Estimation of Nasal Cross-sectional Areas, Using Oral Versus Nasal Pressure Measurements

BONNIE E. SMITH, PH.D.
THOMAS W. GUYETTE, PH.D.

This study examines calculations of model nasal cross-sectional area, using nasal versus oral pressure measurements. The results indicate that greater accuracy of nasal cross-sectional area estimation is achieved by using nasal rather than oral pressures. Nasal pressures measured in the anterior model nose more closely reflect nasopharyngeal pressures under a wide range of nasal constriction sizes and airflow rates.

KEY WORDS: *nasal area, nasal air pressure, oral air pressure.*

Warren recently described a quantitative technique for evaluating nasal airway impairment. This technique was recommended over the use of radiographs, given the latter's "two-dimensional superimposition of shadows of structures" as well as over the use of nasal airway resistance measurements, given their flow dependence. Specifically, the technique provides calculations of the cross-sectional area of the nasal airway from measurements of transnasal pressure and airflow rate, using the formula: Na = $\dot{V}/k(2[\Delta P/d])^{1/2}$, where Na is the cross-sectional area of the nose, $\dot{V}$ is airflow rate through the nose, ΔP is pressure drop across the nose, d is density of air, and k is a correction factor, or constant (Warren, 1984). In this method, pressure drop across the nose is measured by means of a catheter inserted into the mouth, and nasal airflow rate is measured from both nostrils by means of a nose mask. It is suggested that pressure measured orally represents nasopharyngeal pressure (Warren, 1984).

Results of previous studies indicate that pressure measurements obtained by this method may, in part, reflect the contribution of the velopharyngeal region, especially at higher flow rates (Kumlien and Schiratzki, 1979; Warren and DuBois, 1964). Therefore, nasal cross-sectional areas calculated from oral pressures may be less accurate at high flow rates than those made using pressures that more closely reflect pressures in the nasopharynx.

Results of our recent modeling studies suggest that pressure measured in the anterior portion of the nose provides a more accurate estimation of nasopharyngeal pressure. It follows that use of such measurements may lead to more accurate estimates of nasal cross-sectional area than use of oral pressure measurements. This study compares nasal cross-sectional area measurements made using oral versus nasal pressures under controlled conditions in which various degrees of nasal constriction were simulated, using a model of the upper respiratory tract.

MATERIALS AND METHODS

Modeling Apparatus

The model of the upper respiratory tract used to simulate nasal obstruction in this study is similar to that described by Warren (1984). This plastic model has been used in previous breathing research (Warren, 1984; Warren, Lehman, and Hinton, 1984). The model approximates the oral and pharyngeal dimensions of the adult vocal tract, and the cross-sectional

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Dr. Smith is Assistant Professor, Department of Pediatrics and Department of Otolaryngology–Head and Neck Surgery, University of Illinois College of Medicine, Chicago, IL. Dr. Guyette is Assistant Professor, Section of Communicative Disorders, Rush University, Chicago, IL.

Address reprint requests and correspondence to: Bonnie E. Smith, Ph.D., Illinois Eye and Ear Infirmary, 1855 W. Taylor—B.46, Chicago, IL 60612.

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area of the model nose offers resistance to airflow comparable to established values for normal individuals. Its dimensions are described by Warren (1984) and Warren and Devereux (1966).

Procedure

Cross-sectional areas of the model nose were obtained under six conditions (Table 1). The actual cross-sectional area of each nostril, as well as the combined areas, are shown in this table. Condition 1 represents the normal state, in which the nostrils are fully open. Conditions 2 to 6 represent increasing magnitudes of nasal obstruction; they were obtained by inserting plugs approximately 1 cm long into the model nostrils, successively reducing the nasal cross-sectional areas. For conditions 1 to 3, magnitudes of nasal obstruction, i.e., areas of nasal plugs, were equivalent for each nostril. For conditions 4 to 6, magnitudes of obstruction in each nostril differed, as shown by the nasal plug area differences (see Table 1). The model velopharynx was fully open (approximate area, 78.50 mm^2) during testing.

The cross-sectional areas of the model nose were calculated, using both oral and nasal pressures in measurement of nasal pressure drop. For these approaches, the model's airflow was supplied by an air cylinder. The volume rate of nasal airflow was sensed by a Fleisch no. 2 pneumotachograph. Placement of the pneumotachograph varied, depending on whether pressure was measured in the oral or nasal cavity of the model. When oral pressures were obtained, the pneumotachograph was coupled to both nostrils of the model by a Y-section interface. This procedure was employed because pressure measurements with and without this interface indicated no elevation of pressures with the interface in place. When nasal pressures were obtained, the pneumotachograph was coupled to one nostril of the model. In both approaches, the pressure differential across the screen of the pneumotachograph was sensed by a Statham PM 15E differential pressure transducer. Airflow measurements were calibrated with a Fisher-Porter flowmeter (Model 10A1027).

TABLE 1 Known Areas of the Model Nose (mm^2)

Condition	*Right*	*Left*	*Total*
1	33.18	33.18	66.36
2	8.30	8.30	16.59
3	3.40	3.40	6.80
4	33.18	16.62	49.80
5	33.18	8.30	41.48
6	33.18	3.40	36.58

The pressure differential across the model nose was transmitted directly to a differential pressure transducer (Statham PM6). For the oral approach, one side of the transducer was coupled to the oral cavity of the model and these pressures were compared with room pressure. For the nasal approach, each nostril was studied separately. The transducer was coupled to one nostril of the model, and the pressures were compared with room pressure. Given the complete obstruction of this nostril by the pressure sensor, the nasal plugs were removed from this nostril during testing. This procedure was then repeated on the other nostril. Pressure measurements were calibrated using a water manometer.

Transduced pressure-flow signals were amplified (Grass 7PID, 7DAF), and the resulting analog signal was displayed on two channels of a Grass Instruments polygraph recorder (Model 7D).

Measurements were first made using the oral approach. Flow rates were directed into the model until 1.5 cm H_2O pressure was achieved. The flow rate into the model was then increased until 3.0 cm H_2O pressure was achieved. Flow rates associated with each pressure value were then used to calculate total nasal cross-sectional area by the formula: $Na = \dot{V}/k(2[\Delta P]/d)^{1/2}$ (Warren, 1984). Three trials were completed for each pressure reference used under each condition.

For the nasal approach, flow rate was measured from the nostril being examined, and pressure was measured from the occluded, opposite nostril. Flows were delivered to the model to create unilateral nasal pressure drops of 1.5 and 3.0 cm H_2O. Measured flow rates for these transnasal pressures were used to calculate the cross-sectional area for each nasal chamber separately, using the formula cited above. These areas were then added to obtain the total nasal cross-sectional areas.

Finally, comparisons were made between the total calculated nasal cross-sectional areas and the known areas of the model nostrils in the six conditions, using the formula: percent error = (known area − calculated area)/known area $\times 100$.

Results and Discussion

The average, total, calculated nasal cross-sectional areas for the model using oral and nasal pressures at both low and high pressure

TABLE 2 Known Total Areas (mm^2) and Mean Calculated Total Areas (mm^2) of the Model Nose, Using Oral and Nasal Pressure Measurements

Condition	*Known Areas*	*Reference Pressure (cm H_2O)*	*Oral*	*Nasal*
1	66.36	1.5	41.13	57.59
		3.0	43.19	61.16
2	16.59	1.5	18.47	18.16
		3.0	19.70	18.44
3	6.80	1.5	6.68	6.36
		3.0	6.86	6.77
4	49.80	1.5	35.24	48.97
		3.0	38.75	52.60
5	41.48	1.5	32.91	41.65
		3.0	35.51	45.14
6	36.58	1.5	29.96	34.05
		3.0	30.84	35.68

values are shown in Table 2. Mean percent errors for these calculations are shown in Table 3.

These data show that there was greater agreement between calculated and known areas when nasal pressures were used to calculate nasal areas. When oral pressures were used, discrepancies were most notable in conditions 1 and 4 to 6, when nasal areas and nasal flow rates were greatest. It is most likely under these conditions that the velopharyngeal sphincter added additional pressure to the system, leading to oral pressure measurements that no longer accurately reflected those in the nasopharynx. This hypothesis is supported by the finding that the use of oral pressures led to underestimation of nasal areas in conditions of high flow (see Table 2).

In conclusion, our data suggest that there is greater agreement between known and calculated nasal cross-sectional areas when nasal pressures are used. Such pressure measurements more accurately reflect nasopharyngeal pressures under a wide range of constriction sizes and flow rates than do pressures measured orally. However, these findings suggest that nasal pressures measured anteriorly may not reflect obstructions in the velopharynx. These obstructions (including enlarged adenoids and obstructive pharyngeal flaps) need further evaluation.

TABLE 3 Mean Percent Errors in Estimating Total Nasal Areas, Using Both Oral and Nasal Pressure Measurements

Condition	*Known Area (mm^2)*	*Reference Pressure (cm H_2O)*	*Oral**	*Nasal†*
1	66.36	1.5	38.02	13.22
		3.0	34.92	7.84
2	16.59	1.5	11.33	9.46
		3.0	18.75	11.15
3	6.80	1.5	1.77	6.47
		3.0	0.88	0.44
4	49.80	1.5	29.24	1.67
		3.0	22.19	5.62
5	41.48	1.5	20.66	0.41
		3.0	14.39	8.56
6	36.58	1.5	18.10	6.92
		3.0	15.69	2.46

* $\overline{X}$ = 18.83.
† $\overline{X}$ = 6.19.

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