An Analog Study of Cleft Palate Speech

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The production of plosive and fricative sounds requires adequate constriction of both the oral and nasal ports so that air can be held under pressure in the mouth and then released. Although there is information presently available concerning the probable degree of velopharyngeal closure necessary (*1, 9, 10*), the influence of oral port constriction on respiratory parameters associated with speech has been neglected.

In light of evidence revealing a higher incidence of fricative articulation deficits in cleft palate speakers compared to plosive errors (*5, 6, 7*), it is important to consider the possibility that, by its influence on pressure and airflow in the mouth and nose, oral port function may be partly responsible for the observed differences in consonant intelligibility.

Since constriction of the oral port involves complex interaction of such structures as the tongue, lips, teeth, and anterior palate, it is difficult to evaluate oral cavity dimensions during speech. Techniques such as cineradiography, cephalometrics, and manometrics cannot delineate structural relationships well enough for this determination.

In this investigation, therefore, a simple mechanical model of the upper speech mechanism was utilized to evaluate effects of oral constriction on the respiratory aspects of speech. Briefly, it was assumed that if a model could be designed to adequately simulate the physiological parameters of speech, then data obtained from it could be viewed with a fair degree of confidence and could possibly provide a better understanding of the phenomenon of 'cleft palate' speech.

The following questions were considered: a) assuming that the laws of hydraulics apply to pressure-flow relationships during speech, how closely can the respiratory patterns of normal and cleft palate speech be copied by a model, and b) what are the effects of oral port size on pressure-flow relationships in the upper pharynx?

Materials and Methods

The plastic model employed in this study is illustrated in Figure 1. Dimensions, such as oral cavity and nasal pathway length, were ap-

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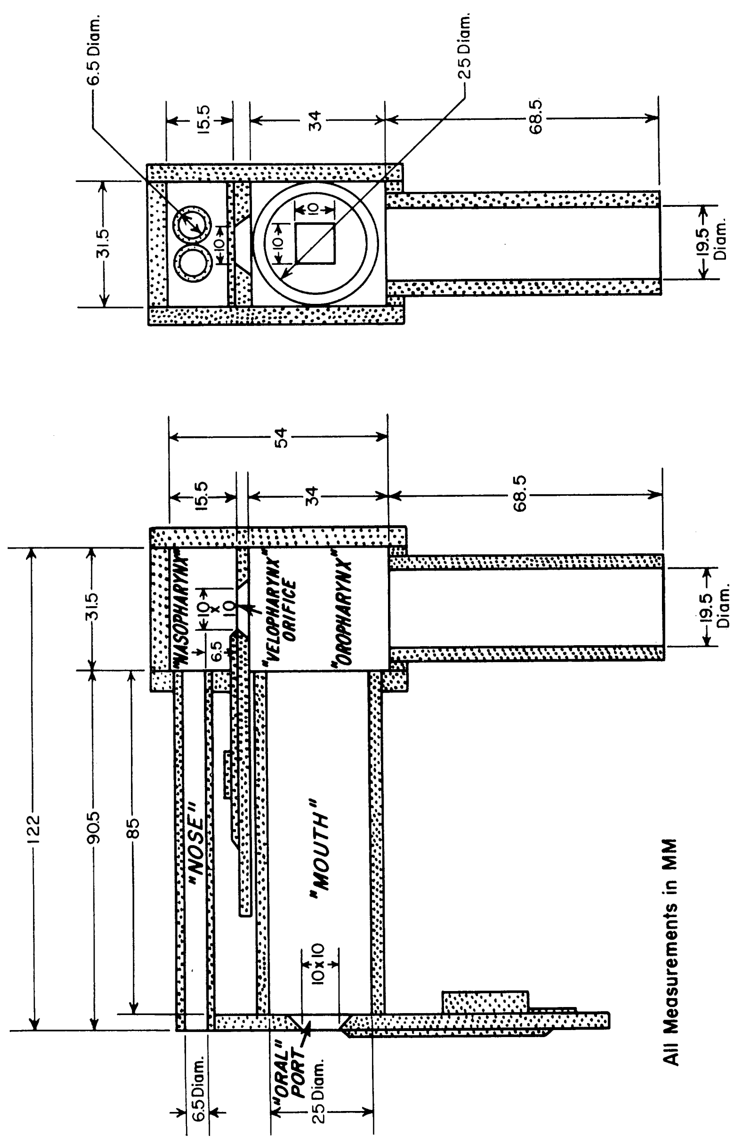

FIGURE 1. Schematic representation of the model.

proximated from cephalometric measurements of normal adults. Structures which could not be approximated from x-ray measurements, such as cross-sectional area of the nose and mouth, were constructed so as to offer resistance to airflow comparable to known values in normal individuals (*2*).

The velopharyngeal orifice was designed so that its dimensions could be varied between 0 and 1.0 cm^2, thereby simulating adequate closure as well as amounts of opening considered to represent varying degrees of incompetency (*9, 10*). The oral port could also be varied from 0 to 1.0 cm^2. Oral port constriction in the model represents pathway occlusion by the lips and teeth for such sounds as *f* or *v,* of the tongue and alveolar ridge for *sh* or *zh,* of the tongue, alveolar ridge and teeth for *s* or *z,* and complete closure in the case of plosives.

Technique with Cleft Palate Subjects for Comparison of Data with the Model. Twenty cleft palate subjects were instructed to phonate two sentences to provide pressure-flow data on consonants for comparison with those simulated by the model. These sentences were *Are you home, Papa?* and *Bessie stayed all summer.* The subjects ranged in age from 7 to 45 years and were selected because they presented varying degrees of velopharyngeal closure. The sample included six surgically treated patients, and 14 patients who were treated prosthetically.

The technique for estimating velopharyngeal orifice size for the subjects from pressure-flow data has been presented earlier (*8, 10*). Differential pressure between the nasopharynx and oropharynx was transmitted directly to a differential pressure transducer by two polyethelene catheters (Figure 2). The catheters were plugged at their tips, but were open at the sides for measurement of static pressures. A water manometer was used to calibrate pressure. Airflow was measured by a heated pneumotachograph connected to the nose and calibrated with a rotameter.

Pressure, rate of airflow, and speech sample were recorded on a four-channel magnetic tape recorder containing oscilloscopes for monitoring each parameter during the task. An oscillograph recording camera was utilized to photograph on paper the data which were replayed from the tape recorder into a cathode ray oscillograph.

Orifice size was then computed from the equation

$$\text{orifice area} = \frac{\text{rate of airflow through orifice}}{.65\sqrt{2\left(\dfrac{\text{orifice differential pressure}}{\text{density of air}}\right)}}$$

Procedure with the Model. The technique with the model is similar to the one described above and is illustrated in Figure 3. Respiratory airflow was simulated by a pump which produced airflow in the form of half sine waves. That airflow could be varied in rate in steps up to .8 liters per second.

First, plosive consonants were simulated at varying amounts of

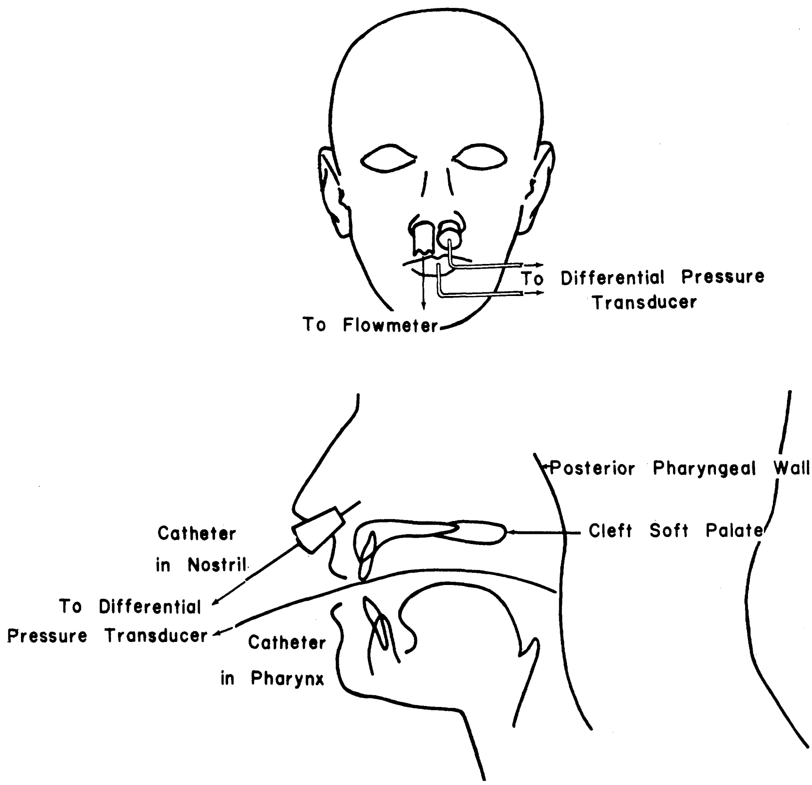

FIGURE 2. Technique for recording orifice pressure drop and nasal airflow for estimation of velopharyngeal orifice size.

velopharyngeal opening and respiratory airflow rates. Next, fricative sounds were simulated by varying velopharyngeal orifice size, airflow rate, and oral port size.

Results

COMPARISON OF SIMULATED AND ACTUAL CONSONANTS. The difference in pressure between the oropharynx and nasopharynx (orifice differential pressure) during phonation of plosive consonants is determined by velopharyngeal orifice size and the volume rate of respiratory airflow. The effect of orifice size on pressure is illustrated in Figure 4, which compares data from the model with those of the subjects. The data indicate that the slope and magnitude of the two curves are essentially the same. That is, pressure declines sharply between 0 and .20 cm^2 and then to a lesser degree for orifice openings above .20 cm^2. The only apparent difference between the two curves is the greater scattering of the speech data due to more variable airflow through the orifice. As airflow rate increases, the curve shifts to the right (Figure 5).

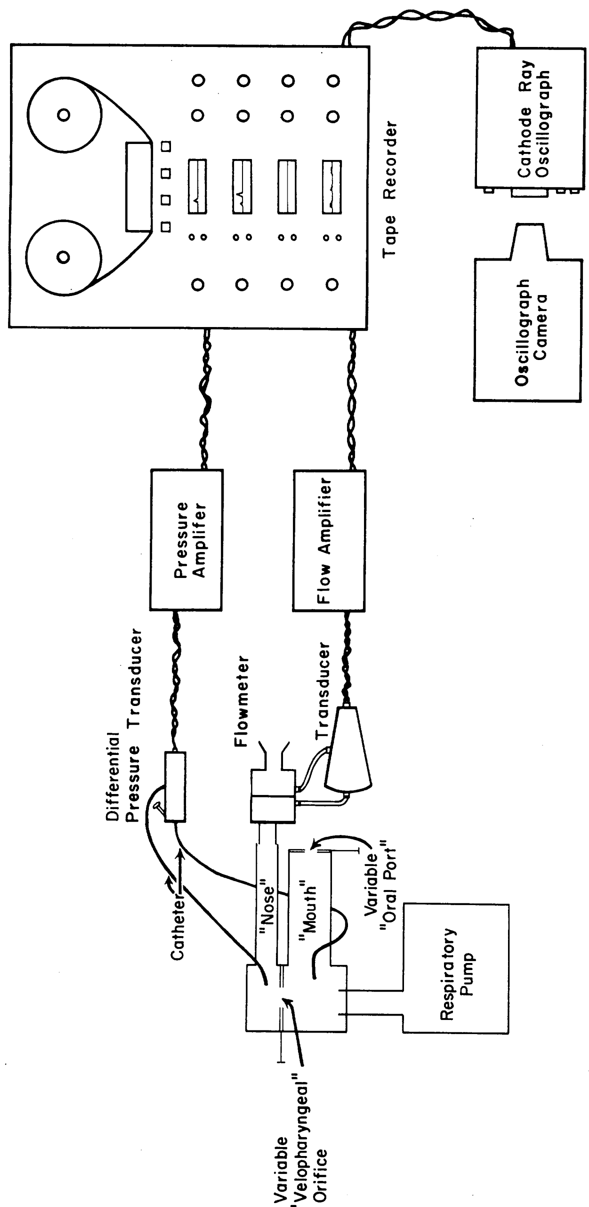

FIGURE 3. Apparatus used to record pressure-flow relationships during simulated speech.

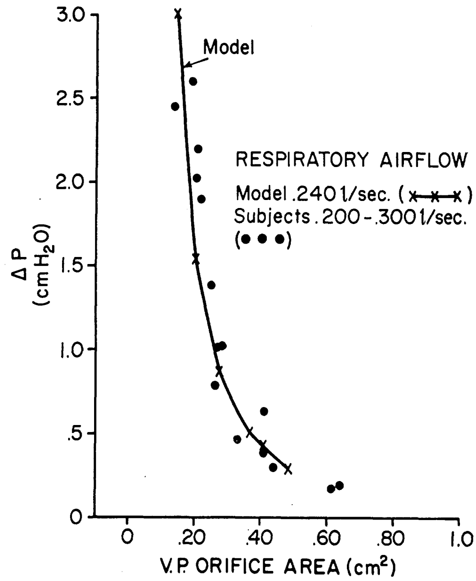

FIGURE 4. The relationship between orifice differential pressure and velopharyngeal orifice size for the model and the subjects. The slopes of the two curves are essentially the same.

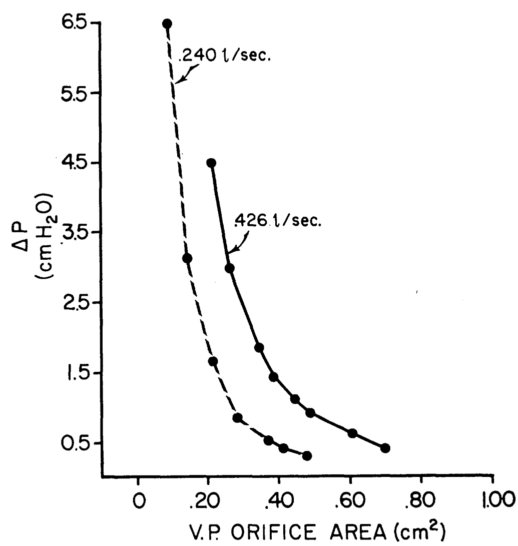

FIGURE 5. The effect of airflow rate on the relationship between orifice pressure and area. As airflow rate increases the curve shifts to the right.

The relationship between pressure, orifice size, and rate of airflow can be described by the equation

$$\Delta P = k(\dot{V}/A)^2$$

where ΔP is the orifice pressure drop in cm H_2O, $\dot{V}$ is the volume rate of airflow through the orifice in liters per second, A is the area of the velo-

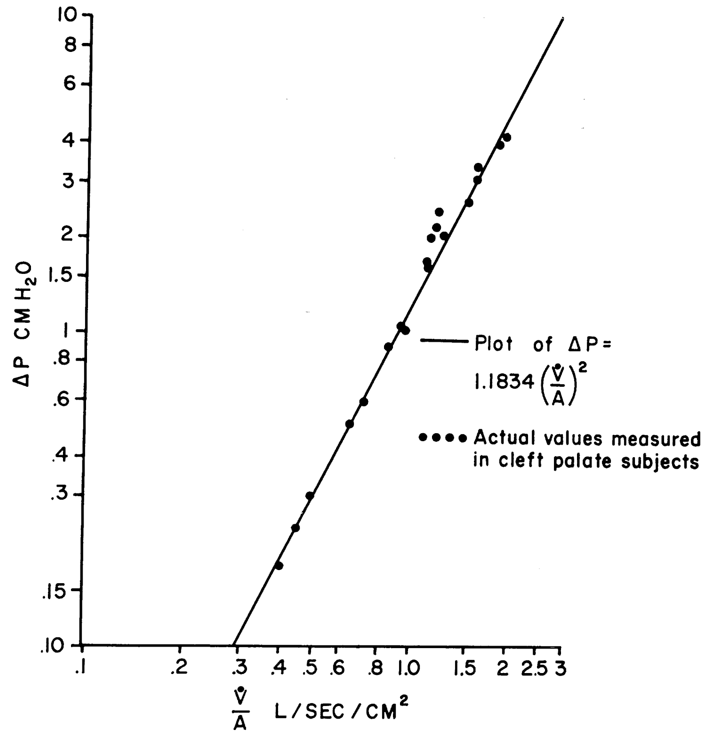

FIGURE 6. A log-log plot of the equation relating orifice pressure drop to rate of nasal airflow and orifice size. Data also presented from the subjects illustrate the closeness of fit.

pharyngeal orifice in cm^2, and k is a constant[1] related to the density of air and the discharge coefficient. Figure 6 relates a plot of the equation to actual values measured with the subjects and demonstrates the apparent closeness of fit.

Effect of Velopharyngeal Orifice Size on Resistance to Nasal Airflow. Orifice resistance to nasal airflow is defined as the ratio of orifice differential pressure/nasal airflow. It is a measure of velopharyngeal orifice impedance to airflow entering the nasal cavity. The data from both the speakers and the model demonstrate high impedance to airflow at sphincter sizes between 0 and .20 cm^2 (Figure 7), and low impedance above this range.

Effects of Oral Port Size on Orifice Differential Pressure and Resistance to Nasal Airflow: Model Study. Opening the oral port just slightly significantly decreases pressure amplitude (Figure 8). The major change in pressure is between 0 and .05 cm^2 and, presumably, this is the difference in oral port size between plosive and fricative sounds. This means that unless respiratory airflow rate is increased, fricative sounds would be produced with less pressure than plosives.

[1] $k = 1.1834$ cm H_2O $cm^4/l^2/sec^2$.

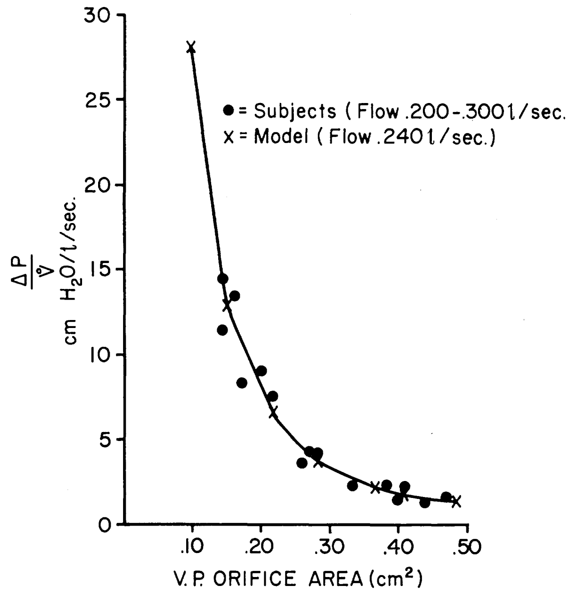

FIGURE 7. The relationship between sphincter resistance to nasal airflow and orifice size. The data presented for both subjects and the model indicate that sphincter resistance impedes nasal airflow significantly when orifice size is below approximately .20 cm^2.

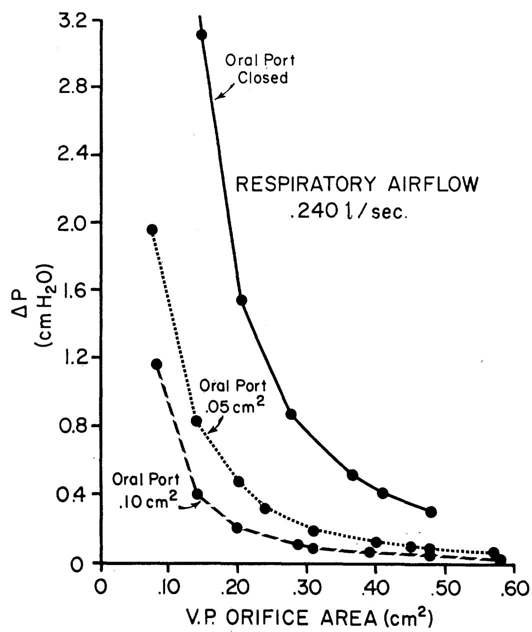

FIGURE 8. The effect of oral port opening on pressure-area relationships. Opening the oral port slightly for simulated fricatives significantly decreases orifice pressure unless airflow rate is increased. The difference in pressure is greatest when velopharyngeal orifice size is small.

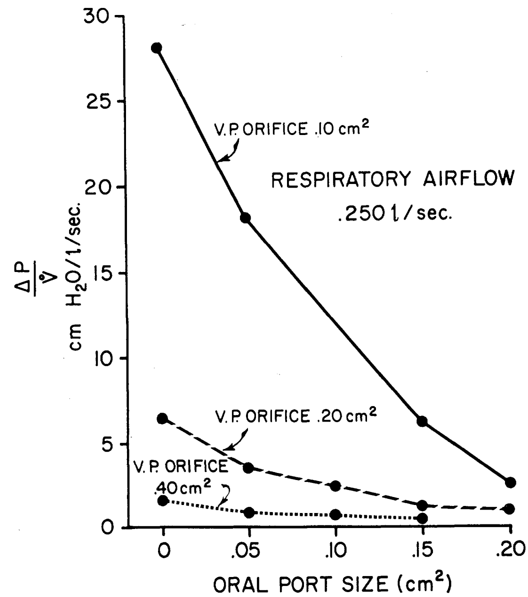

FIGURE 9. The relationship between velopharyngeal orifice resistance and oral port size at varying degrees of velopharyngeal closure.

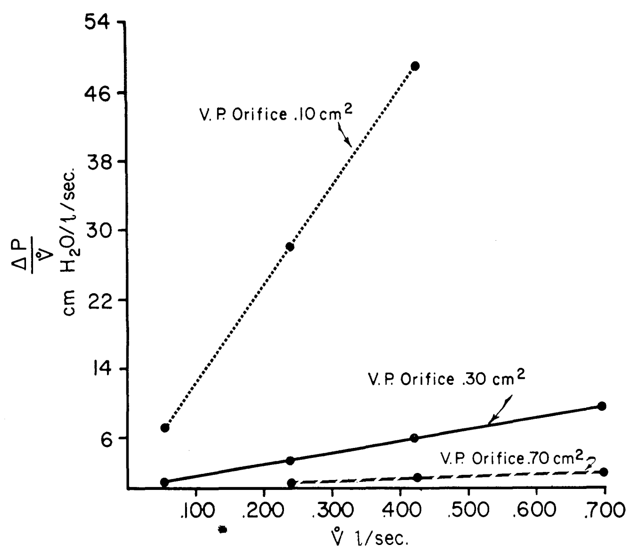

FIGURE 10. The relationship between orifice resistance, respiratory rate, and orifice size. Resistance increases linearly with increasing respiratory airflow rate.

When the oral port is open, velopharyngeal sphincter resistance to nasal airflow is also reduced (Figure 9). This decrease is primarily due to the drop in nasal airflow as some air is released through the oral port. Figure 10 demonstrates that velopharyngeal resistance is linearly related to rate of nasal airflow.

It is interesting to note that the difference in orifice pressure between simulated plosives and fricatives is greatest when the velopharyngeal opening is small. At orifice sizes above .40 cm^2, there is only a slight change in pressure as the oral port opens.

Discussion

Comparison of Model and Subjects Data. The present study indicates that the model adequately simulates the respiratory parameters associated with consonant production. At given velopharyngeal openings, the resulting pressure-flow relationships are comparable and the equation derived for determining orifice pressure fits both simulated and actual conditions. The quadratic relationship indicates that turbulence was present in the airway during both simulated and actual speech.

The data suggest that separation between the nose and mouth is adequate for consonant production only when the velopharyngeal opening is less than approximately .20 cm^2. This is in agreement with previous studies which also indicated that nasal voice quality is subjectively noticeable at orifice sizes above .20 cm^2 (*1, 10*). Low orifice pressure and nasal voice quality apparently occur concurrently with velopharyngeal incompetency.

It must be reiterated at this point that orifice differential pressure is not the same as oral breath pressure or oropharyngeal pressure. Oral breath pressure measurements have been used quite extensively as a means to estimate velopharyngeal function but these measurements are not as reliable as orifice pressure drop recordings because they are significantly influenced by nasal pathway resistance (*9*).

Effect of Velopharyngeal Sphincter Size on Resistance to Nasal Airflow. The data indicate that velopharyngeal sphincter resistance drops sharply as the orifice opens between 0 and .20 cm^2. Above this range, the decline in resistance is slight with increasing sphincter incompetency. It is notable that at .30 cm^2, sphincter resistance is approximately 3 cm H_2O/liter/sec. which is approximately normal nasal pathway resistance during breathing (*2*). This means that nasal resistance to airflow is greater than orifice resistance when the velopharyngeal opening is larger than .30 cm^2. Stated in other terms, nasal pathway resistance is an important determinant of oral pressure amplitude when velopharyngeal closure is inadequate. This may explain why certain cleft palate individuals with wide clefts have fairly intelligible speech (*4*). High nasal resistance allows nearly adequate pressure levels with minimum nasal emission of air.

Effects of Oral Port Opening. Recent studies of articulation deficits in cleft palate individuals have demonstrated a higher incidence of fricative errors than plosive (*5, 6, 7*). Data from this study suggest a possible explanation for these differences in consonant intelligibility. Slight opening of the oral port for simulated fricatives causes a drop in pressure which can only be compensated for by increased respiratory effort. Increased respiratory airflow in the presence of velopharyngeal inadequacy would, however, result in greater nasal emission of air and the possibility of sound distortion and nasality. Indeed, Hess (*3*) has reported greater nasal pressures with fricatives than with plosives in cleft palate speakers. Thus the problem appears to be one of greater respiratory requirements for fricatives in order to compensate for oral port opening as well as velopharyngeal inadequacy.

The difference between simulated plosives and fricatives is even more noticeable when velopharyngeal orifice size is small, that is, less than .20 cm^2. At this size, slight oral opening for fricatives results in a significant decrease in pressure unless respiratory rate is substantially increased. At large sphincter sizes (above .20 cm^2), the difference between the two consonant types is much less. This new finding is relevant in light of a recent study reporting a considerably higher incidence of fricative errors than plosive errors in the speech of cleft palate subjects who, on lateral x-rays, exhibited velopharyngeal openings of 2 mm or less (*7*). Subjects with large velopharyngeal openings also were found to have a high incidence of fricative errors but these subjects also had a comparably high incidence of plosive errors. If Björk's technique (*1*) is used to convert midsagittal x-ray measurements to area measurements then a 2 mm velopharyngeal opening is approximately equal to an orifice size of .30 cm^2. This would mean that the greatest difference in consonant intelligibility between fricatives and plosives occurs when velopharyngeal orifice size is less than .30 cm^2. It is significant that in the present study, this same degree of velopharyngeal opening provided the most noticeable differences in pressure-flow relationships between the two consonant types.

Although more definitive conclusions must await substantiation of these data in patients, it appears appropriate at this time to speculate that the greater respiratory effort required for production of fricatives in certain cleft palate speakers may be partly responsible for the observed differences in consonant intelligibility.

Summary

A model of the upper speech mechanism was utilized to evaluate the effects of oral port constriction on the respiratory aspects of speech. Justification for use of a model is based on a comparative study of 20 cleft palate individuals phonating selected plosive and fricative consonants in continuous speech. Results of this study reveal that consonants simulated by the model are similar in terms of pressure and patterns of airflow to those produced by the subjects. The data obtained from the model also indicate that for simulated fricatives, opening the oral port slightly significantly decreases the pressure difference between the oropharynx and nasopharynx unless respiratory rate is increased. The differ-

ence between simulated fricatives and plosives is most noticeable when velopharyngeal orifice size is .20 cm^2 or less. As the degree of sphincter incompetency increases, the difference in pressure-flow relationships between consonants is diminished. The data also reveal that nasal pathway resistance is an important determinant of oral pressure when velopharyngeal function is incompetent. It appears from these data that the greater difficulty experienced by some cleft palate speakers in producing fricative sounds in comparison to plosives may be related to the greater respiratory requirements necessary for fricative production.

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