surgical implications that exist, which could offer valuable information to patients and surgeons prior to the selection of surgical techniques to remediate VPI.
A successful outcome of the surgery is determined by the perceptual judgments’ of trained professionals such as Speech-Language Pathologists, and with the use of detailed objective instrumental evaluation (Losken et al., 2003). However, it is also necessary to examine the occurrence of surgical revision rates, as this relates to the success or failure of a surgical technique. The purpose of this study is to examine the revision rates for the pharyngeal flap procedure for the treatment of VPI. Clinical and physiological variables along with nasometric speech data will be examined to determine elements that may relate to the likelihood of failure of the initial pharyngeal flap surgery and consequent revision.

If the findings of this proposed study indicate a relationship between higher nasalance levels and a specific closure pattern, these clinical measures may provide health care professionals a pre-surgical indicator for patients who are prone to surgical revision. The data collected in this study may also improve the pre-surgical decision making process of tailoring the pharyngeal flap to decrease the need for revision surgeries. For the purpose of this study, only patients who received a pharyngeal flap procedure will be analyzed.

**CHAPTER II - REVIEW OF THE LITERATURE**

**NORMAL SPEECH PRODUCTION**

When voicing, sound is produced following the controlled exhalation of air from the lungs through the resonating cavities of the vocal tract causing the human vocal folds to vibrate. To produce speech, the articulators in the oral cavity must then move and shape the air into understandable/intelligible speech sounds. The key articulators needed to form speech sounds include the lips, tongue, and soft palate/velum. Typically the soft palate stays elevated, isolating off the nasal cavity from the oral cavity to produce the majority of speech sounds. However, the soft palate lowers in order to produce the nasal consonants such as /n/, /m/, and /ŋ/ in English. In order to produce oral speech sounds, the soft palate or velum needs to be raised so that intraoral pressure can build in the oral cavity and air can flow through the oral constrictions. When the soft palate/velum is lifted, the pharyngeal walls move to make contact with the velum. This function is necessary for normal speech production.

A dynamic and functional velopharyngeal mechanism is crucial for normal respiration, feeding, and intelligible speech. This mechanism is located between the oral and nasal cavities and functions to coordinate appropriate airflow. Normal resonance is highly dependent on normal velopharyngeal structures and function. The velopharyngeal structures include the velum, the lateral pharyngeal walls, and the posterior pharyngeal wall. Velopharyngeal closure is accomplished by the coordinated movement of all of these structures (Kummer & Lee, 1996). In normal speech, the velum moves its position in order to achieve closure against the posterior pharyngeal wall so as to separate the oral and nasal cavities as necessary for speech production. Typical movement consists of the posterior pharyngeal wall moving anteriorly and the lateral pharyngeal wall medially. Movement towards the midline and velum can also occur. This synchronized movement is what provides the closure necessary to create the valve of the velopharyngeal port.
Velopharyngeal closure occurs for many activities, both pneumatic (i.e. for speech) and non-pneumatic (i.e. for swallowing). There are variable movement patterns for both types of activities as well as variability in the closure pattern between velopharyngeal movements of individuals. In normal individuals, differences in closure patterns exist (See Figure 1). These closure patterns occur due to the varying movements of the velum, lateral pharyngeal walls, and posterior pharyngeal wall. In normal speakers, variation in the position of the velum also occurs due to co-articulation due to the "fact that sounds adjacent to nasal sounds have more nasal resonance than the same sound in a different position in a word" (Warren, Dalston, & Mayo, 1993).

Four typical closure patterns exist: coronal, circular, sagittal, and circular with a Passavant's ridge. Because the pattern of closure can impact the type of surgical or prosthetic intervention for patients that have Cleft Palate or VPI, it is important to recognize these variations in the evaluation process (Siegel-Sadewitz & Shprintzen, 1982).

**Abnormal Speech Production in Cleft Palate/Velopharyngeal Insufficiency**

“A resonance disorder can occur when the velopharyngeal mechanism does not function adequately to prevent the transmission of sound into the nasal cavity” (Kummer, 1996). Inadequate velopharyngeal closure can occur due to various circumstances. However, for the purposes of this literature review, abnormal speech resulting in VPI will be the focus.

Cleft palate is a primary cause of VPI. It is defined as a "birth defect that occurs when the tissues of the lip and/or palate of the fetus do not fuse properly in utero" (Centers for Disease Control, 2011). It is a congenital malformation the results from incomplete closure of the lip and/or palate early in the fetal development process. This results in an opening in the roof of the palate/maxilla and may extend through the alveolus and philtrum. Due to this opening, air can flow through the nasal passages and the mouth causing communication difficulties and feeding issues. It can also affect dental development, jaw development, hearing, and the overall appearance of the face. Common practice calls for surgical repair of the structures and treatment relies heavily of the type and severity of the cleft. Following surgical repair, it has been found that 20-30% of children will have persisting VPI (Abdel-Aziz et al., 2011). VPI can also occur due to syndromic conditions such as Pierre Robin Syndrome, Treacher Collins Syndrome, Velocardiofacial Syndrome, and Apert Syndrome. Procedures such as an adenoidectomy can also create VPI.

The lip and palate are formed early in the fetal development between the eighth and twelfth weeks. Children can be born with a cleft and have either a cleft lip alone, cleft palate alone, or both a cleft lip and/or palate. When the cleft occurs in the palate, it can also occur only in the area of the soft palate or both the soft palate and hard palate. "Disturbances at any stage during palate development, for example, defective palatal shelf growth, failed or delayed elevation, and blocked fusion, can result in cleft palate" (Yu, Serrano, San Miguel, Ruest, Svoboda, 2009).

The cause of cleft lip and/or palate commonly results from both environmental and genetic factors (Dixon, Marazita, Beaty, Murray, 2011; Lees 2001; & Yu et al., 2009). Environmental risk factors can
include smoking, drugs, alcohol, and pesticides. With this, cleft lip and/or palate typically occur as an isolated malformation, but it can also be associated with congenital defects or as part of a syndrome (Dixon et al., 2011; Lees, 2001). Cleft lip and/or palate is the most common congenital craniofacial defect and occurs in approximately 1 per 750 live births in the United States. Clefts occur more frequently among Asians (about 1:400) and certain American Indians than in Europeans or European descendants and clefts are relatively less common among Africans and African Americans (about 1:1500) (Dixon et al., 2011). Treatment of the cleft is often done early in the child's life through various surgical plans. In addition, for treatment to be comprehensive, it is completed in a multidisciplinary manner through a cleft palate team.

Due to VPI, individuals with cleft lip and/or palate are typically the center of studies on resonance disorders. The incidence of speech disorders that arise from this population greatly depends on the type of cleft, the surgical methods used to treat the cleft, and the overall development of the child.

There is a continuing debate regarding the appropriate surgical methods for reducing velopharyngeal impairment in cleft palate and regarding the timing of surgery in cleft lip and palate (Peat, Albery, Jones, & Pigott, 1994; Sullivan, Marrinan, & Mulliken, 2010; Kasten et al., 1997; & Hassib, 2005). Speech perception is a principal outcome measure and is therefore important that reliable assessment methods are applied during pre- and postoperative assessment. With this, habilitation of cleft palate revolves around acceptable speech as it is "considered to be (1) the primary goal in treatment of these individuals and (2) more directly related to adequate velopharyngeal closure than to any of the other anatomical differences found in individuals with cleft palate" (Hagerty, Pettit, & Kane, 1958).

**ANATOMY & PHYSIOLOGY OF THE VELOPHARYNGEAL MECHANISM**

Production of normal resonance depends upon the ability to obtain adequate closure of the velopharyngeal port. Complex motor skills that involve the coordination of a diverse group of muscles are needed to achieve normal resonance.

An unimpaired velum typically moves posteriorly and superiorly. The posterior pharyngeal wall can move anteriorly diffusely or as a well-defined shelf, known as the Passavant ridge, and the lateral pharyngeal walls move toward the midline. The uvularis muscle also contracts during speech, adding bulk to the area on the upper surface of the soft palate. The adenoids, residing in the posterior pharyngeal wall, and the pharyngeal tonsils, on the lateral pharyngeal walls, may augment or interfere with the function of those walls in velopharyngeal closure.

As a person prepares to speak, the velum is partially raised and held at the ready position before speech begins; it then moves to the closed position as phonation starts. For nasal sounds (/m/, /n/, /ŋ/), the sphincter remains open. The ability of the sphincter to close is essential for compression of air behind the point of constriction so that consonants, especially high pressure consonants, (e.g. /f/, /s/, /θ/) can release with sufficient strength.
The three muscles of the palate (levator veli palatini, tensor veli palatini, and uvularis) work with the palatopharyngeus, the palatoglossus, and the pharyngeal constrictor muscles to produce velopharyngeal closure. The tensor veli palatini muscles arise from the membranous wall of the eustachian tube and passes around the hamular processes of the medial pterygoid plate of the sphenoid process. It inserts into the palatal aponeurosis. The levator veli palatini muscles also have their origin along the eustachian tube orifice. They meet in the midline in a slings-like fashion above and behind the aponeurosis. The uvularis is a small midline muscle sitting above and behind the levator sling (Hagerty et al., 1958).

The relative movement of the velum, lateral pharyngeal walls and posterior pharyngeal wall varies from individual to individual and as a result, different patterns of closure exist. Overall, four typical closure patterns can occur: coronal, sagittal, circular, and circular with a Passavant’s ridge. Because the pattern of closure can impact the type of surgical or prosthetic intervention for VPI, it is particularly important to recognize these variations in the evaluation process (Siegel-Sadewitz & Shprintzen, 1982). Coronal closure is the most common closure pattern and is present in approximately 55% of patients with normal velar function. The major contribution to closure occurs with the soft palate as it contacts a broad area of the posterior pharyngeal wall. In this pattern, there is little medial motion of the lateral pharyngeal walls. In contrast, sagittal closure is the least common pattern and is present in 10-15% of people. Palatal elevation is minimal here and the main contribution arises from the motion of the lateral pharyngeal walls towards the midline. This is the pattern seen most commonly in patients with persistent VPI after repair of a cleft palate (Kummer, 1996). Circular closure is found in approximately 20% of individuals and involves contributions from both the soft palate and the lateral pharyngeal walls. This results in a closure that resembles the velopharyngeal orifice becoming symmetrically smaller from all sides. And finally, circular closure with

<table>
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<tr>
<th>TABLE 1: SUMMARY OF VELOPHARYNGEAL MUSCLES AND FUNCTIONS</th>
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<tr>
<td><strong>Levator Veli Palatini</strong></td>
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<td><strong>Tensor Veli Palatini</strong></td>
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<td><strong>Musculus Uvulae</strong></td>
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<td><strong>Superior Constrictor</strong></td>
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<td><strong>Palatopharyngeus</strong></td>
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The three muscles of the palate (levator veli palatini, tensor veli palatini, and uvularis) work with the palatopharyngeus, the palatoglossus, and the pharyngeal constrictor muscles to produce velopharyngeal closure. The tensor veli palatini muscles arise from the membranous wall of the eustachian tube and passes around the hamular processes of the medial pterygoid plate of the sphenoid process. It inserts into the palatal aponeurosis. The levator veli palatini muscles also have their origin along the eustachian tube orifice. They meet in the midline in a slings-like fashion above and behind the aponeurosis. The uvularis is a small midline muscle sitting above and behind the levator sling (Hagerty et al., 1958).
the Passavant’s Ridge, occurs in around 15-20% of the population. It’s a circular pattern that involves anterior motion of the posterior pharyngeal wall. The movement of the posterior wall can occur diffusely or move as well defined shelf (the Passavant’s Ridge). When the Passavant’s ridge occurs, it can arise at the level of closure and effectively help to separate the oral and nasal cavities or it may arise below the level of closure.

When the movement of the velum is not sufficient for closure to produce the necessary speech sounds, VPI can arise resulting in hypernasal speech and nasal air emissions. This disorder results from the improper contact of the soft palate, lateral pharyngeal walls, and posterior pharyngeal wall. This closure is necessary for speech in order to accurately produce pressure consonants such as plosives, fricatives, and affricates. Other speech difficulties exist such as hyponasality, hypernasality, and nasal air emission.

Resonance Disorders: Velopharyngeal Mislearning, Incompetence & Inadequacy

Resonance refers to the manner in which airflow for speech is shaped as it passes through the oral and nasal cavities. When speaking, airflow should move smoothly through the oral cavity and out the mouth in order to articulate the speech sounds, excluding those of /m/, /n/, and /ŋ/ in which the air flows through the nasal cavity. In order for air to flow properly through either the oral or nasal cavity the soft palate or velum must lift to make contact with the posterior pharyngeal wall or slacken to open the velopharyngeal port. A resonance disorder occurs when there is an inappropriate opening of the velopharyngeal port, inconsistent movement of the velum, or an obstruction that interferes with the way the air flows through the system.

If the movement of the velum and/or pharyngeal walls are not adequate for closure, velopharyngeal inadequacy or velopharyngeal dysfunction may arise which can result in hypernasal speech, hyponasal speech, nasal air emission and weak pressure consonants. More specific terms are used to describe the nature of this resonance disorder based on the etiology of the velopharyngeal dysfunction. These include: velopharyngeal mislearning, velopharyngeal incompetence, and velopharyngeal insufficiency. The degree of specificity in terminology is felt to be important because each of these categories of velopharyngeal dysfunction has a unique underlying cause and therefore require different treatment and management methods (Kummer, 2006).
**Velopharyngeal Mislearning**

The speech characteristics of velopharyngeal mislearning appear similar to both VPI and velopharyngeal incompetence. However, individuals with velopharyngeal mislearning are not candidates for prosthetic or surgical management primarily due to the fact that there is no muscular or anatomical deficit of the articulators. Velopharyngeal mislearning occurs when the velopharyngeal valve does not close appropriately during speech due to incorrect articulatory placements and movements of the structures. In this case, all anatomical structures are intact and functional. During normal articulation development, children with normal structures who learn to produce speech sounds incorrectly can develop velopharyngeal mislearning. Misarticulations such as pharyngeal fricatives or posterior nasal fricatives may cause the velopharyngeal port to remain open and allow air to escape from the nose. This form of velopharyngeal dysfunction is phoneme specific and oftentimes inconsistent. However, it leads the perceptual speech of individuals to sound hypernasal. Other causes of velopharyngeal mislearning can include habituated speech patterns secondary to surgical correction following cleft palate as well as lack of auditory feedback.

**Velopharyngeal Incompetence**

Velopharyngeal incompetence refers to a physiological or functional deficit that results in poor or limited movement of the velopharyngeal structures. It is described by poor elevation of the velum with insufficient “knee action” during speech tasks (Kummer, 2006). Lateral and pharyngeal wall motion is minimal and closure is limited. The inadequate movement of the velopharyngeal structures is typically due to a neurological disorder or injury. However, numerous etiologies can arise.

Velopharyngeal incompetence has been reported to occur secondary to cleft palate repair resulting from poor muscle function. Oftentimes, muscle orientation and innervation is mended during the palatal repair, however, this does not always guarantee appropriate function following the surgical repair. Hypotonia and/or poor pharyngeal wall movement can also cause velopharyngeal incompetence. Motor speech disorders such as dysarthria and apraxia have also been found as an etiology of velopharyngeal incompetence. In dysarthric patients, hypernasality secondary to velopharyngeal incompetence has been found to be one of the primary characteristics (Yorkston, Beukelman, & Traynor, 1988). In apraxia, difficulty coordinating and sequencing articulatory movements affect the timing and closure of the velopharyngeal valve. Thus, it has been found that velopharyngeal closure occurs after the initiation of phonation, which inhibits the correct direction of the airstream (Warren, Dalston, & Mayo, 1993). Other causes of velopharyngeal incompetence may include cranial nerve defects or velar fatigue and stress incompetence (Kummer, 2006).

**Velopharyngeal Insufficiency**

VPI is caused by an abnormality of the structures. In this form of velopharyngeal dysfunction, an anatomical deficit is present. The deficit lies in the soft palate or superior constrictor muscles which results in the inability to achieve velopharyngeal closure. VPI is common in children with a history of cleft palate or a submucous cleft and is often managed surgically. VPI can also occur after
adenoidectomy and/or tonsillectomy. In this manifestation, structural defects preclude the adequate closure of the velum against the posterior and lateral pharyngeal walls. There is an inability for the velum to achieve firm contact and form a tight seal. With VPI, difficulties arise with the production of nasal and non-nasal speech sounds. The common perceptual signs of VPI such as hypernasality and nasal air emission will be seen. However, due to the complex nature and treatment of VPI, investigation into the appropriate assessment and preoperative predictors of outcomes is needed. Furthermore, in order to develop a better understanding of VPI and its manifestation, hypernasality, hyponasality, and nasal air emission must also be defined.

**Characteristics of Resonance Disorders: Hyponasality, Hypernasality, Nasal Air Emission & The Relation to Velopharyngeal Insufficiency**

**Hyponasality**

Hyponasality results from a resonance disorder that is caused by an obstruction in the nasal cavity, which results in a low nasalance score and an inadequate flow of air through the nose (Dalston, Warren, & Dalston, 1991). Perceptually, this causes an individual’s voice to sound “stuffy”. Hyponasality commonly affects the nasal consonants /m/, /n/, and /ŋ/. Thus, in hyponasal speech, these consonants tend to sound similar to their oral cognate pairs. Nasal obstruction is commonly a result of swelling in the nasal passages secondary to allergic rhinitis, a common cold, adenoid hypertrophy, or hypertrophic tonsils that protrude into the pharynx (Kummer et al., 1993). Hyponasality may also arise secondary to deviation of the nasal septum, choanal atresia, stenotic naris, maxillary retrusion, as well timing difficulties of the velopharynx (Kummer et al., 1996). Hyponasality is managed surgically and it has been found that maxillary advancement can often decrease hyponasality and improve characteristics of airway obstruction (Dalston, 1996). Speech therapy, in regards to management, is only recommended when hyponasality is inconsistent and secondary to timing errors of the velopharyngeal muscles. In addition, hyponasality is a common complication of the surgical management for VPI and linked to a percentage of the necessary revision surgeries (Wiit, Myckatyn, & Marsh, 1998).

**Hypernasality**

Hypernasality is the perceptual correlate of an inappropriate and excessive resonance of sound in the nasal cavity during speech (Kummer, Brigs, & Lees, 2003). Hypernasality is evident when the voice is characterized by excessive nasal resonance. Structurally, hypernasality is caused by excessive velopharyngeal opening, which results in a large amount of acoustic energy released through the nasal cavity (Rong & Kuehn, 2012). It is especially evident on voiced oral consonants and vowels. The severity of perceived hypernasality often correlates to the size of the velopharyngeal gap. For example, mild to moderate perceived hypernasality results in the nasalization of oral phonemes and a dominate use of nasal phonemes heard throughout connected speech (Kummer, 2006). The presence of consistent perceived hypernasality is a useful clinical indicator and often heard when a large velopharyngeal gap is present (Angelo, Lipira, Molter, Govier, Kane, & Woo, 2011). The primary focus of this study is hypernasality and its pre-operative assessment as it relates to VPI and the pharyngeal flap.
Nasal Air Emission/Nasal Turbulence

Audible nasal emission is the perception of air pressure as it escapes through the velopharyngeal valve and into the nasal cavity during the production of pressure consonants (Kummer et al., 2003). Audible nasal air emission and/or nasal turbulence describes an occurrence when the air stream through the nose becomes audible due to friction as the air passes through a narrow passage in the nasal, velar and/or pharyngeal area. Perceptually, this can occur either as a relaxed flow of air that is called nasal air emission or a sharp frication sound which is called nasal turbulence. Other terms for nasal turbulence include nasal snort and nasal rustle. Nasal turbulence is often heard in the presence of a small velopharyngeal gap or oro-nasal fistula. Nasal air emission and/or nasal turbulence is most commonly noted during the production of high pressure consonants such as fricatives, affricates, and plosives. In addition, nasal air emission can co-occur with hypernasality and normal resonance.

Mixed Nasality

Mixed nasality is present when both excessive nasal resonance and reduced nasal resonance occur in conjunction throughout connected speech. While hypernasality and hyponasality cannot occur simultaneously, this mixed resonance can occur in one individual on different phonemes in connected speech. It is commonly observed in those with apraxia. In addition, if a blockage in the nasal cavity such as irregular adenoid tissue and VPI exist, mixed nasality may be present (Dalston et al., 1991).

Additional Characteristics

The occurrence of weak pressure consonants is a common symptom of VPI. When air moves through the velopharyngeal port there is a reduced amount of air pressure available in the oral cavity for the production of oral consonants. Groups of consonants requiring high pressure such plosives, fricatives, and affricates are often affected. Thus, weak pressure consonants are commonly observed in those with hypernasality. Short utterance length is often observed when nasal air emission is present as well (Kummer, 2003). Due to the excessive air escape through the nose, numerous breaths are required which leads to shortened utterance length. In addition, those with large velopharyngeal gaps tend to increase the intraoral pressure by increasing airflow rate resulting in shortened utterance length (Warren, 1964). Numerous compensatory articulation patterns may arise secondary to VPI which includes: mid-dorsum palatal stops, velar fricatives, nasalization of oral consonants and vowels, nasal snorts, nasal sniffs, pharyngeal plosive, fricatives, and affricates, posterior nasal fricatives, and glottal stops.


**Etiologies of Velopharyngeal Insufficiency**

**Cleft Palate**

Individuals with a history of cleft palate are most commonly seen with VPI. Despite having a palatal repair, it has been found that approximately 20% of individuals with a history of cleft palate will demonstrate VPI following the repair (Kummer, 2006). In addition, scar tissue from repaired palate surgeries can increase, dampen, or alter the acoustic transmission in individuals with cleft palate, causing VPI (Gildersleeve-Neumann & Dalston, 2001).

**Submucous Cleft (Overt & Occult)**

A submucous cleft of the soft palate is characterized by a midline deficiency or lack of muscular tissue and incorrect positioning of the muscles (Cleft Palate Association, 2007). Overt submucous clefts are able to be identified upon intraoral examination. Upon observation of the classic stigmata: a bifid uvula, zona pellucida, and notch on the posterior border of the hard palate, a diagnosis can be made. These stigmata can result in VPI with hypernasal speech (Shprintzen, Schwartz, Daniller, & Hoch, 1985).

An occult submucous cleft is a similar defect of the velum. However, it is not visible on the oral surface and can only be visualized with the use of nasoendoscopy. This diagnosis typically arises when the patient has VPI of an unknown etiology.

The incidence of VPI varies when a submucous cleft is present, as the majority of individuals do not exhibit characteristics of a resonance disorder. However some will develop VPI due to the hypo-plastic nature or absence of the muscularis uvulae.

**Non-Cleft Velopharyngeal Insufficiency**

VPI can also be noted in the presence of a short velum or deep pharynx. This arises due to the inability for the velum to meet the posterior pharyngeal wall. Adenoid atrophy is another cause of VPI. As children reach adolescence, there is often a sudden change and atrophy of the adenoids. Thus, an increased distance between the velum and pharyngeal wall is present. Oftentimes, this is corrects on its own when there is no history of a cleft palate or submucous cleft. However, in individuals with a cleft palate, submucous cleft, repaired cleft palate or scarring secondary to a repair, closure may be insufficient upon the atrophy of the adenoids. Thus, the adenoid tissue initiates the resulting VPI (Mason & Warren, 1980). This etiology of VPI is similar to that following an adenoidectomy. Hypernasality can occur in individuals without a history of velar deficiency following an adenoidectomy, however, this typically resolves quickly. Permanent VPI following an adenoidectomy occurs in approximately 1 out of 1500 procedures (Donnelly, 1994). Underlying congenital abnormalities lead to greater risks of VPI post adenoidectomy. Irregular adenoids, scarring following the removal of the adenoids, or adenoid regrowth can also cause VPI due to the irregular indentations left of the posterior pharyngeal wall. However, this is often rare. In addition, hypertrophic tonsils can be another rare cause of VPI if they cause mechanical
interference with the movement of the velopharyngeal valve. Hypertrophic tonsils, if large enough, have the ability to impact the motility of the lateral pharyngeal walls, velum, and tongue. This leads to an inadequate seal during speech tasks (Kummer et al., 2006).

**Assessment of Velopharyngeal Insufficiency & Resonance Disorders**

The assessment process for VPI is unique from other speech disorders. VPI is diagnosed clinically by a constellation of symptoms that include pathologically incurred nasal resonance (hypernasality), compensatory misarticulations, escape of air through the nose (nasal emissions), and unusual facial movements (i.e. grimacing). The evaluative process incorporates the use of perceptual judgments and instrumentation to come to an accurate and complete diagnosis.

In the assessment of VPI, Speech-Language Pathologists often rely on perceptual measures as well as quantitative measures. Quantitative measures are typically gained through the use of a Nasometer as well as direct visualization of the velopharyngeal sphincter. The use of a Nasometer provides valuable objective information and its use was supported in the study by Dalston et al., (1991). The study found that the sensitivity and specificity of nasometry was 89% accurate when identifying subjects with more than mild hypernasality in their speech.

In assessing the physical parameters of the velopharyngeal sphincter, a multiview videofluoroscopy or flexible endoscopic evaluation of speech/swallowing (FEES) is typically obtained. Multiview videofluoroscopy requires patients to coat the nasal and pharyngeal passages with barium which allows for an x-ray view of the velopharyngeal sphincter and identification of the closure pattern. Closure patterns are categorized as coronal, which is the most common pattern, sagittal, circular, or circular with a Passavant ridge (Armour, Fischback, Klaiman, and Fisher, 2005). Witzel and Posnick (1989) reported that in a group of 246 clients, 68% showed a coronal pattern of closure, with most of the activity occurring due to movement of the velum and posterior pharyngeal wall. The lateral pharyngeal walls contribute little to closure in these cases. A circular pattern of closure was noted in 23% of the clients, where all structures contribute equally, so that a "purse-string" or sphincter type pattern is noted. A sagittal pattern was noted in 4% of their clients. This closure pattern is due to the medial movement of the lateral pharyngeal walls, with little contribution of the velum or posterior pharyngeal wall. Finally, 5% of the clients demonstrated a pattern with a Passavant’s ridge on the posterior pharyngeal wall.

**Auditory & Perceptual Assessment in Resonance Disorders**

The starting point for evaluation by a Speech-Language Pathologist is typically an auditory perceptual assessment. This is the most common assessment in clinical settings (Kent, 1996; Peterson-Falzone, Hardin-Jones, & Karnell, 2001). Moll (1964) stated that the ear and the ability to process and interpret what is heard becomes the most important assessment instrument. Kent (1996) found that: “The ear is the essential tool of the Speech-Language Pathologist. Auditory perceptual judgments are typically the final arbiter in clinical decision-making and often provide the standards against which instrumental (objective) measures are evaluated.” Methods for perceptual assessment in resonance disorders include
phonetic transcription, the use of rating scales to quantify speech features (such as hypernasality, audible nasal air emission and/or nasal turbulence, and intelligibility), and qualitative descriptions. In the assessment of nasality rating scales are usually used to quantify hyper- and/or hypo- nasal speech (Peterson-Falzone et al., 2001).

**Perceptual Assessment: Reliability & Validity**

Perceptual analysis is common in the assessment process when evaluating resonance disorders. When using this assessment method, two clinical judgments must be made. First, the type of resonance demonstrated must be identified and described as either hypernasal, hyponasal, mixed, or cul-de-sac. Second, if the resonance is judged to be abnormal, a rating of severity must be made (Peterson-Falzone et al., 2001).

**Reliability**

Two types of rater reliability used clinically include intra-judge reliability that indicates if a rater makes the same rating when judging the same speech sample more than once, and inter-judge reliability which shows if different listeners give the same rating for a given speech sample. There are a number of studies that indicate positive correlations of intra- and inter-judge reliability. In a study by Hardin et al. (1992), inter-judge reliability of clinical perceptual ratings was high with Pearson r coefficients ranging from .82 to .92 for the perception of hypernasal speech and ranging from .80 to .93 for hyponasal resonance. Intra-judge reliability for hypernasality was found to range from .80 to .93 and for hyponasality intra-judge reliability reached as high as .90 to 1.0. However, despite positive correlations, variables that have been reported to impact reliability of perceptual ratings include audible nasal air emission/nasal turbulence, articulatory proficiency, pitch, and loudness (Fletcher, 1973; McWilliams, Morris, & Shelton, 1990).

**Validity**

The validity of the variable hypernasality may come into question when the reliability of intra- or inter-judge ratings does not correlate. Fletcher (1973) performed a series of experiments that demonstrated that the entity of hypernasality is observed by untrained listeners. Their experiments reported that the listeners were able to accurately distinguish between levels of hypernasality, further supporting the reliability and validity of perceptual ratings for the assessment of resonance. In addition, perceptual ratings are ultimately the most important determination in the severity of resonance. If an individual does not perceive themselves to be significantly hyper- or hyponasal and does not perceive a negative impact on their daily life, any instrumental assessment becomes null and void. However, if perceived hyper- or hyponasality is present, an individual is often referred for a full perceptual, nasometric, nasoendoscopy, and videofluoroscopic speech evaluation.
INSTRUMENTAL ASSESSMENT IN VELOPHARYNGEAL INSUFFICIENCY

The assessment process for VPI is unique from other speech disorders. VPI is diagnosed clinically by a constellation of symptoms that include pathologically incurred nasal resonance (hypernasality), compensatory misarticulations, escape of air through the nose (nasal emissions), and unusual facial movements (i.e. grimacing). As previously stated, the evaluative process incorporates the use of perceptual judgments and instrumentation to come to an accurate and complete diagnosis. It has been said that no instrument can surpass the trained human ear for assessing VPI (Peterson-Falzone et al., 2001). However, the use of instrumentation is vital to help supplement the evaluation and documentation of velopharyngeal function. These objective assessments include nasometry which measures the oral to nasal speech signal ratio, nasoendoscopy, in which a fiberoptic nasopharyngoscope is used to directly observe the velopharyngeal port during speech (Biavati & Rocha-Worley, 2006; Kummer & Lee, 1996; Peterson-Falzone, et al., 2001; and Riski, 2007), and videofluoroscopy in which radiographic procedures are used to directly observe the velopharyngeal sphincter during speech (Biavati et al., 2006; Kummer et al., 1996; Peterson-Falzone, et al., 2001; and Riski, 2007).

Nasometry

One key evaluative tool is the use of the instrument called the Nasometer (KayPENTAX, Lincoln Park, NJ). Preceding the Nasometer, clinicians were limited to invasive techniques, such as nasoendoscopy, or instruments that were unavailable to many, such as the videofluoroscopy, to act as a supplement to their perceptual judgment of VPI (Kavanagh, Fee, Kalinowski, Doyle, & Leeper, 1994). Although the assessment of hypernasality and hyponasality has primarily been attained through perceptual judgment, the Nasometer is an additional resource that allows clinicians to gather information about velopharyngeal function in a non-invasive manner (Brunnegard & Van Dooran, 2009; Hardin et al., 1992). Nasometry provides a noninvasive, yet objective, acoustic approach to measuring the relative prevalence of nasal resonance in the acoustic speech signal. Dalston et al. (1991), has provided data supporting the use of nasometry for objective measurement of oronasal resonance. Furthermore, a sound relationship between perceptual judgments of hypernasality and nasalance scores obtained with a Nasometer in the cleft palate population is often seen (Hardin et al., 1992). The need to use the Nasometer as a supplement to perceptual assessment will be highlighted.

During the initial screening or evaluation by the Speech-Language Pathologist, the Nasometer provides quantitative data to substantiate the perceptual judgment of the Speech-Language Pathologist. The Nasometer, developed by KayPentax (Kay Elemetrics Corp., Lincoln Park, N.J.), uses two microphones separated by a plate held by a head set to record the nasal and the oral speech signal simultaneously. This separation of the oral and nasal cavities allows for the two microphones to calculate a ratio of oral and nasal emissions (Dalston, Neiman, & Gonzalez-Landa, 1993). The recorded signal is computed and the nasalance score is then calculated. The formula for calculation of nasalance is: (nasal energy/(nasal energy+oral energy)) x100. The clinician can use the nasalance score to then compare with their own perceptual rating. It is also imperative to take these quantitative measurements with the Nasometer to compare pre- and post-treatment scores. As Seaver and Dalston (1990) suggest, the Nasometer can be a useful tool for tracking differences in nasalance associated with changes in velopharyngeal activity.
Data from the Nasometer is obtained when the patient repeats one of several standardized sets of sentences while wearing the headset. These passages typically consist of orally produced consonants and vowels, nasal sentences, and the Zoo Passage, which is a phonetically balanced connected speech sample. Dalston and Seaver (1992) reported that the use of the Rainbow Passage did not offer additional information beyond that obtained when the Zoo Passage and nasal sentences were assessed. Thus, the data collected for this study will use oral words and sentences, nasal sentences, and the Zoo Passage obtained via the Nasometer.

Due to its non-invasive nature, the Nasometer is useful when assessing velopharyngeal function in children with suspected VPI (Keuning, Wieneke, Van Wijngaarden, & Dejonckere, 2002). Research has found that nasalance scores, when calculated with the nasometer, correlate with perceptual judgments of velopharyngeal function. Dalston et al., (1991) suggested that the sensitivity and specificity of the nasometer accurately identifies hypernasal and hyponasal speech in patients who present with VPI. Results indicate that 89% of the patients in this study who were identified as having a resonance disorder produced a higher nasalance score and 95% of the patients who were identified as not having a resonance disorder produced a lower nasalance score. This strongly correlates with the subjects who were perceptually identified as having hyper- or hyponasal speech.

In contrast, some studies have suggested the Nasometer may not be an adequate instrument to use with perceptual judgments when obtaining information of velopharyngeal function. Watterson, Wright, and McFarlane (1993) studied the perceptual judgments and nasalance scores of 25 individuals. Results indicated that a low correlation (0.49) existed between the two measures of assessment for velopharyngeal function. Nellis, Neiman, and Lehman (1992) studied the perceptual judgments and nasalance scores of 16 cleft palate patients who had undergone pharyngeal flap surgery. They too were unable to find a strong correlation between perceptual judgments of hypernasality and nasalance scores collected from the Nasometer. It is of note, however, that the sample sizes of these studies were small. Yet, these studies suggest that nasalance scores collected from the Nasometer should not be the sole factor taken into consideration when assessing a patient for VPI, but should only act as a supplement to perceptual judgment when used.

However, Karnell (1995) and others have suggested that the Nasometer has proven to be a valuable clinical tool if used for the purpose of objectively documenting oral and nasal acoustic resonance. Though, it should not be used strictly as a measure of perceived hypernasality. The perceptual judgments of clinician’s should be considered the “gold standard” when assessing the effects of VPI on resonance.

As outlined in the majority of the literature, (Brunnegard et al., 2012; Hardin et al., 1992; Keuning et al., 2002; Dalston et al., 1991) the strong relationship between perceptual and acoustic assessments of nasality indicates that the Nasometer and perceptual ratings are valid clinical tools for the evaluation of nasality when a carefully constructed speech sample is used. Furthermore, in an outcome study by Losken et al. (2003), patients who required a revision surgery following a pharyngoplasty (the sphincter pharyngoplasty procedure) for VPI had significantly higher pre-operative oral sentence nasometry percentages when compared to patients who did not require a revision.
**Nasoendoscopy**

Endoscopes are optical instruments which consist of a viewing lens, fiberoptic insertion tube, and eyepiece attached to a camera. For the purposes of velopharyngeal assessment, a flexible fiberoptic nasoendoscopy is commonly preferred and used (Peterson-Falzone et al., 2001). Nasoendoscopy, when performed with a flexible scope, provides a comprehensive view of the nasal surface of the velopharyngeal structures during speech (Croft, Shprintzen, Rakoff, 1981; Karnell, 1994; Siegel-Sadewitz and Shprintzen, 1982; Witt et al., 1995). Endoscopic examination of the velopharyngeal port provides a view similar to the Towne view obtained via a videofluoroscopic speech assessment. The endoscope allows the examiner to observe the velum and pharyngeal walls as they move in relationship to one another.

During the nasoendoscopic portion of the evaluation, the nasoendoscope is placed through the nasal cavity superior to the velopharyngeal port, and the movement of the velum, the lateral pharyngeal walls, and the posterior pharyngeal wall are observed while the patient repeats oral speech targets provided by the Speech-Language Pathologist. In addition, the width of the pharynx and symmetry or asymmetry of the palate and pharyngeal walls are evaluated. With this, Speech-Language Pathologists are able to use nasoendoscopy to describe the structure and function of the velopharynx, pharynx, and larynx. This assists in the development of assessment and treatment planning.

Upon observing the superior view of the velopharyngeal orifice, velopharyngeal gap size can be estimated. Velopharyngeal gap sizes are estimated via comparing the size of the velopharyngeal valve at rest to the velopharyngeal gap during speech (small, medium, or large). In addition, degree of posterior pharyngeal wall displacement is also estimated. This is based on a scale of 0.0 to 1.0 with a normal velopharyngeal mechanism representing 0.0 degree of posterior wall movement at rest and complete contact with the velum of 1.0 during speech tasks. Furthermore, closure pattern (coronal, sagittal, circular, or circular with Passavant’s ridge) is estimated utilizing the nasoendoscope. With these estimations, interpretation of nasoendoscopic findings is typically a matter of clinical judgment, which can be prone to bias. However, several studies have supported a strong correlation between inter- and intra-judge reliability of nasoendoscopic images (Karnell, Ibuki and Morris & Van Demark, 1983).

**Videofluoroscopy**

Videofluoroscopic observation of velopharyngeal closure has been performed for numerous years and has been cited in articles and textbooks as a standard component of surgical planning for VPI. In addition, the variability of velopharyngeal valving in patients with VPI stresses the importance of observing the component movements of velopharyngeal closure (Ysunza, Ramirez, Molina, Mendoza, & Silva, 2002). The videofluoroscopic technique involves the instillation of barium into the nasopharynx. Real-time imaging via an x-ray is utilized to capture the movement patterns of the patient’s velopharyngeal port. The images can be obtained in three dimensions which include a lateral view, towne view, and frontal view. During videofluoroscopic assessment, velar elevation, lateral wall movement, closure patterns, and overall velopharyngeal function is assessed while the patient repeats...
oral speech targets provided by the Speech-Language Pathologist. A major advantage of videofluoroscopy is its ability to visualize the various dimensions of the velopharyngeal port. The examination usually takes 2-3 minutes. This, in combination with a nasoendoscopic evaluation, can directly influence the decision making process of the team. In addition, it is thought that defining the velopharyngeal closure pattern during videofluoroscopic assessment is important in determining the appropriate surgical intervention. The results of videofluoroscopy have also been used to tailor the surgery to the individual patient.

**Management of Velopharyngeal Insufficiency**

Current management routes for hypernasality related to VPI may include surgery, prosthetic devices, therapeutic management with speech therapy, or a combination of these treatments. Speech therapy is often recommended and combined with other treatments in order to provide long-term benefits. Thus, if hypernasality is the result of learned behavior, speech therapy alone is typically the recommended treatment. However, if VPI arises secondary to deficient velopharyngeal anatomy or physiology surgery or prosthetic management may be the suggested treatment method.

**Therapeutic Management for Velopharyngeal Insufficiency**

Speech therapy is an essential part of the management and treatment process for VPI. It has been found that approximately 50% of children with a cleft palate and/or VPI require speech therapy (Bzoch, 1997; Dalston, 1990; Van Demark, 1997). A study by Bzoch (1997) found that 25-30% of children with cleft palate, following surgical management, require speech related services throughout the preschool years.

Speech therapy is the recommended course of management for VPI when the individual demonstrates compensatory articulation patterns, mild or inconsistent nasal rustle, phoneme specific nasal air emission or inconsistent hypernasality due to oral-motor dysfunction (Kummer, 2006). In addition, if the individual is stimulable to the production of appropriate resonance on misarticulated sounds, speech therapy has been found to be successful. Therapy following surgical correction is often recommended as well.

Furthermore, speech therapy is appropriate following surgical correction of the velopharyngeal mechanism. There is a need to retrain the muscles of the velopharyngeal port as changing the structure with surgical management does not necessarily change the function. In addition, therapy is needed to correct compensatory errors and patterns of articulation that were present prior to the surgical management.

Therapeutic management for individuals with VPI tends to focus on auditory feedback, visual feedback, and tactile-kinesthetic feedback (Kummer, 2006). Items that can help achieve feedback include the Nasometer, the See Scape, and recording devices, etc.

Therapeutic intervention will vary depending on the age of the child. In the early years, birth to three, focus centers around the use and stimulation of language while trying to prevent compensatory
articulations. Between the ages of three and four, velopharyngeal function and the evaluation and treatment of correct articulatory placements become the focus.

**Prosthetic Management for Velopharyngeal Insufficiency**

When surgical repair or speech therapy does not provide adequate closure of the velopharyngeal mechanism, prosthetic treatment may be recommended. A speech prosthesis is typically recommended when an individual is considered a poor surgical candidate. It consists of a removable plastic plate that is secured to the maxillary incisors and sits across the palate. The prosthetic device helps to close the palate and raise the velum superiorly and posteriorly to assist in achieving velopharyngeal and/or oral closure. Prosthetic management includes two commonly used devices which are known as a palatal lift or a speech bulb/obturator (See Figure 3).

Palatal lifts are most frequently used for individuals with neurological impairments affecting velar movement (Posnick, 1977; Witt et al., 1995; Yules et al., 1971). This device assists in closure by elevating the palate superiorly and posteriorly to make contact with the posterior pharyngeal wall. The appliance helps to position the velum so that minimal muscular motion is necessary for the pharyngeal walls to attain velopharyngeal closure.

Speech bulbs are commonly used when surgical repair does not lead to the velum being an adequate length for closure. The device is most successful in patients that have adequate inward movement of the pharyngeal walls to improve closure (Mazaheri & Millard, 1965). Furthermore, speech bulbs are most successful when a small velopharyngeal gap is present.

**Surgical Management for Velopharyngeal Insufficiency**

Following a complete physical and speech-language assessment, the team determines the best route for correction of the VPI. Typically, for those that have severe structural deficits, causing higher nasality and VPI, surgical intervention is recommended. The goals of surgery are to eliminate the symptoms of hypernasality and eliminate audible nasal emissions without causing complete obstruction of the velopharyngeal port. The surgical procedures to correct VPI are numerous and vary widely. However, two common surgical processes are the pharyngeal flap and the sphincter pharyngoplasty, which fall under the category of pharyngoplasties. For the purpose of this study, data from patients who received a pharyngeal flap procedure will be analyzed.

![Figure 3: Prosthetic devices used with patients with VPI](image-url)
The pharyngeal flap is the most common method for secondary surgical management of VPI (Ysunza et al., 2002). Tissue from the posterior pharyngeal wall is attached to the soft palate, creating a midline partial obstruction of the oral and nasal cavities. It leaves two small lateral openings, or ports. Ideally, these lateral openings remain patent during respiration and nasal consonant production and closed for oral consonants. Lateral wall motion is important for effective valving after pharyngeal flap surgery (Argamaso, Shprintzen, Strauch, Lewin, Daniller, Ship, & Croft, 1980). The procedure appears to benefit patients with satisfactory lateral pharyngeal wall motion who exhibit sagittal or circular velopharyngeal closure patterns as well as a moderate velopharyngeal gap.

The sphincter pharyngoplasty involves narrowing the central velopharyngeal port, thus minimizing airflow through the nose during speech. It accomplishes this by rearranging the palatopharyngeus muscle, which is transposed to the posterior pharyngeal wall. Theoretically, this procedure tightens the central orifice without creating lateral ports, resulting in a velopharyngeal configuration that is the opposite of that achieved with the pharyngeal flap. Patients with poor posterior pharyngeal wall movement and smaller velopharyngeal ports tend to benefit more from sphincter pharyngoplasty. The height of insertion for this surgical procedure also appears to improve the rate of success (Riski, Serafin, Riefkohl, Georgiade, & Georgiade, 1984).

There is often a debate regarding the type of surgical procedure that is best for each client and the unique movement of the velopharyngeal port of each client plays a strong role in decision making. Furthermore, although sphincter pharyngoplasty procedures have gained a great deal of attention in the recent otolaryngologic literature; pharyngeal flap procedures remain a valuable tool in the hands of surgeons dealing with VPI (Canady, Cable, Karnell, Karnell, & Malick, 2002). The decision rests in the hands of the surgeon and what they feel most comfortable in performing. Also, their considerations include what would achieve the best outcome for the client. Overall, a thorough understanding of the assessment process and the appropriate surgical intervention, if recommended, is crucial for the Speech-Language Pathologist to understand as they play an important role in the rehabilitative process. The outcomes are typically favorable with a knowledgeable team approach (Ysunza et al., 2002).

**The Pharyngeal Flap**

**Background & Candidacy**

The pharyngeal flap surgery is the most commonly used operation to restore velopharyngeal competence or develop a functional seal between the nasal cavity and the oral cavity, and therefore correct hypernasality and nasal air escape (Ysunza et al., 2002). Pharyngeal flaps can be superiorly based or inferiorly based (Lideman-Boshki, Lohmander, Persson, Lith, & Elander, 2005). Superiorly based pharyngeal flaps tend to be completed more often. Compared to superiorly based flaps, inferiorly based flaps are limited in regard to the size of velopharyngeal opening that can be covered (Peterson-Falzone et al., 2001). In addition, when there is a severe absence of palatal tissue, as can be seen in cleft palate occurring secondary to Pierre-Robin Sequence, a primary pharyngeal flap may be incorporated into the palatal repair (Millard, 1980).
Shprintzen et al. (1979), suggested the use of ‘tailor-made’ flaps, in which the width of the flap is established based on the extent of preoperative lateral wall movement. This study found that the base of the pharyngeal flap should be positioned at the site with the greatest level of lateral pharyngeal wall movement. Furthermore, a study by Sloan (2000), suggests that a narrower flap be used when lateral pharyngeal wall movement is increased and a wider flap should be used when limited lateral pharyngeal wall movement is present.

Overall, research has found a higher surgical success rate can be achieved by taking into account an individual patient’s pattern of VPI. However, how to precisely tailor the flap to balance speech and airway is patient-dependent and objectively difficult to estimate. The surgeons at Women’s and Children’s Hospital of Buffalo commonly complete superiorly based pharyngeal flaps that are tailored intra-operatively based on the pre-operative assessment and anatomy of the individual. The current study aims to analyze if additional pre-operative factors such as nasalance, closure pattern and a tailored pharyngeal flap correlates to the revision rate.

Pharyngeal flaps are often recommended for individuals who have persistent VPI and who are unable to achieve appropriate resonance following speech therapy alone. Those with anatomical deficits precluding appropriate closure are candidates as well. The patient’s pattern of VP closure is taken into consideration when deciding whether pharyngeal flap surgery is the appropriate method of treatment (Armour et al., 2005). Research has found that pharyngeal flap surgery is most effective for those with a sagittal closure pattern or good lateral wall movement (Armour et al., 2005). Amour et al. (2005), has also found that when younger children undergo the surgery, fewer speech impairments tend to occur, likely due to the child having less time to develop compensatory strategies that negatively impact speech intelligibility.

**Complications**

In a study by Canady et al. (2002), that assessed complication rates and speech outcomes in patients undergoing a pharyngeal flap surgery, complications were rare, with an overall rate of 3.4% for all children. Overall, 81.8% demonstrated no evidence of hypernasality or mild hypernasality, and 84.1% demonstrated no evidence of hyponasality or mild hyponasality only. However, through the years, several problems and complications have been identified with the pharyngeal flap procedure (Valnicek, Zuker, Halpern, & Roy, 1994). As a result, it has undergone several modifications, and variations of specific techniques have occurred. Key issues that stimulated the development of these modifications include (1) the appropriate width of the flap, (2) whether a superiorly or an inferiorly based flap is more effective in achieving the ideal outcome, and (3) whether the flap should be lined with mucous membrane to prevent postoperative contraction or attenuation of the flap. The pharyngeal flap continues to be used routinely in the surgical management of VPI.

Some of the most common complications of pharyngeal flap surgery include airway obstruction and sleep apnea. Snoring has also been cited as a negative outcome of the surgery (Sloan, 2000). A study by Morris et al. (1995) found that 89% of patients who had a pharyngeal flap procedure snored post-operatively. These complications likely result from the narrowing of the airway secondary to edema following surgery, the impeding of the nasopharynx by the flap itself, and anatomical changes in which
the oropharynx becomes smaller as a result of the pharyngeal flap surgery. There is also a correlation between the individuals who have this surgery and the presence of other craniofacial and neurological conditions that lead to complications (Sloan, 2000).

In the literature, airway obstruction following pharyngeal flap surgery is well documented. It has been concluded that individuals with Treacher-Collins syndrome or Pierre Robin sequence are at an increased risk for developing airway obstruction following pharyngoplasty. This is secondary to their narrow airway and inadequate maxillofacial growth at the time of the surgery. Factors that increase the risk of airway obstruction include associated congenital anomalies and a history of airway problems. However, age does not appear to influence the risk (Anthony & Sloan, 2002). In addition, obstructive sleep apnea has been found to be associated with the pharyngeal flap surgery. Nevertheless, pharyngeal flaps are considered to be more valuable in correcting velopharyngeal function than other treatment options, especially in severe cases of VPI (Sloan, 2000).

**Outcomes & Revision Surgeries**

Pharyngeal flap has been found to improve VPI in the majority of cases. In addition to speech improvements, pharyngeal flap surgery may help eliminate hypernasality, nasal turbulence, and facial grimacing (Tonz, Schmid, Graf, Mischler-Heeb, Weissen, & Kaiser, 2002). However, the outcomes of pharyngeal flap surgery vary among each individual in regards to improvements in hyponasality, hypernasality, nasal turbulence, voice quality, articulation, and intelligibility (Tonz et al., 2002; Liedman-Boshki, Lohmander, Persson, Lith, & Elander, 2005).

It has been found that approximately 20-30% of patients with cleft palates develop hypernasal speech after receiving a pharyngeal flap surgery (Heliovaara et al., 2003). However, the percentage of individuals who develop hypernasal speech following the pharyngeal flap continues to be debated by researchers. It is possible that hypernasality can be a side effect of failed pharyngeal flap surgeries. Yet, hyponasal speech occurs more often after a successful surgery (Liedman-Boshki et al., 2005).

When the initial pharyngeal flap surgery is unsuccessful, patients may require secondary surgery for VPI or a revisional surgery to the initial pharyngeal flap. Individuals who undergo a second surgery have the potential to develop secondary speech problems as well as compensatory articulation and resonance disorders. A study by Witt, Myckatyn, & Marsh (1998), found that there are higher rates of surgical failure in children with a history of perinatal upper airway obstruction, such as those with Robin sequence.

In studies that offer techniques to revise the initial flap have often not reported objective speech data or produced mixed speech results (Hoffman, 1985; Caouette-Laberge et al., 1992). Owsley, Lawson, & Chierici (1976) found that revisions to the initial pharyngeal flap improved speech approximately 50% of the time.

However, additional research has found that the assessment team can prevent the need for revision by preoperative identification of physical stigmata associated with VPI (Conley et al., 1997). In the study by Conley et al. (1997), physical parameters were assessed pre-operatively. However, objective nasometric data was not considered.
CONCLUSIONS OF LITERATURE REVIEW

Review of the literature found that patients who required surgery following an initial pharyngoplasty for VPI had significantly higher pre-operative oral sentence nasometry than those patients who did not require a revision Losken et al., (2003). Other studies have investigated the relationship between pre-operative velopharyngeal closure pattern and the type of revision completed in patients who had a failed initial pharyngoplasty (Kasten et al., 1997; Witt et al., 1995, Amour et al., 2005; Schultz et al., 1973; Conley et al., 1997). There are no studies that have investigated multiple pre-operative indicators together to determine potential risk of surgical revision in patients with VPI.

The purpose of this study is to investigate if pre-operative oral sentence nasometric values and the identification of the type of velopharyngeal closure pattern can improve the pre-surgical decision making process in order to tailor pharyngeal flap surgeries and decrease the need for later revisions. Identification of pre-operative indicators of potential revision cases may ultimately reduce the number of surgical revision procedures in patients with VPI. Thus, the intended outcome of this study is to provide health care professionals possible indicators to identify the patients who will most likely return for revision surgical procedures.
Chapter III

Subject Demographics & Methodology

Approval to use human subjects in this study was granted by the Institutional Review Board (IRB) at Women’s and Children’s Hospital of Buffalo/Kaleida Health (WCHOB) through the University of Buffalo as well as the IRB committee at State University of New York at Fredonia. The purpose of the IRB is to assure, both in advance and by periodic review, that appropriate steps are taken to protect the rights and welfare of humans participating as subjects in the research. To accomplish this purpose, both IRB’s involved in this study used a group process to review research protocols and related materials (e.g., informed consent documents and patient forms) to ensure protection of the rights and welfare of human subjects of research.

The study is a retrospective cohort design, also called a historic cohort study. It is a medical research study in which the medical records of individuals who are alike in many ways but differ by a certain characteristic are compared for a particular outcome.

The groups being studied are patients who have received pharyngeal flap surgery to improve the condition of VPI and the patients from the original group that additionally received a revision of the initial surgical procedure. The intended outcome was to identify if certain nasometric measures and closure patterns of the initial patient group can be identified as likely to need revision surgeries.

Patients who underwent a pharyngeal flap pharyngoplasty at Women’s and Children’s Hospital of Buffalo from 1992-2012 formed the study population.

Demographics

The records of patients who underwent a pharyngeal flap surgery for VPI between January 1992 and August 2012 were reviewed. All patients were evaluated by a multidisciplinary team which included Speech-Language Pathologists, audiologists, geneticists, nutritionists, dental specialists, otolaryngologists, and craniofacial surgeons. Craniofacial clinic databases, medical charts and office notes were used for review. Each patient in this study was characterized according to diagnosis, preoperative assessment, surgical intervention, postoperative assessment, speech analysis, secondary procedures including revision surgery, and the outcome.

59 patients who were diagnosed with VPI and underwent a pharyngeal flap surgery were included in this study. Of these, 23 were female and 36 were male with a mean age of 10 years, 8 months (range, 2-54 years) at the time of the initial pharyngeal flap surgery. The age range of subjects was age 2;11 to 54;0 years. The average age of subjects was 10;8. However, the majority of subjects fell into the age range of 5;0 to 7;6 (27 out of 59 subjects). The underlying diagnoses were divided into five categories. These included VPI alone (n=12), VPI associated with cleft palate (n=27), velocardiofacial syndrome (n=4), submucous cleft palate (n=14), and bifid uvula (n=2) (See Figure 4).
Evaluation

All patients underwent an evaluation for velopharyngeal function by the craniofacial team at Women's and Children's Hospital of Buffalo. This included perceptual and quantitative speech evaluation, clinical screening of velopharyngeal closure, and oral peripheral examination. Perceptual ratings of speech were determined through rating live speech samples of single words, sentences, and conversational speech. Resonance was categorized as hypernasal, hyponasal, mixed, or normal. Patients, who were categorized as having hypernasal speech, hyponasal speech, or nasal air emissions, were evaluated using nasometric instrumentation and multi-view videofluoroscopy/nasoendoscopy.

Nasometric measures were obtained using a Kay Elemetrics Nasometer II 6450 (Kay Elemetrics Corp., Lincoln Park, N.J.). Nasometry scores were obtained for oral word and sentence nasometry as well as nasal words, low pressure context phrases, and high pressure context phrases (See Table 2). Nasoendoscopy was performed using a Pentax FNL 2.4mm flexible endoscope. The endoscope was positioned above the velopharyngeal port and patients were asked to repeat high-pressure and low-pressure oral and nasal speech sounds in words and connected speech to assess velopharyngeal function. Multiview videofluoroscopy was also performed. Barium was instilled and coated the nasal and pharyngeal cavities during the same speech tasks as nasoendoscopy. Velar elevation, lateral wall movement, closure patterns, and overall velopharyngeal function was assessed during speech tasks.
VPI was defined by a perceptual rating of hypernasal or hyponasal speech, an observed velopharyngeal gap and/or nasal bubbling during oral speech tasks via endoscopy or fluoroscopy, and nasalance scores higher than 30% for oral speech samples determined by nasometry measurements.

**Table 2: Oral and Nasal Word and Sentence Stimuli Used to Measure Subjects Nasalance**

<table>
<thead>
<tr>
<th>Oral Words</th>
<th>Oral Sentences</th>
<th>Nasal Utterances</th>
<th>Low-Pressure Utterance</th>
<th>High Pressure Utterance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Alveolars</strong></td>
<td>tire, turtle, teddy</td>
<td>Take teddy a toy</td>
<td>muffins, mittens, lemonade</td>
<td>Where were you</td>
</tr>
<tr>
<td><strong>Bilabials</strong></td>
<td>book, pie, baby</td>
<td>Buy baby a bib</td>
<td>Ten men came in</td>
<td>We were here</td>
</tr>
<tr>
<td><strong>Velars</strong></td>
<td>cookie, car, cake</td>
<td>Give Kate the cake</td>
<td>Mama made lemon jam</td>
<td></td>
</tr>
<tr>
<td><strong>Fricatives</strong></td>
<td>dress, scissors, horse</td>
<td>Sue saw Sally</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sibilants</strong></td>
<td></td>
<td>Sheila shows sheep</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Affricates</strong></td>
<td></td>
<td>I eat cherries with cheese</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Surgical Procedure**

In order to achieve proper oral-nasal resonance with the pharyngeal flap surgery, tissue from the posterior pharyngeal wall is attached to the soft palate, creating a midline subtotal obstruction of the oral and nasal cavities with two small lateral openings, or ports. Ideally, these lateral openings remain patent during respiration and nasal consonant production and closed for oral consonants. The procedure appears to benefit patients with satisfactory lateral pharyngeal wall motion and who exhibit sagittal or circular velopharyngeal closure patterns as well as a moderate velopharyngeal gap.

The surgeons in this study followed a standard procedure by creating a superiorly based pharyngeal flap. This was completed by creating sutures which were placed bilaterally in soft palate to enhance visualization followed by a midline incision that divided the soft palate to the posterior nasal spine. The soft palate flaps were retracted and an incision was made along the posterior pharyngeal wall. Thus, a pharyngeal flap was created and a "book flap" incision that lined lateral ports with mucous membrane was then made bilaterally on nasal surface of soft palate. Two soft palate flaps were opened laterally and the free inferior edge of pharyngeal flap was sutured to posterior edge of soft palate. Sutures were placed between pharyngeal flap and nasal edges of soft palate and the raw surfaces arising from origin of pharyngeal flap were closed by simple approximation of tissue. Two flaps from soft palate, used to cover raw tissue of pharyngeal flap, were sutured to the base of pharyngeal flap and the oral side of soft palate was sealed to conceal the pharyngeal flap.

Revision surgery was defined as any secondary surgical modification following the initial pharyngeal flap. The need for revision was determined by clinical examination by the craniofacial team, perceptual speech evaluation, and objective instrumental assessment. All revision subjects included in this study
were recommended based on continued perceived hypernasality following the initial pharyngeal flap surgery. Subjects whom required revision secondary to obstructive sleep apnea and persistent hyponasality were not included due to the limited number of subject data available. Typical revision of the pharyngeal flap surgery for subjects in this study consisted of port tightening.

**Statistical Analysis**

Statistical analysis to correlate revision rates and preoperative nasometric data was completed using a multiple logistic regression analysis. A multiple logistic regression is designed to predict the outcome of a dependent variable based on several independent variables. In this present study, this analysis was used to determine the maximum likelihood of preoperative factors (independent variables) such as oral sentence nasometry and other nasometric measures, velopharyngeal gap size, and velopharyngeal closure pattern as predictors to a possible revisional surgical procedure (dependent variable).

The goal of using a multiple logistic regression analysis was to predict the outcome of a categorical variable or response variable (revision surgery) based on one or more predictor variables (nasometry, closure pattern, and velopharyngeal gap size). This formula established the relationship between the dependent variable of patients who underwent a revisional surgery and the independent variable(s) of nasometry and physiological factors by converting the dependent variable into probability scores. Statistical analysis was carried out using a chi-square test with an alpha level of \( \rho \leq .05 \) for comparisons between patients who required a revision and those who did not. In addition, factors such as diagnosis and age were also analyzed.
Chapter IV

Results

Revisional Surgery Analysis

The records of 59 patients who received a pharyngeal flap were analyzed. Success of the initial pharyngeal flap procedure was defined by improvement in the perceptual speech quality and the absence of a need for revision to the initial surgery. Success was seen in 79% of the subjects (43 out of 59 subjects). Need for surgical revision was demonstrated in 21% of the subjects (16 out of 59 subjects). The group that showed consistent persisting velopharyngeal incompetence required a port tightening procedure. Following revision, no tertiary revisional surgeries occurred in the subjects.

Analysis of Age & Diagnosis

Statistical regression analysis indicated no statistically significant relationship between the average age at which the initial pharyngeal flap surgery occurred for those subjects requiring a revision surgery and those who did not (−0.61, p = 0.114). Results confirmed that age at the time of the pharyngeal flap operation or revision operation was not a factor in the success or failure of the surgery.

Statistical regression analysis indicated no statistically significant relationship between the category of diagnosis between patients who received a revision to the initial pharyngeal flap surgery and those who did not (−0.00, p=0.999). However, of the 59 subjects in this study, those who had VPI associated with a repaired cleft palate (9 out of 27 or 33%) and submucous cleft palate (5 out of 14 or 36%) were more likely to need revision compared to those with velocardiofacial syndrome (1 out of 4 or 25%), VPI not associated with cleft palate (1 out of 12 or 8%), and a bifid uvula (0% required revision) (See Table 3).

Table 3. Stratification of Diagnosis and Revision Rate

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Number</th>
<th>Revision Rate</th>
<th>Revision %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Submucous Cleft</td>
<td>14</td>
<td>5/14</td>
<td>35.7</td>
</tr>
<tr>
<td>Cleft Palate</td>
<td>27</td>
<td>9/27</td>
<td>33.3</td>
</tr>
<tr>
<td>Velocardiofacial Syndrome</td>
<td>4</td>
<td>1/4</td>
<td>25.0</td>
</tr>
<tr>
<td>Bifid Uvula</td>
<td>2</td>
<td>0/2</td>
<td>00.0</td>
</tr>
<tr>
<td>VPI without Cleft</td>
<td>12</td>
<td>1/12</td>
<td>08.3</td>
</tr>
</tbody>
</table>
Speech Analysis

Statistical regression analysis of nasometric data revealed statistically significant results in both oral word nasometry scores and oral sentence nasometry scores (See Table 4). Post-operative results were not analyzed. Overall, nasometric data obtained for patients who required a revision to the initial pharyngeal flap surgery were objectively higher than those who did not require a revision.

### Table 4. Significance of Oral Word and Sentence Nasometry Scores

<table>
<thead>
<tr>
<th>Oral Word Nasometry</th>
<th>p Values</th>
<th>Z Scores</th>
<th>Degree of Freedom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alveolars</td>
<td>ρ = 0.001*</td>
<td>3.24</td>
<td>59</td>
</tr>
<tr>
<td>Bilabials</td>
<td>ρ = 0.022*</td>
<td>-2.29</td>
<td>59</td>
</tr>
<tr>
<td>Velars</td>
<td>ρ = 0.028*</td>
<td>-2.20</td>
<td>59</td>
</tr>
<tr>
<td>Sibilants</td>
<td>ρ = 0.314</td>
<td>1.01</td>
<td>59</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Oral Sentence Nasometry</th>
<th>p Values</th>
<th>Z Scores</th>
<th>Degree of Freedom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alveolars</td>
<td>ρ = 0.339</td>
<td>-0.96</td>
<td>51</td>
</tr>
<tr>
<td>Bilabials</td>
<td>ρ = 0.259</td>
<td>1.13</td>
<td>51</td>
</tr>
<tr>
<td>Velars</td>
<td>ρ = 0.653</td>
<td>-0.45</td>
<td>51</td>
</tr>
<tr>
<td>Fricatives</td>
<td>ρ = 0.649</td>
<td>0.46</td>
<td>51</td>
</tr>
<tr>
<td>Sibilants</td>
<td>ρ = 0.115</td>
<td>-1.58</td>
<td>51</td>
</tr>
<tr>
<td>Affricates</td>
<td>ρ = 0.036*</td>
<td>2.10</td>
<td>51</td>
</tr>
</tbody>
</table>

* Values statistically significant at α= 0.05

<table>
<thead>
<tr>
<th>Table 5. Significance of Nasal Utterances, Low Pressure Utterances, &amp; High Pressure Utterances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nasal Utterances</td>
</tr>
<tr>
<td>Muffins, mittens, lemonade</td>
</tr>
<tr>
<td>Ten men came in</td>
</tr>
<tr>
<td>Mama made lemon jam</td>
</tr>
<tr>
<td>Low Pressure Context</td>
</tr>
<tr>
<td>Where were you</td>
</tr>
<tr>
<td>We were here</td>
</tr>
<tr>
<td>High Pressure Context</td>
</tr>
<tr>
<td>The Zoo Passage</td>
</tr>
</tbody>
</table>

* Values statistically significant at α= 0.05

Relationship of Preoperative Oral Single Word Nasometry and Revision Rate:

Statistical regression analysis of preoperative nasometric oral single words compared to revision rate revealed several significant results at an alpha level of p ≤ .05 for alveolar, bilabial and velar single words.

Nasalence percentages for single alveolar words were significantly correlated to revision rate (3.24, ρ= 0.001). Nasalence percentages were higher for alveolar single words pre-operatively for patients who
received a revision surgery as compared to those who did not require a revision (50.8% vs. 43.7%, see Figure 5). Nasalance percentages were higher for bilabial single words pre-operatively for patients who received a revision surgery as compared to those who did not require a revision (46.13% versus 42.9%, see Figure 5). Nasalance percentages were also higher for velar single words pre-operatively for patients who received a revision surgery as compared to those who did not require a revision (47.07% versus 46.2%, see Figure 5). Therefore, preoperative measures of alveolar, bilabial, and velar single word nasalance scores predict a potential revision to the pharyngeal flap.

**Relationship of Preoperative Oral Sentence Nasometry and Revision Rate:**

Statistical regression analysis of preoperative oral sentence nasometry compared to revision rate revealed significant results at an alpha level of $p \leq .05$ for affricate sentences.

Nasalance percentages for affricate sentences were significantly correlated to revision rate (2.10, $\rho=0.036$) (See Table 4). Nasalance percentages were higher for affricate sentences words pre-operatively for patients who received a revision surgery as compared to those who did not require a revision (56.71% vs. 48.5%, see Figure 6). Therefore, preoperative measures of nasalance for affricate sentences also predict a potential revision to the pharyngeal flap.

No statistical significance was seen in the regression analysis for alveolar, bilabial, velar, fricative, or sibilant sentences of patients who required a revision to the initial pharyngeal flap versus patients who did not require revision (See Table 4). These preoperative measures of alveolar, bilabial, velar, fricative, and sibilant oral sentence nasometry scores do not predict a potential revision to the pharyngeal flap.

**Relationship of Preoperative Nasometry Scores for Nasal Utterances, Low Pressure Context, High Pressure Utterances Nasometry and Revision Rate**

No statistical significance was seen in the regression analysis for nasal utterances, low pressure context, or high pressure context utterances of patients who required a revision to the initial pharyngeal flap versus patients who did not require revision (See Table 5). However, in patients who eventually required a revision to the initial pharyngeal flap surgery, these nasometric scores were typically higher than those of patients who did not require a revision to the initial pharyngeal flap (See Figure 7 & Figure 8). These preoperative measures do not predict a potential revision to the pharyngeal flap.
**Figure 5:** Mean pre-operative nasalance % for oral alveolar, bilabial, sibilant and velar single words of subjects requiring revision and not requiring revision.

**Figure 6:** Mean pre-operative nasalance % for oral alveolar, bilabial, velar, fricative, sibilant, and affricate sentences of subjects requiring revision and not requiring revision.

*Figure 5 & 6: Subjects stratified via oral word & sentence nasometry scores for pharyngeal flap (labeled as flap on figure) versus subjects who received pharyngeal flap + revision (labeled as revision on figure)*
**Figure 7:** Mean pre-operative nasalance % for nasal utterances of subjects requiring revision and not requiring revision

- Muffins, mittens, lemonade: Flap 63.28, Revision 64.13
- Ten men came in: Flap 62.55, Revision 68.13
- Mama made lemon jam: Flap 61.28, Revision 67.2

**Figure 8:** Mean pre-operative nasalance % for high & low pressure context utterances of subjects requiring revision and not requiring revision

- Where were you: Flap 48.53, Revision 54.33
- We were here: Flap 44.6, Revision 49.87
- The Zoo Passage: Flap 46.28, Revision 52.13

*Figure 7 & 8: Subjects stratified via oral word & sentence nasometry scores for pharyngeal flap (labeled as flap on figure) versus subjects who received pharyngeal flap + revision (labeled as revision on figure)
Physiological Analysis of Closure Pattern

Of the 59 subjects analyzed, no statistically significant relationship was seen in the regression analysis between closure patterns and need for revision of the initial pharyngeal flap surgery (See Table 5). Both coronal closure patterns (n=6) and circular closure patterns (n=6) returned equally for a revision to the initial pharyngeal flap surgery and had the highest rate of revision surgery of the subjects analyzed. Those with a sagittal closure pattern (n=3) and a circular with Passavant’s Ridge closure pattern (n=1) returned the least for revision to the initial pharyngeal flap surgery. These preoperative measures alone do not predict a potential revision to the pharyngeal flap.

<table>
<thead>
<tr>
<th>Closure Pattern</th>
<th>p Values</th>
<th>Z Scores</th>
<th>Degree of Freedom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coronal</td>
<td>ρ = 0.777</td>
<td>-0.28</td>
<td>6</td>
</tr>
<tr>
<td>Circular</td>
<td>ρ = 0.776</td>
<td>-0.28</td>
<td>6</td>
</tr>
<tr>
<td>Circular with Passavant’s</td>
<td>ρ = 0.309</td>
<td>-1.02</td>
<td>6</td>
</tr>
<tr>
<td>Sagittal</td>
<td>ρ = 0.681</td>
<td>-0.41</td>
<td>6</td>
</tr>
</tbody>
</table>

* Values statistically significant at α=.05

Physiological Analysis of Gap Size

Of the 59 patients analyzed, 56% had a small gap (n=33), 29% had a medium gap (n=17), 10% had a large gap (n=6), and 5% had data missing (n=3). Those with missing data were not analyzed. While no statistical significance was found in the regression analysis of gap size versus revision rate, it was noted to approach significance. The larger the preoperative velopharyngeal gap size, the more likely the need for revision to the initial pharyngeal flap surgery became. Subjects with a large preoperative velopharyngeal gap were noted to receive a revision 50% of the time, while those with medium sized velopharyngeal gaps received revisions 41% of the time, and those with small velopharyngeal gaps received revisions 26% of the time.
CHAPTER V

DISCUSSION

It has been found that approximately 20-30% of patients with cleft palates develop hypernasal speech after receiving a pharyngeal flap surgery (Heliovaara et al., 2003). However, the percentage of individuals who develop hypernasal speech following the surgery continues to be debated by researchers. It is possible that hypernasality can be a side effect of failed pharyngeal flap surgeries. However, hyponasal speech occurs more often after a successful surgery (Liedman-Boshki et al., 2005). Therefore, there is a need to investigate why revisions are common and why the current procedures do not always ameliorate VPI and in some cases, cause resonance problems such as hyper- and hyponasality.

Past research studies have demonstrated that the assessment team can prevent the need for revision by preoperative identification of physical stigmata associated with VPI (Conley et al., 1997). This study looked at physical parameters pre-operatively such as cleft palate, submucous cleft palate, and adenoidectomy, in addition to other physiological and anatomical aspects. However, objective nasometric data was not considered in this study. Conley et al. (1997), determined that perceptual speech assessment is the criterion standard and serves as the basis of all instrumental evaluations to establish a diagnosis of a resonance disorder. Yet, without the inclusion of nasometric measures in regards to assessment of resonance, the outcome of the intervention provided is difficult to determine. We also know from Losken et al., 2003, that noninvasive measurement of nasalance can be effective in predicting the future revision surgeries in these patients. Their subjects requiring surgery following an initial pharyngoplasty for VPI had significantly higher pre-operative oral sentence nasometry than those patients who did not require a revision. Other studies have found predictive measures including investigating pre-operative velopharyngeal closure pattern and the type of revision completed in patients who had a failed initial pharyngoplasty (Kasten et al., 1997; Witt et al., 1995, Amour et al., 2005; Schultz et al., 1973; Conley et al., 1997). Each study selected one or two of the aforementioned variables to determine if prediction of revision was possible. However, there are currently no studies that have investigated all pre-operative indicators together in order to determine potential risk of surgical revision of the pharyngeal flap in patients with VPI or decipher which variable contributed the most to prediction of revision.

This study investigated if pre-operative oral sentence nasometric values and the type of velopharyngeal closure pattern predicts the incidence of revision in patients who receive the pharyngeal flap surgery. Identification of pre-operative indicators of potential revision cases may ultimately reduce the number of surgical revision procedures in patients with VPI and provide health care professionals possible indicators to identify the patients who will most likely return for revision surgical procedures.

In this study, there was no relationship between the initial VPI diagnosis type, age and closure pattern as compared to revision rate. This indicated that these factors are not predictive of revision rate. Significant relationships were found between pre-operative oral single word and oral sentence nasometry and revision rates. These results suggest it is not age, closure pattern or the subject’s VPI diagnosis that determines the revision procedure, but instead, pre-operative nasometry results that predict revision rate.
This result seems plausible because the surgeons in this study determined the specific surgical tailoring of the pharyngeal flap intraoperatively. This tailoring alters the anatomical positioning of the velum, pharyngeal walls of the velopharyngeal mechanism to produce the best possible velopharyngeal closure for the patient, tailoring the surgery to meet individual variability in the velopharyngeal anatomy. Knowing the pattern of closure and physiological parameters of the pharyngeal wall movement aids in tailoring the end anatomical positioning of the velopharyngeal musculature in order to improve the resonance. Therefore, results indicate that age, diagnosis, and closure pattern aid the surgeon in deciding the best approach to functionally improve the current VPI, but do not act as predictions for later revisions. In addition, age may not have been a factor due to the general consistency of the age group. Most subjects were between the ages of 5;0 to 7;6 (27 out of 59 subjects). The intra-operative tailoring of each individual surgery also seems to negate any influence due to age or closure pattern. The surgeons in this study use the preoperative information of age, closure pattern, and diagnosis to support their decision on improving the physiological compensation response to the change in anatomy. These specific factors do not predict revision. However, they help with the surgical decision making as to how to best reduce the current resonance deviance caused by VPI.

Oral word and sentence nasometry percentages were also measured pre-operatively in patients who received an initial pharyngeal flap and those that received a revision of the original surgery. It was determined that nasalance of single words containing alveolar, bilabial or velar phonemes were significantly related to revision. In addition, only the affricate sentences were significantly related to revision rate. There were no significant findings when analyzing nasal, plosive, sibilant and other sentence stimuli. However, it appears that in those subjects who needed a revisional surgery, higher pre-operative nasometric values were reported across all words and sentences measured.

Furthermore, the surgeons in this study determined and tailored the pharyngeal flap parameters intra-operatively with the goal of developing a pharyngeal flap that is specific to the anatomy of the individual and most appropriate to reduce the perception of VPI. Success was seen in 79% of the subjects (43 out of 59 subjects). Need for surgical revision was demonstrated in 21% of the subjects (16 out of 59 subjects), despite any intraoperative tailoring the surgeons performed. The group that showed consistent persisting velopharyngeal incompetence required a port tightening procedure. Following revision, no tertiary revisional surgeries occurred in the subjects. This would suggest that pre-operative severity of nasometry values is related to the need for revision to the pharyngeal flap surgery. The fact that a revision was required in 21% of patients (who were found to have clinically higher preoperative oral word and sentence percentages across all nasometry scores and a tailored flap), suggests that the severity of VPI pre-operatively seems to be the determining factor which necessitates multiple surgeries to remediate VPI. Thus, high pre-operative nasometry scores correlate to severity of VPI and this shows a strong relationship to the need for revision. In addition, those who have been found to have high nasometry scores typically present with larger velopharyngeal gaps and/or minimal pharyngeal wall movement. This larger anatomical area can prove to be more difficult to amend with a single pharyngeal flap surgery.

After removing factors that did not have any significance, and in the regression analysis of all significant variables, the ρ values decreased for oral word velar, bilabial, and alveolar nasometry scores while the ρ value of oral sentence nasometry affricates increased. This outcome suggests that oral word nasometry scores contribute more substantially to revision rate than oral sentence nasometry scores. Thus, the
higher a patient’s pre-operative oral word nasometry scores, the more likely the need for a revision will become.

Furthermore, post data collection, 30 additional subjects with VPI were added to the regression analysis. The addition of these subjects led to a substantial decrease in the p values of oral word and sentence nasometry. This outcome suggested that the addition of more subjects would lead to significance of the majority of nasometry scores.

Overall, if the mean percentage of nasometry values are 50.8% or above for alveolar words, 47.07% or above for velar words, 46.13% or above for bilabial words and 56.71% or above for affricate sentences, the more likely the patient is to have a revision. Pre-operative nasometric values may help clinicians and surgeons to instruct the patient of potential surgical outcomes.
CHAPTER VI

CONCLUSION

It remains difficult to predict the likelihood of revision to pharyngeal flap surgery based on pre-operative velopharyngeal anatomy alone. However, by understanding the relationship of pre-operative indicators, such as nasometry scores in relation to the physiological parameters of the velopharyngeal mechanism, patients who may need revision becomes apparent.

The pre-operative diagnosis of hypernasal resonance and increased severity of nasometric scores in individuals with VPI suggests a higher probability of revision to the initial pharyngeal flap surgery. The results of this study provide health care professionals indicators to identify the patients who will most likely return for revision of surgical procedures. It also aides in the pre-operative patient counseling process.
REFERENCES


# APPENDIX A: DATA FORMS

**Nasometry & VFSS Data**

<table>
<thead>
<tr>
<th>Subject #: __________</th>
<th>Age: _______</th>
<th>Gender: _______</th>
</tr>
</thead>
</table>

**Non-Nasal Utterances**

### Single words

<table>
<thead>
<tr>
<th>Utterance</th>
<th>Mean % Pre-op</th>
<th>Mean % Pre-Revision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tire, Turtle, Teddy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Book, Pie, Baby</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dress, Scissors, Horse</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cookie, Care, Cake</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Short phrases

<table>
<thead>
<tr>
<th>Utterance</th>
<th>Mean % Pre-op</th>
<th>Mean % Pre-Revision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Take teddy a toy.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buy baby a bib.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Give Kate the cake.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sheila shows sheep.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sue saw Sally.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I eat cherries with cheese</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Nasal Utterances**

<table>
<thead>
<tr>
<th>Utterance</th>
<th>Mean % Pre-op</th>
<th>Mean % Pre-Revision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muffins, Mittens, Lemonade</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ten men came in.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mama made lemon jam.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Low Pressure Context**

- We were here. 
- Where were you? 

**High Pressure Context - Zoo Passage**

Look at this book with us. It's a story about a zoo. That is where bears go. Today it is very cold out of door, but we see a cloud overhead that’s a pretty, white, fluffy shape. We hear that straw covers the floor of the cages, to keep the chill away; yet, a deer walks through the woods with her head held high. They feed seeds to birds so they’re able to fly.

<table>
<thead>
<tr>
<th>Utterance</th>
<th>Mean % Pre-op</th>
<th>Mean % Pre-Revision</th>
</tr>
</thead>
</table>

**Syndrome or Type of Cleft Lip/Palate:** __________________________

**Pharyngeal Flap:** ☐

**Date:** __________

**Revision:** Yes or No

**Date:** __________
Videofluoroscopic Findings:

Lateral view:

_____ Consistent functional contact of soft palate to the posterior pharyngeal wall
_____ Borderline contact that is not adequate for functional velopharyngeal function
_____ Inconsistent, but adequate palatal elevation to posterior pharyngeal wall
_____ Passavant’s ridge present: assists in contact
_____ Gap between soft palate and posterior pharyngeal wall

_____ Small    Moderate    Large

Frontal view:

_____ Lateral pharyngeal wall motion estimate
      (on a scale from 0 at rest to 1.0 for midline closure)

Towne view:

_____ Coronal– movement in anteriorposterior direction prominent, limited lateral pharyngeal wall motion and no posterior wall motion.

_____ Sagittal – lateral pharyngeal wall movement primary with little velar movement

_____ Circular– essentially equal contribution of velum and lateral pharyngeal walls, but no posterior pharyngeal wall movement
_____ Circular with Passavant’s ridge – same as circular with movement in the posterior pharyngeal wall

Notes: