Predictions of Modeled Palatopharyngeal Port Openings Under Conditions Simulating Pharyngeal Flap Reconstruction

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This study examined the estimation of modeled palatopharyngeal orifice areas under conditions similar to those created by pharyngeal flap reconstruction. Results indicated that accurate estimates of the palatopharyngeal orifice area can be obtained using Warren’s pressure-flow approach when the calculated area is actually the combined area of the lateral palatopharyngeal port openings. Our findings lend additional support to the view that pressure-flow techniques can provide objective information about the degree to which surgical procedures provide palatopharyngeal competence for speech.

Previous investigators have shown that aerodynamic measurements can provide unique and quantifiable information about palatopharyngeal function for speech (Warren, 1974; Thompson and Hixon, 1979; Smith et al, in press). Such data have been used to evaluate palatopharyngeal function prior to and following surgery to establish palatopharyngeal competence for speech (Subtelny et al, 1970; Hogan, 1975; Smith et al, in press). A commonly used procedure to establish palatopharyngeal competence is the pharyngeal flap reconstruction. Hogan (1975) and Smith et al (in press) evaluated the results of the pharyngeal flap operation using Warren’s pressure-flow approach (Warren and DuBois, 1964). In these investigations it was assumed that estimates of palatopharyngeal orifice area were actually estimates of the combined area of lateral palatopharyngeal port openings.

There is no information currently available concerning the accuracy of palatopharyngeal orifice area estimation when this area is actually the total of the lateral port areas. Therefore, the purpose of this project was to determine the predictive nature (means and standard deviations) of modeled palatopharyngeal orifice area calculations under conditions simulating pharyngeal flap reconstruction.

Method

Modeling Apparatus

The vocal tract model used in this project was constructed following the dimensions outlined by Warren and Devereux (1966) and was like that used in our previous modeling studies. The velopharyngeal orifice of the model is constructed so that its dimensions can be varied by inserting cover plates over the fully open

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1Vocal tract model design altered by Jerald B. Moon and Bernd Weinberg, Department of Audiology and Speech Sciences, Purdue University. Model constructed by Alfred Nelken and George Mertz, Research Resources Center, Instrument Shop Facility, University of Illinois at Chicago.
velopharyngeal port. In this study, six cover plates were constructed for insertion into the model. Two circular openings were made in each cover plate to provide known port diameters of approximately 2 mm and 2 mm (approximate total area, 6.22 mm²), 1 mm and 3 mm (approximate total area, 7.84 mm²), 3 mm and 3 mm (approximate total area, 14.11 mm²), 2 mm and 4 mm (approximate total area, 15.64 mm²), 4 mm and 4 mm (approximate total area, 25.07 mm²), and 3 mm and 5 mm (approximate total area, 26.57 mm²). Using a micrometer, these circular areas were calculated from the diameter of the bores used to create the openings. Cover plates were created to simulate both the symmetrical and asymmetrical lateral port openings likely to exist during speech production. The oral port of the model was closed throughout this investigation to simulate conditions known to exist during stop consonant production.

Orifice Airflow and Differential Pressure Measurements

The volume rate of airflow through the palatopharyngeal port openings of the model and the pressure drop across the modeled palatopharyngeal orifice were obtained following the procedure outlined in Smith et al, 1985.

Procedure

The model was driven with varying airflow rates supplied by a compressed air source. Flow rates ranged from approximately 0.05 to 0.50 liters per second and were selected to simulate aerodynamic events known to exist during the production of stop consonants. Simultaneous nasal airflow and differential pressure measurements were made at airflow peak loci and were used to calculate the palatopharyngeal orifice area using Warren's hydrokinetic equation:

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

where \( A \) is palatopharyngeal orifice area (cm²), \( V \) is volume rate of airflow through the port openings, \( P_1 \) is measured pressure below the port openings, \( P_3 \) is pressure above the port openings, \( D \) is the density of air, and 0.65 is a correction factor or constant term (Warren and DuBois, 1964). In addition, percent error in calculated orifice area was determined as follows:

$$ \text{Percent error} = \frac{KA - CA}{KA} \times 100 $$

where \( KA \) is the known area and \( CA \) is the calculated area.

For each condition, 40 orifice estimates and percent error values were obtained. The following three measures were obtained for each of the six lateral port conditions: (1) mean orifice area, (2) standard deviation in calculated orifice area, and (3) percent error.

RESULTS AND DISCUSSION

The accuracy of palatopharyngeal orifice area estimation obtained under conditions simulating pharyngeal flap reconstruction is summarized in Tables 1 and 2. The data in Table 1 show that, in general, average calculated orifice areas corresponded favorably with orifice openings known to be present in the model. In addition, variation (standard deviation) in predicted orifice areas was small for all known orifice openings. The magnitudes of orifice estimation error found in this study (Table 2) compare favorably with those established in previous modeling studies in which one circular opening was being estimated.

Consistent overestimation of known areas occurred at the smallest (6.22 mm² and 7.84 mm²) and largest (25.07 mm² and 26.57 mm²) opening sizes. This is expected at smaller port openings, given the observation that as orifice area decreases, airflow speed increases and results in turbulent loss of energy. A turbulent dissipation term was neglected in the derivation of the hydrokinetic equation (see Appendix, Warren and DuBois, 1964). If such a term were included in the equation, the effective
TABLE 1. Calculated Palatopharyngeal Port Area Means (mm²) and Standard Deviations for Known Orifice Openings

<table>
<thead>
<tr>
<th>Known Total Orifice Area (mm²)</th>
<th>Mean Calculated Areas</th>
<th>Standard Deviations</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.22</td>
<td>6.80</td>
<td>0.23</td>
</tr>
<tr>
<td>7.84</td>
<td>8.23</td>
<td>0.10</td>
</tr>
<tr>
<td>14.11</td>
<td>13.93</td>
<td>0.45</td>
</tr>
<tr>
<td>15.64</td>
<td>15.86</td>
<td>0.22</td>
</tr>
<tr>
<td>25.07</td>
<td>27.19</td>
<td>1.14</td>
</tr>
<tr>
<td>26.57</td>
<td>28.59</td>
<td>0.54</td>
</tr>
</tbody>
</table>

TABLE 2. Mean Percent Errors in Prediction for Known Orifice Openings

<table>
<thead>
<tr>
<th>Known Total Orifice Area (mm²)</th>
<th>Mean Percent Errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.22</td>
<td>9.37</td>
</tr>
<tr>
<td>7.84</td>
<td>4.91</td>
</tr>
<tr>
<td>14.11</td>
<td>1.29</td>
</tr>
<tr>
<td>15.64</td>
<td>1.37</td>
</tr>
<tr>
<td>25.07</td>
<td>8.47</td>
</tr>
<tr>
<td>26.57</td>
<td>7.59</td>
</tr>
<tr>
<td>( \bar{X} = 5.50 )</td>
<td></td>
</tr>
</tbody>
</table>

pressure differential would be greater, and would lead to smaller orifice area calculations (i.e., less overestimation) and thereby more precise estimation. At larger orifice areas, the palatopharyngeal orifice area becomes more like that of the oral cavity. Under these conditions, flow velocity in the oral cavity is no longer negligible, as is assumed in the derivation of the hydrokinetic equation. Consideration of flow velocity in the oral cavity would necessitate addition of a term to the hydrokinetic equation which would result in a smaller orifice area calculation (i.e., less overestimation) and a more precise estimation. Despite simplification of aerodynamic events in the derivation of the hydrokinetic equation, the results of this study and others (Warren and DuBois, 1964; Lubker, 1969; Smith and Weinberg, 1980, 1982, 1983; Smith et al, 1984; Smith et al, 1985) show that accurate estimates of modeled palatopharyngeal orifice areas can be obtained using the hydrokinetic equation.

In summary, our findings suggest that Warren's pressure-flow method can be used to obtain the combined area of lateral palatopharyngeal port openings like those created by the pharyngeal flap operation. Since this operation is currently the most commonly used secondary procedure to correct velopharyngeal incompetence for speech, these results have important clinical significance. Our results lend additional support to the view that pressure-flow techniques can provide objective indices of the degree to which surgical procedures provide palatopharyngeal competence for speech (Hogan, 1975; Smith et al, in press).

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REFERENCES

SMITH BE, MADDOX CM, KOSTINSKI A. Modeled velopharyngeal orifice area prediction during simulated stop consonant production in the presence of increased nasal airway resistance. Cleft Palate J 1985; 22(2):.