Velopharyngeal Incompetence: A Guide for Clinical Evaluation

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Learning Objectives: After studying this article, the participant should be able to: 1. Understand the mechanism of speech production. 2. Recognize the specific cause of a speech abnormality (structural deficit, neurogenic deficit, misarticulation, or mechanical interference). 3. Perform a thorough clinical assessment using an intraoral examination and speech production analysis. 4. Understand the advantages and disadvantages of various types of instrumental modalities and their specific indications in diagnosing speech abnormalities.

Various causes of velopharyngeal disorders and the myriad of diagnostic methods used by speech-language pathologists and plastic surgeons for assessment are described in this article. Velopharyngeal incompetence occurs when the velum and lateral and posterior pharyngeal walls fail to separate the oral cavity from the nasal cavity during speech and deglutination. The functional goals of cleft palate operations are to facilitate normal speech and hearing without interfering with the facial growth of a child. Basic and helpful techniques are presented to help the cleft palate team identify preoperative or postoperative velopharyngeal incompetence. This information will enable any member of the multidisciplinary cleft palate team to better assist in the differential diagnosis and management of patients with speech disorders. (Plast. Reconstr. Surg. 112: 1890, 2003.)

The functional goals of cleft palate surgery are to facilitate normal speech and hearing without interfering with the facial growth of a child. Unfortunately, after primary palatoplasty, up to 20 percent of patients have unsatisfactory speech results and require secondary management because of insufficient velopharyngeal closure.1-11 The speech-language pathologist plays a vital role in identifying this group of patients. With early recognition and intervention, the chances for development of normal speech and hearing are increased. Further, the specific treatment plan and surgical procedure will be based on the causes of the inadequate velopharyngeal closure. The purpose of this article is to describe the various causes of velopharyngeal disorders and the myriad of diagnostic methods used by speech-language pathologists and plastic surgeons for assessment. This will enable any member of the multidisciplinary cleft palate team to better assist in the differential diagnosis and management of patients with speech disorders.

Velopharyngeal closure refers to the normal apposition of the soft palate, or velum, with the posterior and lateral pharyngeal walls.12-18 It is primarily a sphincteric mechanism consisting of a velar component and a pharyngeal component. Movement of the velar component is produced principally by the action of the levator veli palatini muscle. Movement of the pharyngeal component is more dependent on the constriction of the superior constrictor muscle and the palatopharyngeal muscles. The upward and backward movement of the velum, coupled with the mesial movement of the lateral pharyngeal walls and the slight anterior movement of the posterior pharyngeal walls (at the level of the first cervical vertebra), separates the oral cavity from the nasal cavity during deglutination and speech. Velopharyngeal incompetence occurs when the velum and lateral and posterior pharyngeal walls fail to separate the oral cavity from the nasal cavity during speech and deglutination.
ETIOLOGY

Different nomenclature exists that attempts to describe subgroups of velopharyngeal disorders based on etiology. We prefer the use of a single generic term, velopharyngeal incompetence, to denote any type of abnormal velopharyngeal function in which the velum and lateral and posterior pharyngeal walls fail to separate the oral cavity from the nasal cavity. The etiology of velopharyngeal incompetence includes structural deficits, neurogenic impairment, and mechanical interference to velopharyngeal closure.19–30

Of particular concern to the craniofacial surgeon is velopharyngeal incompetence occurring in patients with cleft palate secondary to a structural deficit of the velum or pharyngeal walls at the level of the nasopharynx with insufficient tissue to accomplish closure. Structural congenital defects include gross tissue deficiency, submucous or overt unoperated clefts, a short or immobile soft palate, a large and deep nasopharynx, or a palatal fistula. Velopharyngeal incompetence may also be acquired due to anatomic pathology as a result of cancer treatment or maxillofacial trauma. Similarly, neurogenic impairment can result in partial or total immobility of the soft palate and/or pharyngeal walls and lead to velopharyngeal incompetence. This neurogenic, impaired velopharyngeal valve closure will produce dysarthric speech. Protective and reflexive acts such as gagging and swallowing may be impaired depending on the nature and the level of the lesion. Velopharyngeal incompetence secondary to a neurogenic deficit may be congenital, although it is most often acquired after trauma. The disturbance in speech production is caused by a weakness, paralysis, or a lack of coordination of speech musculature. The injury may be localized to cranial nerves IX, X, or XI, lower motor nerves, upper motor nerves, and/or the cerebellum. The localization and severity of the impairment will dictate whether speech intelligibility will improve with velopharyngeal valve remediation.

Velopharyngeal incompetence may also be present secondary to mechanical interference with the velopharyngeal valve closure. For example, severely hypertrophied tonsils can cause a mechanical interference resulting in incomplete valve closure. Similarly, an excessively wide pharyngeal flap may inhibit apposition of the velum with the pharyngeal walls. Misarticulations may present in a manner similar to that seen in velopharyngeal incompetence.31–35 Phoneme-specific misarticulations refer to the occurrence of nasal emission on certain (but not all) pressure consonants in the absence of any hypernasal resonance. Fricatives (s, z) and affricates (ts, dz) are most vulnerable to this type of misarticulation. Recognizing this selective phoneme emission is crucial in identifying the cause of articular impairment in patients with inconsistent nasal emission, since a resonance disorder does not exist.

VELOPHARYNGEAL FUNCTION

The ability to achieve properly articulated speech pivots on the dynamic interaction of the palatal and pharyngeal wall musculature, which is driven by neural pathways to constrict the velopharyngeal portal. Because the entire vocal tract is a resonating cavity, coupling and uncoupling of the nasal and oral cavity are necessary to produce various sounds and intelligible speech. The velum and pharynx act as a valve that selectively channels airflow and acoustic energy under different pressures into the oral and nasal cavities. To produce nasal sounds (m, n, ng), the velopharyngeal valve channels airflow to the nasal cavity. Similarly, for the oral sounds (all vowels and remaining consonants), the valve closes off the nasal cavity and selectively transmits airflow and energy through the oral cavity. Thus, for normal speech, one must have rapid and competent velopharyngeal function in addition to being able to produce appropriate airflow and adequate pressure. With competent velopharyngeal valving, a pressure column of exhaled air is shared with the oral cavity, where interrelating tongue, palatine shelves, dentition, and lips fashion the various sound waves. Combined intermittently with nasal resonance, these sound waves characterize human speech.

Abnormal resonance can result from previously described structural, neurogenic, physiologic, or mechanical impairment. When the normal space relationship or coupling between the velum and nasopharynx is disturbed, velopharyngeal incompetence results. This produces three common speech characteristics secondary to increased transmission through the nasal cavity: hypernasality, nasal emission, and reduced aspiration and frication. Hyper-
nasality is secondary to excess nasal resonance (particularly with vowel production) just as turbulent airflow through the nasal cavity is responsible for nasal emission. On the other hand, stop plosives and fricatives are secondary to a leak, which prohibits the accumulation of sufficient oral pressures.

**Evaluation of Velopharyngeal Activity**

Two types of evaluation are used to obtain a thorough assessment of velopharyngeal function: a clinical evaluation and an instrumental evaluation. An understanding of the various subjective and objective techniques of each type of evaluation that are available to assess velopharyngeal function will enable the practitioner to identify the exact cause and determine the specific management of any velopharyngeal disorder. As no single modality is adequate for complete appraisal of velopharyngeal function, a variety of techniques should be used for evaluation. Utilizing different modalities will reveal the presence, size, location, and contour of an opening between the oral and nasal cavities during speech and delineate the nature of the velar and pharyngeal wall movements and interactions. The following is a description of the methods available, with particular focus on the approaches used most often at our institution in the diagnosis and treatment of velopharyngeal incompetence.

**Clinical Assessment of Velopharyngeal Activity**

The clinician’s eyes and ears are used as the first and primary diagnostic tools. As the most valid measure of adequate velopharyngeal function is sound produced during normal speech, by simply listening, one can judge whether further investigation is warranted. When a patient’s speech deviates from normal, a complete clinical evaluation is performed. After a thorough history is obtained, the clinical examination proceeds with an intraoral examination to assess structural integrity, reflexive behavior, and voluntary phonetic behavior. The speech production characteristics are then assessed. Particular focus is paid to resonance quality, airflow, air pressure, and whether compensatory articulatory productions exist.

**Intraoral Examination**

The first step in the intraoral examination is the direct visual assessment of structural integrity. The lips, teeth, tongue, tonsils, hard and soft palate, uvula, and pharyngeal walls should be carefully inspected. The symmetry of the velum, tonsils, and nasopharynx is noted. Submucous clefts are revealed through palpation of a notch in the hard palate, identification of a zona pellucida in the soft palate, or a bifid uvula. The presence of an oral nasal fistula should be sought. A rhinoscopic examination should be included to check for hypertrophied turbinates, septal deviation, and nasal obstruction.

The second step in the intraoral examination is to assess reflexive and voluntary behavior. Reflexive behavior assists in determining the overall dysarthric status. This assessment is performed by repetitive stimulation of a gag reflex at different loci. Delay, fatigue, asymmetry, or lack of response is noted. The presence or absence of nasal regurgitation during swallowing of liquids should also be determined. Unlike reflexive behavior, a voluntary behavioral assessment is limited to competent, cooperative patients. Visual intraoral assessment during sustained phonation of “a” assists in determining velar motion (elevation, length, asymmetry, amplitude, fatigue, and speed).

**Speech Production Characteristics**

Upon completion of a thorough intraoral examination, the clinical examination proceeds with an assessment of speech production characteristics. Four specific characteristics are assessed: resonance quality, airflow, air pressure, and compensatory articulation. Deviations in the normal movement of a pressurized airstream through the resonating vocal tract will cause specific alterations in these four characteristics. The recognition of these alterations will assist in obtaining the correct diagnosis.

The first characteristic, resonance quality, is assessed by checking for the presence of nasal vibration during vowel production (i, u, and e). With an incomplete velopharyngeal seal, the nasal cavity becomes coupled with the oral cavity and the airstream escapes through the open velopharyngeal port, causing hypernasal resonance. This resonance can be detected clinically by comparing occluded and unoccluded nares for the presence of a nasal vibration during vowel production.

The presence or absence of nasal emission of the airstream is the second speech production characteristic to assess. Nasal emission may be audible or inaudible. In addition to the noise that may be produced, the occurrence of nasal
flaring assists in identification. Other methods helpful in diagnosing inaudible nasal emission include a mirror that fogs when placed under the nares during vowel production and the deflection of tissue paper.

The third characteristic is the adequacy of intraoral air pressure build-up. The average adult requires 5 to 7 cm of water pressure build-up in the oral cavity behind the site of constriction to produce most oral consonants, particularly plosives (p) and fricatives (f). When velopharyngeal insufficiency is present, an inadequate amount of pressure is accrued in the oral cavity secondary to incomplete closure of the velopharyngeal valve. The phrase used frequently at our institution to test air pressure is “I pet puppies.”

To complete the speech production assessment, the presence or absence of compensatory articulation productions should be sought. Patients with cleft palate will derive compensatory articulation in a different anatomic area that will compensate for a poor or absent velopharyngeal valve. Specific types of compensatory articulations used by these patients include glottal stops, pharyngeal fricatives, pharyngeal stops, velar fricatives, and middorsal palatal stops (Table I). In other words, the patient substitutes a functioning glottis or pharynx or uses the mid dorsum and the back of the tongue to valve the airflow. The neurogenic patient, however, will have compensatory productions occurring at the same anatomic level but deviating in the manner of speech production. Thus, glottal and pharyngeal productions are absent. Rather, labial substitution is performed for tongue inadequacy. Regardless of the derivation of compensatory productions, they are all learned behaviors, which frequently persist even after adequate surgical or prosthetic management.

**Instrumental Assessment of Velopharyngeal Activity**

The subjective yet invaluable information gathered from the clinical examination should be used to complement objective structural data obtained from an instrumental assessment. The goal of the instrumental assessment is to obtain anatomic data regarding the adequacy of velar length, palatal elevation, velopharyngeal gap, excursion of the lateral and posterior pharyngeal walls, nasopharyngeal depth, pattern, and level of attempted closure. Two subgroups of techniques are used in the diagnostic process: direct and indirect. Direct instrumental techniques are those that enable the investigator to observe activity at the velopharyngeal port. Examples of direct techniques include lateral cephalogram, cineradiography, multi-view videofluoroscopy, oral-nasal panendoscopy, and magnetic resonance imaging. Indirect instrumental techniques provide information about vocal tract behavior, and gathered data are used to make relative inferences. Phototransduction, electromyography, and movement transduction are a few examples of indirect instrumental techniques.

**Direct Instrumental Techniques**

**Lateral cephalometric radiography.** The lateral cephalometric radiograph continues to be a mainstay of the evaluation process at our institution as well as many others. It is the primary direct method of assessing structures of the velopharynx and the surrounding tissues. Obtained at a constant magnification factor both at rest and during a sustained “-ee” production, lateral cephalogram views permit visualization of soft palate elevation and its contact with the posterior pharyngeal wall. The addition of barium allows for enhanced visualization of the margins of the velum and pharyngeal wall. Using this technique, we have had a greater than 90 percent rate of accurate prediction of the need for a pharyngeal flap based solely on this radiographic study.

Obvious advantages include the ability to assess structural features and velopharyngeal relationships in a simple, reliable, and quantifiable method. The length of a pharyngeal flap is

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<th>TABLE I</th>
<th>The Phonetic Alphabet: Consonants</th>
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<tr>
<td></td>
<td>Bilabial</td>
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<tr>
<td>Nasals</td>
<td>m</td>
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<tr>
<td>Plosives</td>
<td>p-b (pat-put)</td>
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<td>Fricatives</td>
<td>f-v (fat-vat)</td>
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<td>Sibilants</td>
<td>s-s (see-see)</td>
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<td>Affricates</td>
<td>ts-dz (cheap-jep)</td>
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determined by assessing the relationships provided. Because the velopharyngeal mechanism is three-dimensional and dynamic, the disadvantages of a lateral still radiograph are obvious: it is a two-dimensional study representative of structural features only in the sagittal plane. Hence, the width of a pharyngeal flap cannot be determined by this method. Further, because it is a static study, the events occurring between the two extremes of movement (between the resting state and the “ee” production) are not visualized. Despite its limitations, it continues to be a vital part of the diagnostic battery at multidisciplinary cleft palate centers.

Multiview videofluoroscopy. In response to the limitations of the lateral still radiograph, lateral view motion picture radiography was introduced to study velopharyngeal function in motion. With advances in technology, this evolved from cine (motion picture films) to multiview videofluoroscopy. Multiview videofluoroscopy has distinct advantages, such as less radiation exposure (10 times less than cinefluoroscopy), the ability to record and replay immediately, assessment of velopharyngeal function in three planes (sagittal, coronal, and transverse), and a dynamic view during connected speech from beginning to end. The lateral views depict movements of the velum and posterior pharyngeal walls. The frontal view of the oropharynx demonstrates gradations of mesial motion of the lateral pharyngeal walls, which ultimately determines the width of a proposed pharyngeal flap. Although its primary limitation is the inability to provide an absolute measurement of structural relationships, the width of a proposed pharyngeal flap is easily determined by a relative scale. The degree of lateral pharyngeal wall motion ranges from zero (no motion during quiet respiration) to five (maximal motion to the midline; Fig. 1). This ability to obtain an accurate preoperative assessment of lateral pharyngeal wall motion appears to be a prime determinant of postoperative success after a pharyngeal flap operation. In addition to being excellent in depicting necessary information on velopharyngeal function and dictating surgical management, compared with other techniques, it has the least variability and is most reflective of actual speech pattern.

Nasopharyngoscopy. The limitations of nasopharyngoscopy are similar to those of videofluoroscopy. The information obtained to assess gap size is in the form of a ratio than an absolute number. Although nasopharyngoscopy provides a substantial amount of information through visualization of the velum and pharyngeal walls, it is difficult to obtain standardized views or infer relative dimensions. Other limitations include the inability to identify small velopharyngeal gaps or pinpoint the exact anatomical location of the gap. Patient cooperation becomes a critical factor that further limits the use of nasopharyngoscopy in the pediatric population unless the patient is anesthetized. D’Antonio et al. have described the criteria, indications, and impact of nasal endoscopy on tailoring pharyngeal flaps, flap revisions, and the fitting of palatal prostheses. Similarly, Pigott finds the 70-degree endoscope to be indispensable and complementary to multiview videofluoroscopy in the evaluation of the velopharyngeal sphincter.

Magnetic resonance imaging. Magnetic resonance imaging uses the resonant absorption and remission of radio waves by hydrogen nuclei to
obtain images. It has a number of advantages over the methodologies currently used to study the vocal tract and velopharyngeal mechanism.\textsuperscript{47,48} Magnetic resonance imaging technology allows noninvasive visualization of the vocal tract without exposure to radiation or any known biohazards and provides better soft-tissue resolution. Functional images at any chosen level can be obtained in the sagittal, frontal, and transaxial views without changing the position of the patient. The current limitations of this method for imaging include the potential distortion of the velopharyngeal mechanism by gravitational forces in the supine position, the need for patient cooperation, and cost. It is hoped that further technological developments will result in near–real-time functional imaging that will soon reach its full potential and provide unique full-range vocal tract configuration data.

\textit{Indirect Instrumental Techniques}

Indirect techniques used to study the velopharyngeal mechanism are those that provide inferences through data about the structure and kinematics of the velopharyngeal mechanism. Examples include phototransduction, electromyography, and movement transduction. Other types of indirect measures study the effects of velopharyngeal function on other physiologic parameters. Aerodynamics, acoustics, sound pressure, and spectrography fall under this category. Although indirect measures provide objective information, they do not necessarily dictate the decision-making process.

\textit{Phototransduction.} Photoelectric technology uses light transmission to obtain relative information on the velopharyngeal port. A fiberoptic device couples a light source to an electronic detector. The two fibers are introduced through the nasal cavity until the light source is below the velopharyngeal port and the detector fiber is above the velopharyngeal port. Quantifiable data are produced that provide information regarding the opening and closing movements of the velopharyngeal port.

\textit{Electromyography.} Electromyography studies the electrical activity produced by muscle contraction using hooked wire electrodes. The limitations of electromyography are intuitive, such as discomfort from placement of needle electrodes, small and malpositioned muscles in cleft patients, and multiple passive and active forces acting on the velopharynx.

\textit{Movement transduction.} Movement transduction combines the use of mechanical and electrical devices to transduce velopharyngeal movement. The second maxillary molar acts as an anchor, with placement of a bar/spring attachment along the oral midline. With velar motion, the spring sensor converts motion into an electrical output along the strain gauge resistor. Although this technique is not currently used as an evaluation tool, it has been helpful as a biofeedback device.

\textit{Aerodynamics.} The study of pressure and flow provides significant information that allows a distinction to be made between velopharyngeal insufficiency and dysfunction secondary to other anatomic valve abnormalities. In addition, it helps determine the presence and magnitude of velopharyngeal incompetence and obstruction (nasal or pharyngeal). Specific information details the relative contributions of velopharyngeal components and nasal components to total airway resistance. In a complex case, this technique may be useful before surgical intervention to isolate and determine various contributions to insufficiency. Similarly, it is helpful after surgical intervention to determine whether a pharyngeal flap is the cause of a patient’s difficulty with nasal respiration.

\textit{Acoustics.} Quantitative changes in nasal resonance that occur with different degrees of coupling (the nasal and oral cavities) provide information about the presence and degree of velopharyngeal incompetence. In these patients, excessive acoustic energy in the nasal cavity is observed during reading from passages with oral sounds. In children with velopharyngeal obstruction, lack of acoustic energy in the nasal cavity is observed during reading from passages containing many nasal sounds. In addition to deciphering the location and degree of abnormal resonance, the information is provided instantaneously. Therefore, the acoustic assessment is a helpful method used for biofeedback during treatment sessions. Further, acoustic analyses with a sound spectrograph will identify subtle changes in the acoustic signal and can be used to monitor speech characteristics objectively. These acoustic findings should validate the more subjective perceptual ratings.

\textbf{DISCUSSION}

The multidisciplinary cleft palate team is indispensable in coordinating evaluation, diagnosis, and management of velopharyngeal insufficiency, as is the speech pathologist. The focus of this article is to present basic and
helpful techniques to improve the capabilities of any member of the cleft palate team in identifying preoperative or postoperative velopharyngeal incompetence. Through improvements in preoperative diagnostic techniques, improvements in outcomes are sure to follow. Similarly, the ability to critique a speech outcome after surgical intervention and to identify factors in patients with poor outcomes that may be avoided or modified in the future will lead to an improvement in outcomes. A thorough understanding of the mechanism of velopharyngeal function and the instrumental techniques used for evaluation may inspire new treatment modalities or improve those that currently exist. It is hoped that the multidisciplinary team will use the thorough clinical assessment and data obtained from instrumental techniques discussed in this article to determine the most appropriate intervention for a given patient. Clearly, without an armamentarium of several surgical techniques, the surgeon will be limited to applying a single treatment modality to a problem with varied physiological and structural causes.

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This is the last paper written by Dr. Donnell F. Johns before his untimely death. He left it on his desk, almost completed. The last time I spoke with him, he reminded me that he needed to finish it. His dedication to the correction of neurogenic velopharyngeal insufficiency, particularly in underprivileged children, demonstrated his humanity. His dedication exemplified who he was as an individual. He was a tremendous asset to us and to our profession. We miss him.

REFERENCES
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1. WHICH OF THE FOLLOWING IS THE MOST COMMON CAUSE OF VELOPHARYNGEAL INCOMPETENCE?
   A) Undiagnosed submucous cleft palate
   B) Short or immobile palate following primary cleft repair
   C) Mechanical obstruction
   D) Neurologic deficit
   E) Palatal fistula

2. DURING VELOPHARYNGEAL CLOSURE, MOVEMENT OF SOFT PALATE IS PRINCIPALLY DUE TO ACTION OF WHICH MUSCLE?
   A) Tensor veli palatini
   B) Levator veli palatini
   C) Pharyngopalatinus
   D) Palatoglossus
   E) Superior constrictor

3. SINCE THE ENTIRE VOCAL TRACT IS A RESONATING CAVITY, NORMAL SPEECH PRODUCTION REQUIRES THE VELOPHARYNGEAL PORT COUPLING AND UNCOUPLING OF THE NASAL AND ORAL CAVITIES.
   A) True
   B) False

4. SURGICAL CORRECTION OF VELOPHARYNGEAL INCOMPETENCE WILL IMPROVE EACH OF THE FOLLOWING EXCEPT:
   A) Resonance quality
   B) Nasal airflow
   C) Intraoral air pressure
   D) Articulation errors
   E) Nasal regurgitation

5. ACCORDING TO THE AUTHORS, THE BEST METHOD TO ASSESS SOFT-PALATE ELEVATION AND CONTACT WITH THE POSTERIOR PHARYNGEAL WALL IS:
   A) Lateral cephalometric radiography
   B) Magnetic resonance imaging
   C) Multiview videofluoroscopy
   D) Nasopharyngoscopy
   E) Aerodynamics

6. ACCORDING TO THE AUTHORS, THE DEGREE OF LATERAL WALL MOTION USED TO DETERMINE THE WIDTH OF A PLANNED PHARYNGEAL FLAP IS BEST DETERMINED USING:
   A) Lateral cephalometric radiography
   B) Magnetic resonance imaging
   C) Multiview videofluoroscopy
   D) Nasopharyngoscopy
   E) Movement transduction

To complete the examination for CME credit, turn to page 1982 for instructions and the response form.