Instrumental Assessment of Velopharyngeal Closure for Speech

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ABSTRACT

The presence of a palatal cleft at birth should not prevent good speech production in most children provided they have (1) appropriate surgical intervention to close the palate at or around the child's first birthday, (2) careful monitoring of speech development throughout childhood, (3) speech therapy when needed, and (4) secondary surgical or speech-prosthetic intervention when needed. When managed carefully by an experienced, well-prepared multidisciplinary team that applies the criteria listed above, ~70% of children with nonsyndromic palatal clefts will have no significant difficulties with speech intelligibility or speech quality due to velopharyngeal insufficiency by the time they enter elementary school. Speech assessment is the first step toward comprehensive team management of children with cleft palate. The purpose of this chapter is to describe the use of instrumentation in the evaluation of speech of children with palatal clefts, within the context of a multidisciplinary team. The focus of this article is on instruments that are used to supplement the perceptual assessment to document current speech status and plan management strategies.

KEYWORDS: Cleft palate, velopharyngeal insufficiency, nasometry, speech videofluoroscopy, nasendoscopy, nasopharyngoscopy

Learning Outcomes: As a result of this activity, the reader will be able to (1) describe the role of instrumentation in the evaluation of cleft palate speech and velopharyngeal function; (2) list the types of acoustic, aerodynamic, and image-based instrumentation available for assessment; and (3) describe the relative advantages of each type of instrumental procedure.

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ROLE OF INSTRUMENTATION IN THE ASSESSMENT OF CLEFT PALATE SPEECH

Speech is a perceptual entity. Every child's speech should be easy to understand and qualitatively acceptable. Articulation testing examines the accuracy of individual speech sound productions and relates closely to speech *intelligibility* in children with cleft palate. Assessment of speech *quality* usually involves approaches that categorize or rate the sound quality of speech along a continuum between acceptable and unacceptable. Ratings of hypernasal resonance, for example, attempt to distinguish speech that is appropriately oral (oral sounding when oral sounds are produced) from speech that is excessively hypernasal (nasal sounding when oral sounds are produced). Abnormal speech quality can affect intelligibility but usually less so than abnormal articulation.[1–4]

Speech articulation and speech quality interact in most speakers to determine intelligibility. For example, children who have adequate articulation but whose speech quality is affected by hypernasal resonance may be judged as being less intelligible than children who have similarly adequate articulation but who are not hypernasal. How these perceptual observations are described and coded during the course of a speech evaluation is the subject of an article by Kummer (pages 127–140), this issue. Difficulties associated with sorting through these perceptually based observations and relating them to recommendations for intervention have been a major motivator for development of instrumentation-based systems.

When speech is perceptually intelligible and qualitatively acceptable, instrumentation is needed only for documentation. It is important to objectively document all aspects of the child's speech production, even when the speech is found to be normal. When a problem does exist, instrumentation is used to facilitate the choice of appropriate treatment options. Questions that must be answered include: "Is the problem severe enough to treat?" "What sort of treatment options might be appropriate given the severity of the problem?" and "Are the child and family ready for the needed treatment?" Instrumentation can play a role in answering one or all of these questions.

ACOUSTIC-BASED INSTRUMENTATION

The acoustic speech signal, when properly recorded, contains relevant information that determines most of the perceptual characteristics of speech. Acoustic recordings and measurements are routinely performed as part of the speech assessment for children with cleft palate.

Audio Recordings

Audio recordings are valuable for documenting speech quality and intelligibility and may be obtained any time perceptual testing is performed. Recordings are essential, however, when perceptual testing identifies a speech problem that may require physical intervention. It is important to have a quality microphone and sound-recording device that each record frequencies between 60 and 10,000 Hz or better. In addition, the recording conditions should include minimal room noise, appropriate and constant mouth to microphone distance, recording levels adjusted to optimize signal-to-noise ratio, and use of a standardized speech sample that is sufficient to capture a representative sample of the child's speech ability.

The acoustic speech signal is commonly recorded and stored directly to digital storage media, although good-quality analog recording devices are adequate. Standard sentences should be used so the same utterances may be compared across time for a given individual and across individuals. Speech samples containing all oral phonemes provide a record of how the individual performs when rapid coupling and decoupling of the oral and nasal passages is not required. Speech samples that include a mixture of oral and nasal phonemes document speech performance when the child's velopharyngeal mechanism is challenged to rapidly accommodate both oral and nasal productions. Samples that include a high density of nasal phonemes may be particularly useful when testing for nasal obstruction that may be caused by nasal congestion, adenoid hypertrophy, or

an excessively obstructive pharyngeal flap or sphincter pharyngoplasty. Examples of some all-oral and oral-plus-nasal speech samples appear in Table 1. More extensive recordings may be obtained, including samples from conversational speech, articulation testing, and language testing.

Nasometry

Children with a history of cleft palate frequently have some degree of hypernasal resonance. When perceptual judgments and acoustic speech recordings confirm a problem with velopharyngeal valving, there is a particular need for objective measurement. Nasometry is one commonly used approach that involves comparison of the relative acoustic energy emitted from the nasal cavity to the total acoustic energy emitted from both the oral and nasal cavities during speech production. Originally conceived and tested by Fletcher[5] as TONAR and later marketed by Kay Elemetrics (now KayPentax, Lincoln Park, NJ), the Nasometer includes a headset with two identical microphones—one positioned directly in front of the patient's nose and the other directly in front of the patient's mouth. The microphones are mounted on a horizontal metal plate that provides limited acoustic separation between the oral and nasal acoustic signals (Fig. 1). Signals from both microphones are received by an electronic interface that measures signal intensity and ultimately plots data on a computer screen that represents the percentage of nasal energy produced in the recorded speech. Several display options are available including a graph of nasalance over time (Fig. 1).

Nasalance is the term used to refer to the average ratio of nasal acoustic energy to nasal + oral acoustic energy for a given speech sample.[6] The resulting nasalance measure ranges from 0 (no nasal resonance) to 100 (no oral resonance). In practice, however, measures of 0 and 100 will not occur in connected speech due to the imperfect acoustic separation between the nasal and oral microphones.

The amount of nasal energy present in a speech sample depends on (1) the speaker's ability to achieve velopharyngeal closure when needed, (2) the architecture of the nasal and pharyngeal passages, (3) the presence of an intact hard and soft palate, and (4) the presence and prevalence of nasal phonemes in the speech sample. To simplify measurements of hypernasality or nasal emission (excessive nasalance), it is common practice to use a series of utterances containing no nasal consonant sounds. Therefore, excessive nasalance measured during these utterances can be attributed to imperfect

Table 1 Examples of Standard Sentences Used for Acoustic Recording, Nasometry, and Endoscopy

All oral sentences containing pressure consonants	Look at this book with us.
	It's a story about a zoo.
	That's where bears go.
	Today it's very cold out of doors.
	But we see a cloud overhead.
	That's a pretty white fluffy shape.
All oral sentences containing no pressure consonants	You were away.
	Where were you?
	Why were you away?
	We were away earlier.
	Will you wear a lily?
	Roll a yellow wheel.
Sentences containing a high concentration of nasal phonemes	Mama made some lemon jam.
	Ten men came in when Jane rang.
	Dan's gang changed my mind.
	Ben can't plan on a long rain.
	Amanda came from Bounding, Maine.

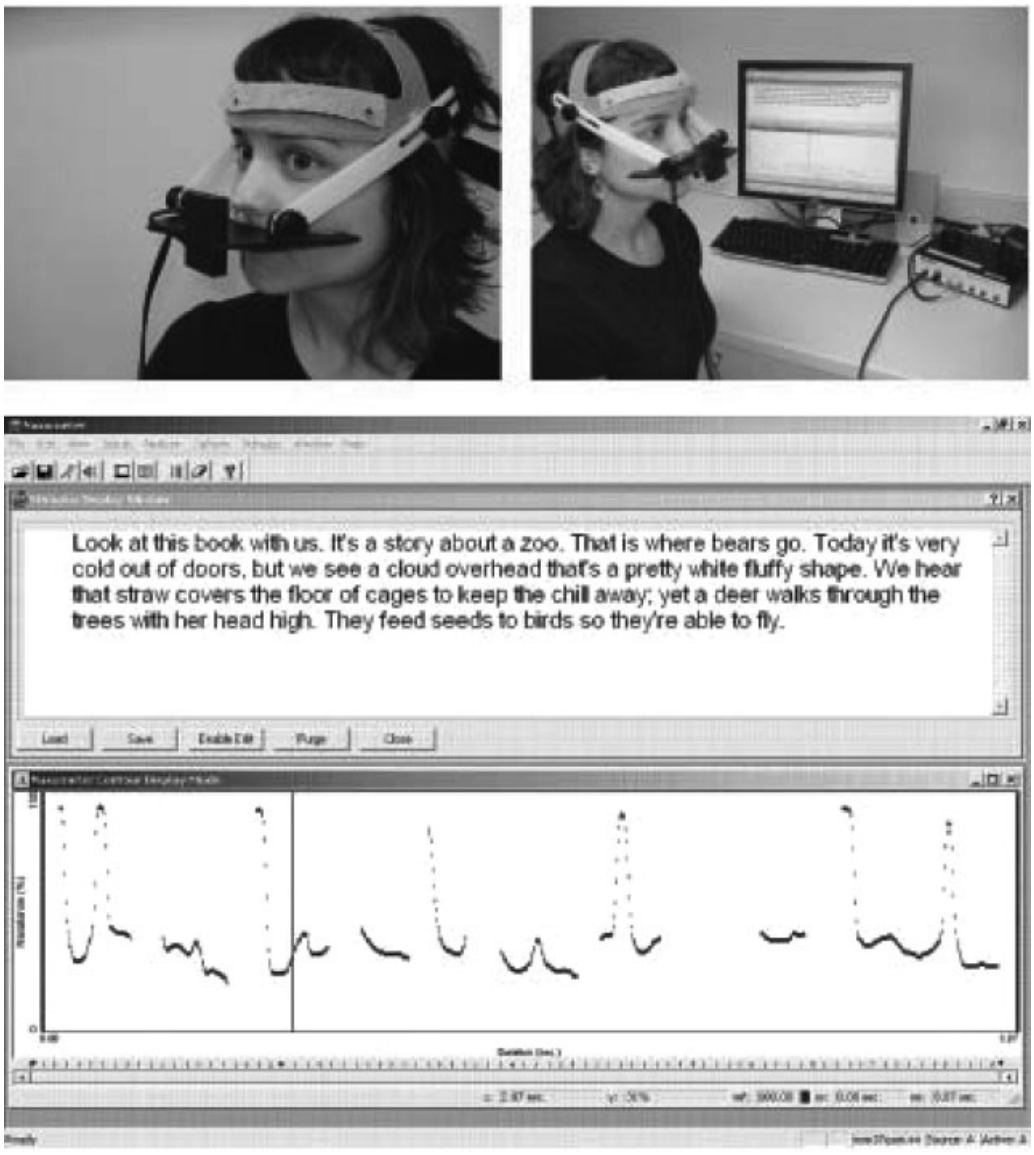


Figure 1 Nasometry headset and screen display.

velopharyngeal valving rather than the prevalence of nasal phonemes in the sample. To test for the presence of hyponasality, another set of utterances is commonly used that are loaded with nasal consonants. If low nasalance measures are obtained when these sentences are produced, there is reason to suspect some degree of nasal obstruction.

Some clinicians have adopted other utterance sets for special purposes. For example, sentences have been devised that contain no nasal consonants and no oral pressure consonants. The resulting utterances are made up of only vowels and semivowels, which require a lower aerodynamic demand for oral speech articulation. Still other utterances have been designed specifically for the limited vocabulary available to very young children.[16] At our clinic, we use the same three sentence sequences for nasometry that we use for acoustic recordings and for endoscopy (Table 1).

Published nasalance norms have appeared in the literature for English speakers from various regions of the United States.[7–10] Norms for countries and other languages have also been published.[11–16] In addition, there are

norms for repetitive production of consonant-vowel syllables with high vowels (i.e., si si si si, etc.) and low vowels (i.e., sa sa sa sa, etc.). This allows the examiner to make a distinction between phoneme-specific hypernasality or phoneme-specific nasal emission versus characteristics of VPI.

Although there is some variability among these reports, mean nasalance in normal speakers will be less than 30 for utterances containing no nasal phonemes, and speakers who have some degree of clinically significant hypernasal resonance will usually produce a mean nasalance measure at 30 or higher.[17] On the other hand, for nasal sentences, normal-speaking children should produce a mean nasalance score greater than 50. A child with nasal obstruction due to anatomic anomaly or even acute rhinitis (common cold) may sound perceptually hyponasal. These children are unable to produce normal-sounding nasal consonants and will produce a nasalance measure below 50 when producing nasal sentences.

The value of the nasalance measure lies in its objectivity—it reports what the microphones detect. However, there is not always perfect agreement between a clinician's perceptual ratings of oronasal resonance and the nasometer's measurements of nasalance . There are many possible explanations for discrepancies between the two. Clinician's ratings are typically based on all the speech the clinician may have heard from a patient, while nasalance measurements pertain only to the utterances measured during nasometric testing. In addition, the human auditory perceptual system cannot be replicated by the nasometer. This is partly due to the fact that nasometry picks up both hypernasality and nasal emission. Therefore, the Nasometer does not actually "hear" all aspects of the speech. (Human auditory-perceptual nervous system is not included with the Nasometry circuitry.) For that, the human ear is critical. The clinical significance of the nasalance measurement for each patient ultimately must be carefully considered and interpreted in the context of a complete perceptually based evaluation by a qualified and experienced speech-language pathologist. Some children who perceptually sound hypernasal may have nasalance measures within normal limits (<30). Others who do not seem to have clinically significant hypernasal resonance may have nasalance measures that indicate otherwise. Some children have elevated nasalance measures for some oral sentences but not others. Although such cases are among the minority[a], they happen frequently enough that nasalance measures alone must *not* be considered the basis for management decisions. Nothing trumps the experienced speech pathologist's perceptual judgment when oral-nasal resonance for speech is involved except, perhaps, the pooled perceptual judgment of multiple experienced speech-language pathologists. Some sample nasalance data are provided in Table 2,[18] including mean nasalance measures for each of six levels of oral-nasal resonance ratings recorded during clinical assessments at a Midwestern health care center in the United States.

AERODYNAMIC-BASED INSTRUMENTATION

Pressure-flow measurements using aerodynamic instrumentation are obtained at some clinics, although they seem to be more valued for research than for daily clinical applications.[19–22] Aerodynamic measures are particularly useful when there is interest in detailed understanding of the aerodynamics of the oral pressure consonant productions, which are critical to speech intelligibility.[23,24] Acquisition of these measurements is technically complex and, like nasopharyngoscopy, requires considerable cooperation from the patient.

IMAGING-BASED INSTRUMENTATION

When the perceptual and acoustic assessment confirms hypernasality or nasal emission, the need for intervention is then considered. Options include doing nothing (if the family is not interested in correction or if intervention puts the child's health unacceptably at risk),

[a] *After 1133 nasometry tests documented with perceptual ratings of nasal resonance by the author, indices of predictive utility of nasalance measures were as follows: sensitivity = 0.85, specificity = 0.84, negative predictive power = 0.68, relative risk = 5.4.*[18]

Table 2 Mean Nasalance Measures for Speakers Who Also Received at the Time of Nasometry Testing Ratings of Perceived Oral-Nasal Resonance*

Perceive Oral-Nasal Resonance	Number of Tests	Zoo Passage (Excerpt)	Low-Pressure Sentences	Nasal Sentences
1	210	20.6	23.0	58.9
2	151	35.5	37.9	63.8
3	140	46.1	47.5	64.2
4	77	48.4	47.8	63.9
5	75	54.7	53.6	64.6
6	79	58.8	59.7	65.8

*1, normal oral-nasal resonance; 6, severe hypernasal resonance.
Karnell MP, unpublished clinical data, 2011.

referring for speech therapy if the hypernasality or nasal emission are due to faulty articulation, or physical management if the problem is due to abnormal structure or physiology. Physical management options include surgery (or prosthetic management if surgery is not an option). The ability of the child and the child's family to comply with the demands of physical management should also be carefully considered. The clinicians involved in physical management (surgeon or prosthodontist) need to be aware of the physiological nature of the problem before settling on a management plan. This requires another speech evaluation designed to view the velopharyngeal anatomy and physiology during speech.

Speech Nasopharyngoscopy (aka Speech Nasendoscopy or Speech Videonasendoscopy)

Speech nasopharyngoscopy is a type of endoscopy used to visualize the velopharyngeal port during speech.[25–28] The equipment includes a flexible fiberoptic endoscope (Fig. 2) with specialized audio/video recording equipment.[29] The endoscope's flexible insertion tube is carefully inserted through the middle meatus of the nasal cavity and back to the pharynx (Fig. 3) so the velopharyngeal port can be visualized and recorded (Fig. 4). Because this is a speech evaluation endorsed by the American Speech-Language-Hearing Association,[30] it may best be labeled as a "speech videonasendoscopy". "Speech videonasendoscopy" should not be confused with endoscopic evaluations performed without involvement of an experienced speech pathologist.

A clinically relevant speech nasopharyngoscopy must be performed and recorded while the child is producing speech representative of conversational speech. As with nasometry, consideration must be given to the speech sample used during the endoscopic assessment of speech. Endoscopic speech examinations may employ the same speech

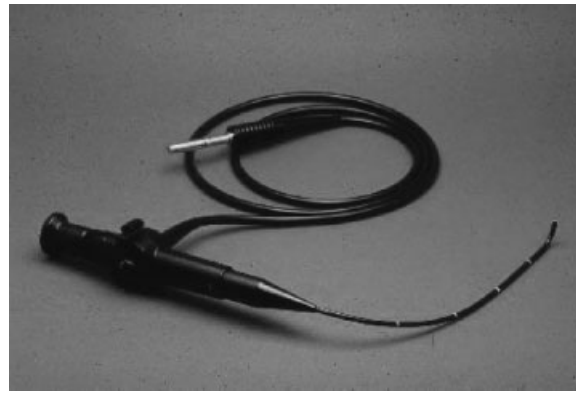


Figure 2 Flexible fiber-optic endoscope.

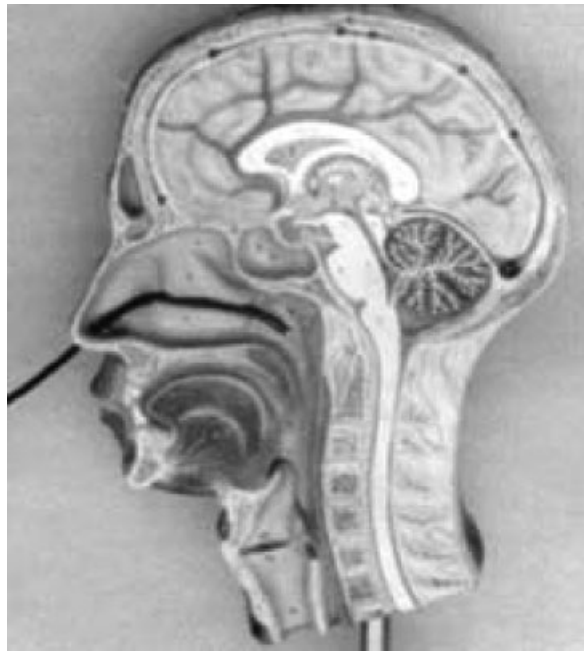


Figure 3 Placement of a flexible fiber-optic endoscope insertion tube in the middle nasal meatus, positioned for observation of velopharyngeal closure for speech.

samples that are used for acoustic recording purposes and nasometry but may also include additional utterances, conversational speech, and multiple repetitions of individual phonemes provided the child is tolerating the procedure and cooperating well.

Descriptions of speech nasopharyngoscopy should include a rationale for performing the evaluation, including findings from perceptual and acoustic evaluations, a brief description of the patient's clinical history, a description of how the procedure was performed, and a description of the physiological findings relevant to speech production[31–37] (Fig. 5). The most important findings to document are the size, location and cause of the opening, and the

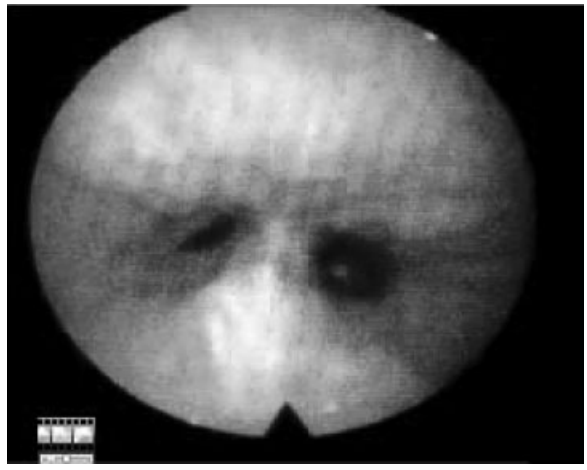
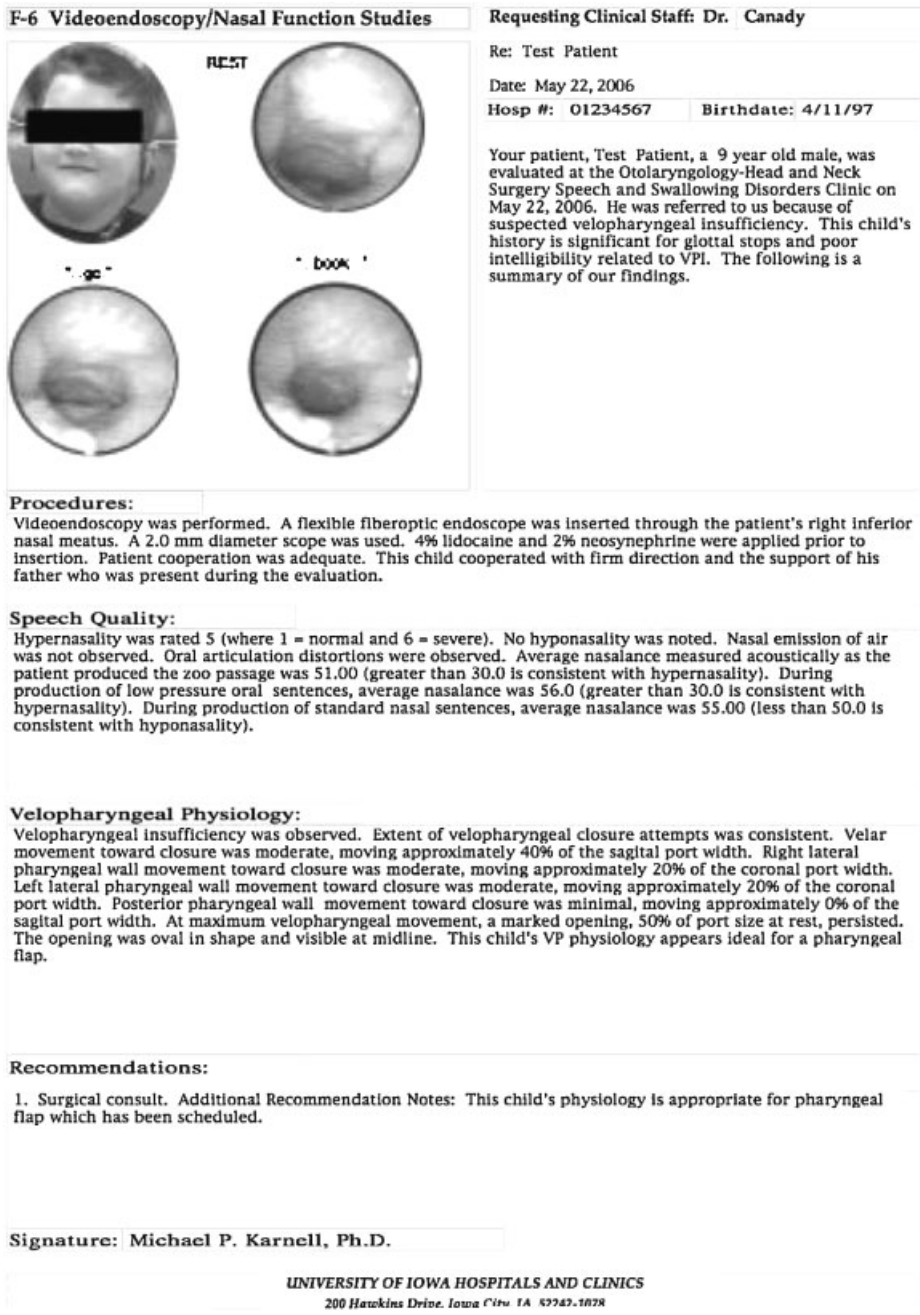


Figure 4 Example of a still image taken from a video record of a flexible fiber-optic endoscopic examination of velopharyngeal closure in a child after receiving a pharyngeal flap.



F-6 Videoendoscopy/Nasal Function Studies

Requesting Clinical Staff: Dr. Canady

Re: Test Patient

Date: May 22, 2006

Hosp #: 01234567 Birthdate: 4/11/97

Your patient, Test Patient, a 9 year old male, was evaluated at the Otolaryngology-Head and Neck Surgery Speech and Swallowing Disorders Clinic on May 22, 2006. He was referred to us because of suspected velopharyngeal insufficiency. This child's history is significant for glottal stops and poor intelligibility related to VPI. The following is a summary of our findings.

Procedures:

Videoendoscopy was performed. A flexible fiberoptic endoscope was inserted through the patient's right inferior nasal meatus. A 2.0 mm diameter scope was used. 4% lidocaine and 2% neosynephrine were applied prior to insertion. Patient cooperation was adequate. This child cooperated with firm direction and the support of his father who was present during the evaluation.

Speech Quality:

Hypernasality was rated 5 (where 1 = normal and 6 = severe). No hyponasality was noted. Nasal emission of air was not observed. Oral articulation distortions were observed. Average nasalance measured acoustically as the patient produced the zoo passage was 51.00 (greater than 30.0 is consistent with hypernasality). During production of low pressure oral sentences, average nasalance was 56.0 (greater than 30.0 is consistent with hypernasality). During production of standard nasal sentences, average nasalance was 55.00 (less than 50.0 is consistent with hyponasality).

Velopharyngeal Physiology:

Velopharyngeal insufficiency was observed. Extent of velopharyngeal closure attempts was consistent. Velar movement toward closure was moderate, moving approximately 40% of the sagital port width. Right lateral pharyngeal wall movement toward closure was moderate, moving approximately 20% of the coronal port width. Left lateral pharyngeal wall movement toward closure was moderate, moving approximately 20% of the coronal port width. Posterior pharyngeal wall movement toward closure was minimal, moving approximately 0% of the sagital port width. At maximum velopharyngeal movement, a marked opening, 50% of port size at rest, persisted. The opening was oval in shape and visible at midline. This child's VP physiology appears ideal for a pharyngeal flap.

Recommendations:

1. Surgical consult. Additional Recommendation Notes: This child's physiology is appropriate for pharyngeal flap which has been scheduled.

Signature: Michael P. Karnell, Ph.D.

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Figure 5 Example of a report describing the perceptual, acoustic, and endoscopic findings of a complete examination of speech in a child with a palatal cleft.

relative contributions of velar, lateral pharyngeal wall and posterior pharyngeal wall movements to attempted velopharyngeal closure. These factors are used in determining the recommendations, including the surgical procedure that would be most effective with these factors. When possible, photographic still images of velopharyngeal structures should be included to demonstrate the relevant clinical points described in the report. In general, the report should provide a clear and comprehensive justification for the recommendations offered,

which may include (1) no intervention, (2) speech therapy, (3) physical management, or (4) repeat follow-up examination.

Speech Videofluoroscopic Speech Studies

Speech videofluoroscopy is a radiological procedure that is used by some clinics for speech assessment.[38–40] This protocol involves imaging of the same speech sample during multiple views (i.e., lateral, anterior-posterior, base, and occasionally the Townes or Waters views).[32,41] Some clinics use speech videofluoroscopy primarily for children who cannot cooperate for the endoscopic assessment. It is also used to assess speech articulatory movements or to provide a better view of the pharynx than can be seen through nasopharyngoscopy.

Magnetic Resonance Imaging

In recent years, magnetic resonance imaging has been applied to address specific research questions involving brain structure and function and velopharyngeal anatomy. Recent data have suggested differences in cerebellar structure that may help explain some of the differences reported in speech and learning abilities in some individuals with cleft palate.[42–45] Other reports have demonstrated how magnetic resonance imaging may provide additional insight into the anatomic effects of the cleft and its repair on levator muscle anatomy and physiology.[46–48]

Imaging in the Future

Additional procedures may be developed in the future that offer more detailed information about variations in velopharyngeal port opening and size during time-varying speech production. Such procedures or instruments may provide new insights into why some patients appear to achieve only marginal or inconsistent velopharyngeal closure for speech and others achieve adequate closure and still others never achieve adequate closure. One such approach currently being pursued involves velopharyngeal photodetection performed with endoscopy.[49] Although it was originally suggested more than 25 years ago,[50] it continues to be an idea of considerable theoretical yet unproven value as of this writing.

CONCLUSIONS

Instrumentation is routinely used in cleft palate centers to supplement the perceptual assessment of cleft palate speech and velopharyngeal function. Some instrumentation (i.e., nasometry) can provide objective data. Still other instrumental procedures (i.e., speech nasopharyngoscopy) can provide needed information to guide physical management. Acoustic recordings, nasometry, and nasopharyngoscopy are used most commonly as they have demonstrated practical, clinical, and research value.

REFERENCES

1. Karnell MP, Van Demark DR. Longitudinal speech performance in patients with cleft palate: comparisons based on secondary management. Cleft Palate J 1986;23(4):278–288
2. Hardin-Jones MA, Brown CK, Van Demark DR, Morris HL. Long-term speech results of cleft palate patients with primary palatoplasty. Cleft Palate Craniofac J 1993;30(1):55–63
3. Persson C, Lohmander A, Elander A. Speech in children with an isolated cleft palate: a longitudinal perspective. Cleft Palate Craniofac J 2006; 43(3):295–309
4. Lohmander A, Persson C. A longitudinal study of speech production in Swedish children with unilateral cleft lip and palate and two-stage palatal repair. Cleft Palate Craniofac J 2008;45(1):32–41
5. Fletcher SG, Bishop ME. Measurement of nasality with tonar. Cleft Palate J 1970;7:610–621
6. Fletcher SG. "Nasalance" vs. listener judgements of nasality. Cleft Palate J 1976;13:31–44
7. Dalston RM, Warren DW, Dalston ET. Use of nasometry as a diagnostic tool for identifying patients with velopharyngeal impairment. Cleft Palate Craniofac J 1991;28(2):184–188; discussion 188–189
8. Hardin MA, Van Demark DR, Morris HL, Payne MM. Correspondence between nasalance scores and listener judgments of hypernasality and hyponasality. Cleft Palate Craniofac J 1992;29(4):346–351
9. Dalston RM, Neiman GS, Gonzalez-Landa G. Nasometric sensitivity and specificity: a cross-dialect and cross-culture study. Cleft Palate Craniofac J 1993;30(3):285–291

10. Watterson T, McFarlane SC, Wright DS. The relationship between nasalance and nasality in children with cleft palate. J Commun Disord 1993;26(1):13–28
11. Haapanen ML. Nasalance scores in normal Finnish speech. Folia Phoniatr (Basel) 1991;43(4):197–203
12. Santos Terron MJ, Gonzalez-Landa G, Sanchez-Ruiz I. Normal patterns of nasalance in children who speak Castilian. [in Spanish]Rev Esp Foniatr 1991;4:71–75
13. Kavanagh ML, Fee EJ, Kalinowski J, Doyle P, Leeper H. Nasometric values for three dialectal groups within the Atlantic Provinces of Canada. J Speech Lang Pathol Audiol 1994;18:7–13
14. Anderson RT. Nasometric values for normal Spanish-speaking females: a preliminary report. Cleft Palate Craniofac J 1996;33(4):333–336
15. Nichols AC. Nasalance statistics for two Mexican populations. Cleft Palate Craniofac J 1999;36(1): 57–63
16. Kummer AW. Simplified Nasometric Assessment Procedures (SNAP): Nasometer Test-Revised. Lincoln Park, NJ: Kay Elemetrics; 2005
17. Karnell MP. Nasometric discrimination of hypernasality and turbulent nasal airflow. Cleft Palate Craniofac J 1995;32(2):145–148
18. Sacket D, Straus S, Richardson W, Rosenberg W, Haynes R. Evidence-Based Medicine: How to Practice and Teach EBM. 2nd ed. London, United Kingdom: Churchill Livingstone; 2000
19. Hoit JD, Watson PJ, Hixon KE, McMahon P, Johnson CL. Age and velopharyngeal function during speech production. J Speech Hear Res 1994; 37(2):295–302
20. Devani P, Watts R, Markus AF. Speech outcome in children with cleft palate: aerophonoscope assessment of nasal emission. J Craniomaxillofac Surg 1999;27(3):180–186
21. Dotevall H, Ejnell H, Bake B. Nasal airflow patterns during the velopharyngeal closing phase in speech in children with and without cleft palate. Cleft Palate Craniofac J 2001;38(4):358–373
22. Zajac DJ, Hackett AM. Temporal characteristics of aerodynamic segments in the speech of children and adults. Cleft Palate Craniofac J 2002;39(4): 432–438
23. Zajac DJ, Weissler MC. Air pressure responses to sudden vocal tract pressure bleeds during production of stop consonants: new evidence of aeromechanical regulation. J Speech Lang Hear Res 2004;47(4):784–801
24. Williams WN, Wharton PW, Paulk MF, Brown WS, Turner GE, Stevens G. Intraoral air pressure discrimination under conditions of experimental velopharyngeal insufficiency. Cleft Palate Craniofac J 2005;42(3):297–303
25. de Sousa TV, Marques IL, Carneiro AF, Bettiol H, Freitas JA. Nasopharyngoscopy in Robin sequence: clinical and predictive value. Cleft Palate Craniofac J 2003;40(6):618–623
26. Yoon PJ, Starr JR, Perkins JA, Bloom D, Sie KC. Interrater and intrarater reliability in the evaluation of velopharyngeal insufficiency within a single institution. Arch Otolaryngol Head Neck Surg 2006;132(9):947–951
27. Polzer I, Breitsprecher L, Winter K, Biffar R. Videoendoscopic, speech and hearing in cleft palate children after levator-palatopharyngeus surgery according to Kriens. J Craniomaxillofac Surg 2006;34(Suppl 2):52–56
28. Pereira V, Sell D, Ponniah A, Evans R, Dunaway D. Midface osteotomy versus distraction: the effect on speech, nasality, and velopharyngeal function in craniofacial dysostosis. Cleft Palate Craniofac J 2008;45(4):353–363
29. VanLue M, Cox KM, Wade JM, et al. Development of a microportable imaging system for otoscopy and nasoendoscopy evaluations. Cleft Palate Craniofac J 2007;44(2):121–125
30. American Speech-Language-Hearing Association. Vocal Tract Visualization and Imaging (Policy statement). Available at: asha.org/policy. Accessed May 4, 2011
31. Osberg PE, Witzel MA. The physiologic basis for hypernasality during connected speech in cleft palate patients: a nasendoscopic study. Plast Reconstr Surg 1981;67(1):1–5
32. Stringer DA, Witzel MA. Waters projection for evaluation of lateral pharyngeal wall movement in speech disorders. AJR Am J Roentgenol 1985; 145(2):409–410
33. Karnell MP, Linville RN, Edwards BA. Variations in velar position over time: a nasal videoendoscopic study. J Speech Hear Res 1988;31(3): 417–424
34. Witzel MA, Posnick JC. Patterns and location of velopharyngeal valving problems: atypical findings on video nasopharyngoscopy. Cleft Palate J 1989;26(1):63–67
35. Golding-Kushner KJ, Argamaso RV, Cotton RT, et al. Standardization for the reporting of nasopharyngoscopy and multiview videofluoroscopy: a report from an International Working Group. Cleft Palate J 1990;27(4):337–347; discussion 347–348
36. Kummer AW, Curtis C, Wiggs M, Lee L, Strife JL. Comparison of velopharyngeal gap size in patients with hypernasality, hypernasality and nasal emission, or nasal turbulence (rustle) as the primary speech characteristic. Cleft Palate Craniofac J 1992;29(2):152–156
37. Witt PD, Marsh JL, Marty-Grames L, Muntz HR, Gay WD. Management of the hypodynamic velopharynx. Cleft Palate Craniofac J 1995;32(3): 179–187
38. Sommerlad B, Rowland N, Harland K. Lateral videofluoroscopy: a modification to aid in

velopharyngeal assessment and measurement. Cleft Palate Craniofac J 1994;31(2):134–135
39. Lam DJ, Starr JR, Perkins JA, et al. A comparison of nasendoscopy and multiview videofluoroscopy in assessing velopharyngeal insufficiency. Otolaryngol Head Neck Surg 2006;134(3): 394–402
40. Dudas JR, Deleyiannis FW, Ford MD, Jiang S, Losee JE. Diagnosis and treatment of velopharyngeal insufficiency: clinical utility of speech evaluation and videofluoroscopy. Ann Plast Surg 2006;56(5):511–517; discussion 517
41. Stringer DA, Witzel MA. Comparison of multiview videofluoroscopy and nasopharyngoscopy in the assessment of velopharyngeal insufficiency. Cleft Palate J 1989;26(2):88–92
42. Nopoulos P, Choe I, Berg S, Van Demark D, Canady J, Richman L. Ventral frontal cortex morphology in adult males with isolated orofacial clefts: relationship to abnormalities in social function. Cleft Palate Craniofac J 2005;42(2): 138–144
43. Shinagawa H, Ono T, Honda E, Kurabayashi T, Iriki A, Ohyama K. Distinctive cortical articulatory representation in cleft lip and palate: a preliminary functional magnetic resonance imaging study. Cleft Palate Craniofac J 2006;43(5): 620–624
44. Levine D, Cavazos C, Kazan-Tannus JF, et al. Evaluation of real-time single-shot fast spin-echo MRI for visualization of the fetal midline corpus callosum and secondary palate. AJR Am J Roentgenol 2006;187(6):1505–1511
45. Conrad AL, Dailey S, Richman L, et al. Cerebellum structure differences and relationship to speech in boys and girls with nonsyndromic cleft of the lip and/or palate. Cleft Palate Craniofac J 2010; 47(5):469–475
46. Perry JL, Kuehn DP. Three-dimensional computer reconstruction of the levator veli palatini muscle in situ using magnetic resonance imaging. Cleft Palate Craniofac J 2007;44(4):421–423
47. Ha S, Kuehn DP, Cohen M, Alperin N. Magnetic resonance imaging of the levator veli palatini muscle in speakers with repaired cleft palate. Cleft Palate Craniofac J 2007;44(5):494–505
48. Atik B, Bekerecioglu M, Tan O, Etlik O, Davran R, Arslan H. Evaluation of dynamic magnetic resonance imaging in assessing velopharyngeal insufficiency during phonation. J Craniofac Surg 2008;19(3):566–572
49. Karnell MP, Seaver EJ. Integrated endoscopic/photodetector evaluation of velopharyngeal function. Cleft Palate Craniofac J 1993;30(3):337–342
50. Dalston RM. Photodetector assessment of velopharyngeal activity. Cleft Palate J 1982;19(1):1–8