The Effects of Increased Nasal Airway Resistance on Modeled Velopharyngeal Orifice Area Estimation

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Research has shown that cleft lip and palate individuals have higher nasal airway resistance than normal subjects (Warren, Duany, and Fischer, 1969). The present work examined the predictive nature of modeled velopharyngeal orifice area calculations obtained using the hydrokinetic equation (Warren and DuBois, 1964) under conditions simulating increased degrees of nasal obstruction. The results of this project suggested that Warren’s hydrokinetic method can be used to obtain accurate estimates of velopharyngeal orifice area under conditions of increased nasal airway resistance when airflow rates are nonvariant.

Smith and Weinberg (1980, 1982, 1983) have completed a series of modeling studies to assess the predictive nature of velopharyngeal orifice area estimation using hydrokinetic methods (Warren and DuBois, 1964). In these studies, estimations were made under steady airflow conditions and under non-steady airflow conditions known to exist during consonant production. The results of these studies indicated that accurate velopharyngeal area estimations could be obtained under steady airflow conditions (4–6 percent overall error in estimation) and under aerodynamic conditions simulating the production of voiceless stop consonants (6 percent overall error in estimation) and voiceless fricative consonants (8 percent overall error in estimation).

The model used in these investigations was provided by Warren (Warren and Devereux, 1966). In this model, the oral and pharyngeal dimensions of an adult vocal tract are approximated and the cross-sectional area of the model nose offers resistance to airflow comparable to established values for normal individuals. Mean nasal resistance for adults with rhinoscopically normal noses ranges from approximately 1–3 cm H2O/LPS (Butler, 1960; Warren, Duany, and Fischer, 1969; Hasegawa, Kern, and O’Brien, 1979). Hence, these estimations of velopharyngeal orifice area (Smith and Weinberg, 1980, 1982, 1983) were obtained in the presence of small, normal magnitudes of nasal resistance.

Warren, Duany, and Fischer (1969) measured nasal pathway resistance in normal and cleft lip and palate individuals in three age categories. They found that for the 9–11, 12–13, and 15 and older age groups, normal subjects had mean nasal resistances of 3.0, 2.4, and 2.0 cm H2O/LPS, respectively. Average nasal resistances for three comparably aged cleft lip

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and palate subject groups were 4.9, 3.6, and 3.5 cm H₂O/LPS, respectively. Warren et al. attributed the elevated airway resistance in cleft lip and palate subjects to the presence of nasal deformities and maxillary growth deficits. Both of these factors have been related to a reduction in the size of the nasal passages (Drettner, 1960; Foster, 1962; Aduss and Pruzansky, 1967).

In an earlier work, Warren and Ryon (1967) indicated that the presence of increased magnitudes of nasal resistance in association with velopharyngeal inadequacy may alter pressure-flow patterns during consonant productions. Alterations in pressure-flow patterns associated with increases in nasal resistance may influence estimation of velopharyngeal orifice area.

Unfortunately, there is an absence of information concerning the predictive nature (accuracy and variability) of velopharyngeal orifice estimation made in the presence of increased magnitudes of nasal resistance. This issue is not unimportant given information suggesting that 1) children have higher nasal airway resistance than adults and 2) cleft lip and palate individuals have higher nasal resistance than normal subjects (Warren, Duany, and Fischer, 1969). Hence, the purpose of this project was to quantify the nature of modeled velopharyngeal orifice area estimation under conditions simulating increased degrees of nasal obstruction.

**Method**

**Modeling Apparatus.** The vocal tract model used in this project was provided by Warren. As indicated earlier, the cross-sectional area of the model nose offers resistance to airflow comparable to established values for normal individuals. In this project, two degrees of nasal obstruction were simulated by inserting plugs (tubing) into the model nostrils. The airway resistances offered by these plugs were 24.4 cm H₂O/LPS for one nostril and 427.4 cm H₂O/LPS for the other nostril at flow rates of approximately 0.17 LPS. This situation was designed to simulate extreme conditions of nasal obstruction which have been observed clinically. Resistances were calculated using the formula \( R = \frac{P}{V} \), where \( P \) is the pressure drop across the plug and \( V \) is the volume rate of airflow through the plug (Warren, Duany, and Fischer, 1966; Butler, 1960).

The area of the model velopharyngeal orifice was varied by placing cover plates over the fully open velopharyngeal port. In this study, seven cover plates were used. There was a circular opening in each cover plate to provide known velopharyngeal port areas of approximately 3.12, 7.29, 12.48, 19.46, 31.65, 40.06, and 49.46 mm². These orifice areas were chosen to sample a wide range of portal openings. The oral port of the model was closed throughout this investigation.

**Airflow and Differential Pressure Measurements.** The volume rate of airflow (V) through the model was sensed by a Silverman-type pneumotachograph. This device was coupled to one nostril of the model. The pressure differential across the screen of the pneumotachograph was sensed by a Statham PM 15 differential pressure transducer. The signal from this transducer was amplified and fed into a Honeywell Visicorder (Model 1508). The airflow measurement system was calibrated with a flowmeter (Fischer & Porter).

The pressure differential across the velopharyngeal orifice was transmitted directly to a differential pressure transducer (Statham PM 6). The signal from this transducer was amplified and fed into a second channel of the Honeywell Visicorder. A water manometer was used to calibrate these pressure measurements.

**Procedure.** The model was driven with steady airflow rates supplied by an air cylinder. Flow rates ranged from approximately 0.05–0.50 LPS and were selected to sample a range of flows known to exist during respiration and speech. Simultaneous measurement was made of airflow rate and orifice differential pressure to estimate velopharyngeal orifice area.

A large number of measurements were made for each modeled velopharyngeal orifice area and nasal resistance condition and were used to calculate the size of velopharyngeal orifice opening using Warren's hydrokinetic equation (Warren and DuBois,
1964)

\[ A = \frac{\dot{V}}{0.65 \sqrt{\frac{2}{D} \left( \frac{P_1 - P_3}{D} \right)}} \]

where \( A \) is orifice area (cm²), \( \dot{V} \) is volume rate of airflow through the orifice, \( P_1 \) is pressure measured below the orifice, \( P_3 \) is pressure measured above the orifice, \( D \) is density of air, and 0.65 is a correction factor introduced to account for "unsteady, non-uniform, and rotational" characteristics of airflow that exist during speech production (Warren and DuBois, 1964). In addition, measurements of velopharyngeal orifice area were used to compute percent error in calculated velopharyngeal orifice areas using the formula

\[
\text{Percent error} = \frac{\text{known area} - \text{calculated area}}{\text{known area}} \times 100
\]

As indicated earlier, velopharyngeal orifice area and percent error calculations were obtained for two conditions of nasal obstruction. In one condition, flow was measured through the least resistive plug \((R = 24.4 \text{ cm } H_2O/LPS)\) and nasal pressure was sensed through the other, highly resistive nostril \((R = 427.4 \text{ cm } H_2O/LPS)\). In the second condition, flow was measured through the highly resistive plug and nasal pressure was sensed through the other, less resistive nostril. A total of 105 orifice area and percent error calculations were made under condition #1, while 63 orifice area and percent error calculations were made under condition #2. The number of calculations made under condition #2 was less because the buildup of pressure in the model became excessive at higher flow rates.

### Results and Discussion

The accuracy of velopharyngeal orifice area estimation obtained under conditions of elevated nasal airway resistance is summarized in Tables 1 and 2.

The data in Table 1 shows 1) that average calculated orifice areas corresponded favorably with orifice openings known to be present in the model and 2) that variation (standard deviation) in predicted orifice areas was small for all known orifice openings and resistive conditions. Although the overall average predictive accuracy of velopharyngeal orifice area estimation associated with almost complete nostril obstruction (condition #2) was re-
duced in comparison with estimation under a less resistive circumstance (condition #1), the magnitudes of orifice estimation errors found in this study (Table 2) compare favorably with those established under conditions of normal nasal airway resistance (Smith and Weinberg, 1980, 1982). That is, accurate estimates of modeled velopharyngeal orifice areas were obtained in the presence of increased magnitudes of nasal resistance when the model was driven with steady airflow rates.

The results of this project suggest that Warren’s pressure-flow method can be used to obtain accurate estimates of velopharyngeal orifice areas under conditions of extreme nostril obstruction. Since children with cleft lip and palate have increased magnitudes of nasal resistance (Warren, Duany, and Fischer, 1969), these findings have important clinical significance. Additional research is needed to determine whether accurate velopharyngeal orifice area measurements can also be obtained under non-steady airflow conditions known to exist during consonant production in the presence of increased magnitudes of nasal resistance.

References


