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The airflow resistance profile of healthy nasal cavities*

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SUMMARY *Distribution of resistance to respiratory airflow in the nasal cavities was determined by digitized pressure/flow measurements of consecutive 2-cm airway segments between nostril and nasopharynx. Healthy adult subjects seated in a head-out body plethysmograph breathed exclusively through a single nasal cavity while transnasal pressure and flow signals were transduced, digitized and processed by a programmed desk-top computer to provide resistance values. Mean total resistances of untreated and decongested single nasal cavities were 0.44 (n=30; SD ± 0.25) and 0.26 (n=15; SD ± 0.06) Pa/cm^3/s, respectively. The proportion of total airway resistance of successive 2-cm segments from nostril to nasopharynx was 56%, 22%, 16%, and 6% in the untreated nose, and 88%, 5%, 2%, and 5% following decongestion. The findings from 45 nasal cavities are consistent with previous pressure/flow measurements from six nasal cavities and support recent acoustic reflection assessments of nasal cross-sectional areas of both untreated and decongested noses.*

Key words: airflow resistance, nasal flow, nasal pressure

INTRODUCTION

Measurements of resistance to airflow partitioned between segments of the respiratory passages have shown the nasal cavities to provide the major single contribution in healthy awake adults (Ferris et al., 1964). Nasal resistances of similar magnitude to those of the combined pulmonary air passages have been demonstrated by several investigators and measurements obtained from six nasal cavities have shown respiratory airflow resistance to be localized mainly to the anterior nose (Haight and Cole, 1983). In addition, cast studies (Bachman, 1972; 1982) and, more recently, demonstrations of nasal airway geometry by acoustic reflection (Grymer et al., 1991; Lenders and Pirsig, 1990) have localized the minimum cross-sectional area also to the anterior nose.

To date, reported partitioning of nasal airflow resistance has been limited to a small number of nasal cavities (Haight and Cole, 1983). In order to establish the nasal resistance profile more firmly and in greater detail and to relate the findings to the recently developed technique of acoustic rhinometry, the investigation reported in this presentation employs a larger number (45 nasal cavities) of healthy adults seated and at rest breathing spontaneously through untreated and decongested nasal cavities.

METHODS

Subjects

Subjects were selected from volunteers and from patients in the course of routine rhinomanometric testing (16 male and seven female, aged 17 to 74 years). History and rhinoscopy led to the exclusion of subjects exhibiting abnormalities of nasal structure or mucosa.

Airflow

Airflow was measured by means of a head-out body plethysmograph (Niinimaa et al., 1979) which avoids air leaks and disturbances of the compliant nasal vestibule, which are risks associated with facial masking (Cole and Havas, 1987).

Pressures

Pressures were measured via an 8F infant feeding catheter which was passed along the floor of a nasal cavity to the naso-

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pharynx. The catheter was marked at 2-cm intervals from the lateral orifice near its tip and it was positioned initially with the orifice 8 cm beyond the ventral lip of the nostril. Measurements were made at 8, 6, 4, and 2 cm as the catheter was withdrawn along the floor of the intubated nasal cavity while the opposite nostril was occluded. Previous measurements had determined that no obstructive disturbance resulted from the presence of the catheter.

Resistances

Resistances (pressure/flow ratios) were computed from transduced differential trans-airway pressures and respiratory airflow signals digitized at 50 Hz. Signal processing was achieved with a programmed desktop IBM-compatible computer (Cole, 1988; 1989). Resistance measurements were repeated at each site until five values with a coefficient of variation of <5% were obtained. The sites were at 2-cm intervals in 30 untreated nasal cavities and in 15 nasal cavities in which the mucosa decongested with topical 0.1% xylometazoline.

RESULTS

Computer-averaged resistances were obtained from 30 untreated and 15 decongested nasal cavities of 23 healthy adult subjects. The coefficient of variation of total unilateral nasal resistances between subjects was 57% for untreated noses and 23% for decongested noses, the difference probably reflecting mucosal variation.

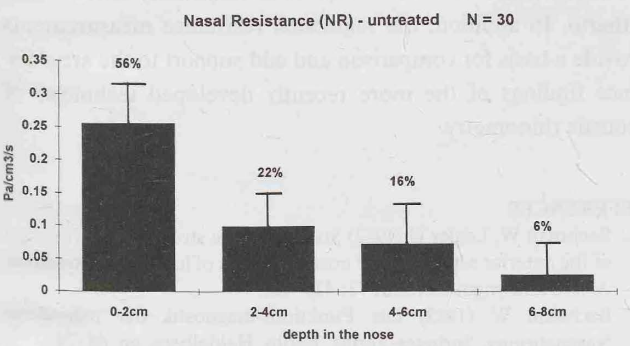

Figure 1. Distribution of respiratory airflow resistances in 30 untreated nasal cavities of healthy adults. The resistance of each 2-cm segment in the series that provides the total resistance over the 8-cm length of the proximal nasal airway is shown in the figure.

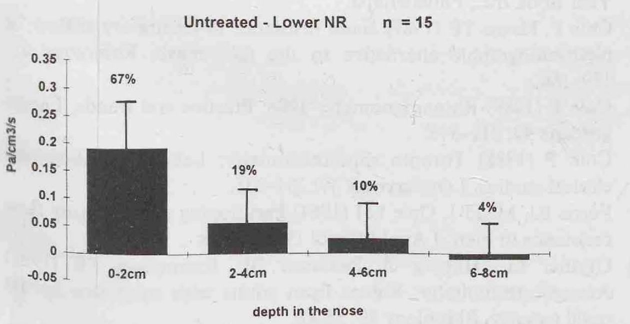

Figure 3. Distribution of respiratory airflow resistances in the 15 lesser resistive of the 30 untreated nasal cavities. Resistances in series as shown in Figure 1.

Pressure/flow measurements in consecutive 2-cm nasal airway segments provided the series of resistances presented in Figures 1–4. Averaged results from 30 untreated nasal cavities are shown in Figure 1. Figures 2–4 demonstrate the changes in distribution of 2-cm segmental resistances that accompany differing total resistances. Figure 2 shows the series of resistances in half (15) of the untreated nasal cavities exhibiting the greatest total resistance, and Figure 3 shows a similar series with the remaining half (15) of the untreated lesser resistive nasal cavities. Figure 4 represents the resistive series of 15 decongested nasal cavities and they exhibit the least total resistance. The major resistive segment in all cases was situated within the anterior 4-cm segment of the nasal cavities ($p < 0.01$).

Mean resistances in untreated nasal cavities were 0.44 ± 0.25 Pa/cm^3/s (78%) between 0 cm and 4 cm from the nostril. Mean resistances of decongested nasal cavities were 0.26 ± 0.06 Pa/cm^3/s (88%) between 0 cm and 2 cm from the nostril.

The 30 untreated subjects who were divided into two equal groups with greater and lesser total resistances showed the latter to exhibit a distribution of segmental resistances approaching the decongested group more closely than the former. In other words, as total resistance of nasal cavities decreased the most resistive segment was found nearer to the nostril.

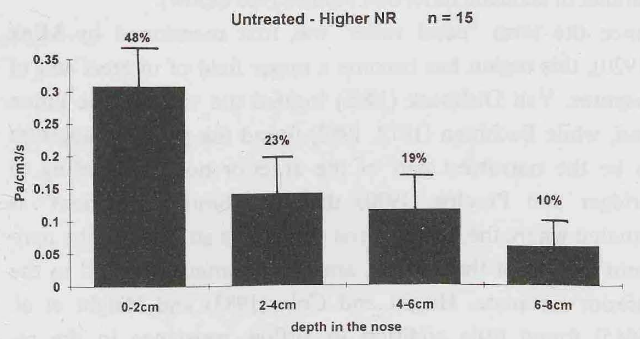

Figure 2. Distribution of respiratory airflow resistances in the 15 more resistive of the 30 untreated nasal cavities. Resistances in series as shown in Figure 1.

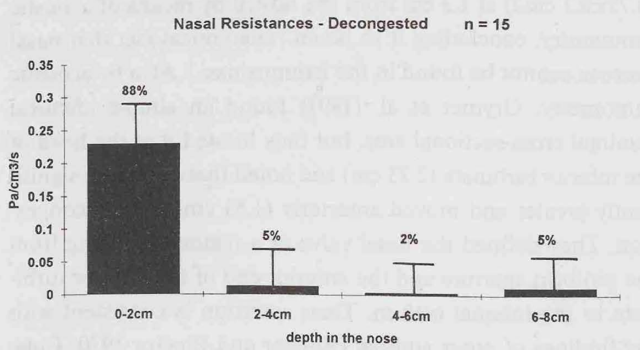

Figure 4. Distribution of respiratory airflow resistances in 15 decongested nasal cavities. Resistances in series as shown in Figure 1. Note progression of the most resistive site towards the nostril as total airflow resistances decrease from Figure 1–4.

DISCUSSION

The series of measurements demonstrated that between subjects unilateral nasal resistances varied over a wide range which was smaller among decongested noses. This is to be expected since unilateral variation is dependent not only on individual structural differences but also on mucosal thickness, a dimension that responds physiologically to many stimuli and changes spontaneously with the nasal cycle (Stoksted, 1952). Despite the magnitude of intersubject variation, the major resistive segment was localized to the anterior nose in all subjects, male and female.

It is recognized that the pressure determinations refer only to sites along the floor of the nose, they provide no data on the distribution of isobars beyond these points and, since the precise course and distribution of airstream velocities is unknown, calculated resistances provide an incomplete aerodynamic picture. Nevertheless, although incomplete, the picture provided by both individual and mean values in 45 nasal cavities is similar in that the major portion of nasal airflow resistance is localized to a short segment of a few millimeters in length in the anterior nose. Studies of nasal casts (Bachman, 1972; 1982), airflow velocities (Swift and Proctor, 1977) and acoustic reflexion (Lenders and Pirsig, 1990; Grymer et al., 1991) add support to these findings. Moreover, as application of a topical decongestant shrinks erectile tissue and reduces nasal airflow resistance the site of almost all residual resistance moves to within 2 cm of the nostril. The apparent anterior progression of the resistive site as the more posterior erectile tissues are decongested has a parallel in acoustic reflection studies (see below).

Since the term "nasal valve" was first mentioned by Mink (1920), this region has become a major field of interest and of disputes. Van Dishoeck (1965) located the valve at the limen nasi, while Bachman (1972, 1982) found the pyriform aperture to be the narrowest part of the anterior nose. According to Bridger and Proctor (1970) the "flow-limiting segment" is situated where the upper lateral cartilage is attached to the pyriform margin of the maxilla, and it is intimately related to the inferior turbinate. Haight and Cole (1983) and Haight et al. (1985) found little addition to airflow resistance in the remaining portions of the nasal passages or the choanae. Lenders and Pirsig (1990) postulated the minimal cross-sectional area of the nasal cavity (the isthmus nasi) to be constant in site and size (0.73±0.2 cm2) at 1.3 cm from the nostril by means of acoustic rhinometry, concluding it to be an "anatomical fact that nasal mucosa cannot be found in the isthmus nasi." Also by acoustic rhinometry, Grymer et al. (1991) found an almost identical minimal cross-sectional area, but they located it at the head of the inferior turbinate (2.23 cm) and noted that it became significantly greater and moved anteriorly (1.53 cm) after decongestion. They defined the nasal valve as a region extending from the piriform aperture and the anterior end of the inferior turbinate to the intemal ostium. Their assertion is consistent with the findings of other authors (Bridger and Proctor 1970; Cole, 1992; Haight and Cole, 1983) who state that erectile tissues closely related to the valve region are to be found in the caudal septum and lateral nasal wall (Wustrow, 1951; Cole, 1992). Haight and Cole (1983) found resistance of the nasal segment between 2.6 cm and 1.9 cm to average 0.48 Pa/cm^3/s and between 1.9 cm and 1.0 cm to only 0.02 Pa/cm^3/s, in six untreated noses with little increase in the remaining portion of the nasal airway. Our results based on 30 untreated nasal cavities showed resistance in the segment between 8 cm and 6 cm from the nostril to be only 0.025 Pa/cm^3/s or 6%. Between 6 cm and 4 cm it was 0.07 Pa/cm^3/s or 16%, and between 4 cm and 2 cm 0.09 Pa/cm^3/s or 22%. In the segment between 2 cm and the nostril it was 58%.

Percentages are related to total values measured at 8 cm from the nostril. About 78% was found within the anterior 4 cm of the cavity which involves the head of the inferior turbinate, while more than half this resistance is generated in the anterior 2 cm of the nose. The 16% of resistance found in the 4- to 6-cm segment was reduced to 2% with decongestant indicating that erectile tissues contribute to resistance in this portion of the airway. The toll of additional work of nasal breathing exacted by the resistor sited near the nasal entrance is not a waste of energy. It provides a function of physiological importance by ensuring disruption of laminar flow in the upper airways. Otherwise, a marginal lamina would restrict exchanges of contaminants, water and heat beween airstream and mucosa (Cole, 1992)

CONCLUSIONS

The results of the investigations were obtained from a larger number of nasal airways and provide a more detailed profile of the distribution of nasal resistance to respiratory airflow than hitherto. In addition, the segmental resistance measurements provide a basis for comparison and add support to the area/distance findings of the more recently developed technique of acoustic rhinometry.

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