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ON THE RELATION OF NASAL CYCLING WITH NASAL AIRWAY DIMENSIONS

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Abstract — The size and configuration of the nasal airways of humans change with time as a result of the normal process of congestion/decongestion of the erectile tissue of the nasal mucosa. To determine the extent to which airway areas change in vivo, we used magnetic resonance imaging (MRI) to quantitate both the cross-sectional area and perimeter of coronal sections of the entire nasal airway of a human subject. Changes in airway size or patency were indexed to measured changes in unilateral nasal airway resistance determined by posterior rhinomanometry. The results of this study in which two MRI scans were performed for presumed left-side patency and two for right-side patency, showed that changes in nasal airway resistance were difficult to ascribe to systematic changes in the sizes of the airways.

Recent efforts of task groups of the ICRP and NCRP that are revising the existing respiratory tract dosimetry models have pointed out the deficiencies in our knowledge of the nasal airways. The importance of the nasal airway epithelium as a potential site of aerosol deposition and retention, as well as a known site of cancer production from a variety of radioactive and nonradioactive aerosols in animals and humans is now appreciated. As a first step in developing a more realistic description of human nasal airways, we have been using magnetic resonance imaging (MRI) techniques to obtain shape and dimension data on the human nasal airways in vivo (1986-87 ITRI Annual Report, LMF-120, pp. 101-104). This technique, which images the air-mucosa interface directly, provides evidence that the size of the nasal airways previously described in the literature, and derived from studies on cadavers, were significantly overestimated by a factor of two to three in certain regions of the airways. This report addresses the issue of variability of nasal airway dimensions for a single individual relative to the normal periodic (or aperiodic) congesting and decongesting of the nasal airway mucosa that occurs in most humans and is commonly referred to as the nasal cycle. These data provide an indication of the variability of nasal airway dimensions that one might expect in vivo.

MATERIALS AND METHODS

The subject used in this study was a nonsmoking Caucasian male, 40 yr of age, 1.84 m in height and 82 kg body mass. He was free of nasal congestion at the time of measurement. The MRI measurements were done at the University of New Mexico Center for Noninvasive Diagnosis under the direction of Dr. J. D. Wicks, Clinical Director. A total of four MRI scans were performed in three days over a two-week period using the one-meter bore proton imaging unit (General Electric Signa 1.5 Tesla unit). For each of the scans, the subject's head was immobilized in a head coil and placed within the sensitive volume of the magnet. Position within the magnet was indexed to the nasion. A sagittal scan was performed to obtain reference positions of the airways from the external nares to the posterior pharynx. Then contiguous coronal images were collected in 3-mm thicknesses for the entire length of the nasal airway. The data were collected on a Data General computer that was integral to the imager. Hard-copy transparency films were obtained for each airway section; the mucosa-airway were traced and digitized using a sonic digitizing device (Graf-Pen). From these tracings, both cross-sectional area and perimeter values were calculated.

Prior to each scan, unilateral and bilateral nasal resistance measurements were made using a posterior rhinometric method.[1] Transnasal-pharyngeal pressure differential was measured from the difference in pressure signals originating from probes placed inside the oral cavity and inside of a mask that was fit over the nose and mouth. The flow was measured using a pneumotachograph that was securely fitted to the mask. Resistance was then calculated, using a strip chart recorder, from the concurrent tracings of pressure and flow, where the resistance values corresponded to the peak flow and pressure readings for the inspiratory part of the breathing cycle. The average peak inspiratory flows for unilateral measurements was 0.5 L sec^{-1} with a range of 0.25 to 0.70 L sec^{-1}; for bilateral measurements, the flow rate averaged 1.1 L sec^{-1} with a range of 0.9 to 1.3 L sec^{-1}.

RESULTS

Nasal resistance measurements made of this subject prior to MRI indicated that he had an irregular nasal cycle period. Changes in nasal resistance did not necessarily occur in a bilateral complementary manner, i.e., when the nasal resistance in one airway increased, that of the other airway decreased, thus yielding a bilateral resistance that was constant (Table 1). In general, the resistance of the right nasal airway of this subject was always greater than that of the left side (Table 1). Additionally, the magnitude of the change in nasal resistance was also greater for the right side, in both absolute or relative terms.

Table 1
Inspiratory Nasal Airway Resistance Measured by Posterior Rhinomanometry

	Airway Resistance (cm H_2O L sec^{-1})		
Time (min)	Left	Right	Both
0.00	6.87	19.0	8.40
20	8.75	9.50	4.55
35	6.72	13.4	7.81
50	7.29	17.6	9.07
75	8.61	23.8	9.96
85	10.8	21.3	9.02
90	6.97	21.8	7.47
100	5.55	13.4	6.03
165	8.32	15.3	8.05
175	7.93	15.3	10.3
250	7.31	13.7	6.19

Figure 1 shows representative tracings of the MR coronal images of the subject's nasal airways. The distances, in mm, are indexed to the first section in the anterior nares in which airway was first detected in the MR images. As such, sections 0-18 are images of the nares and include the anterior portion of the nasal valve, sections 21-23 contain the nasal vestibule and the posterior segment of the nasal valve, sections 36-84 contain the region of the inferior, medial and superior turbinates, and sections 87-96 contain the choanae.

Figures 2 and 3 show the cross-sectional areas and perimeters of the left and right nasal airways derived from the coronal MRI sections. Two sets of measurements were taken with the right side patent, two with the left side patent. In this study, patency was defined as that point when

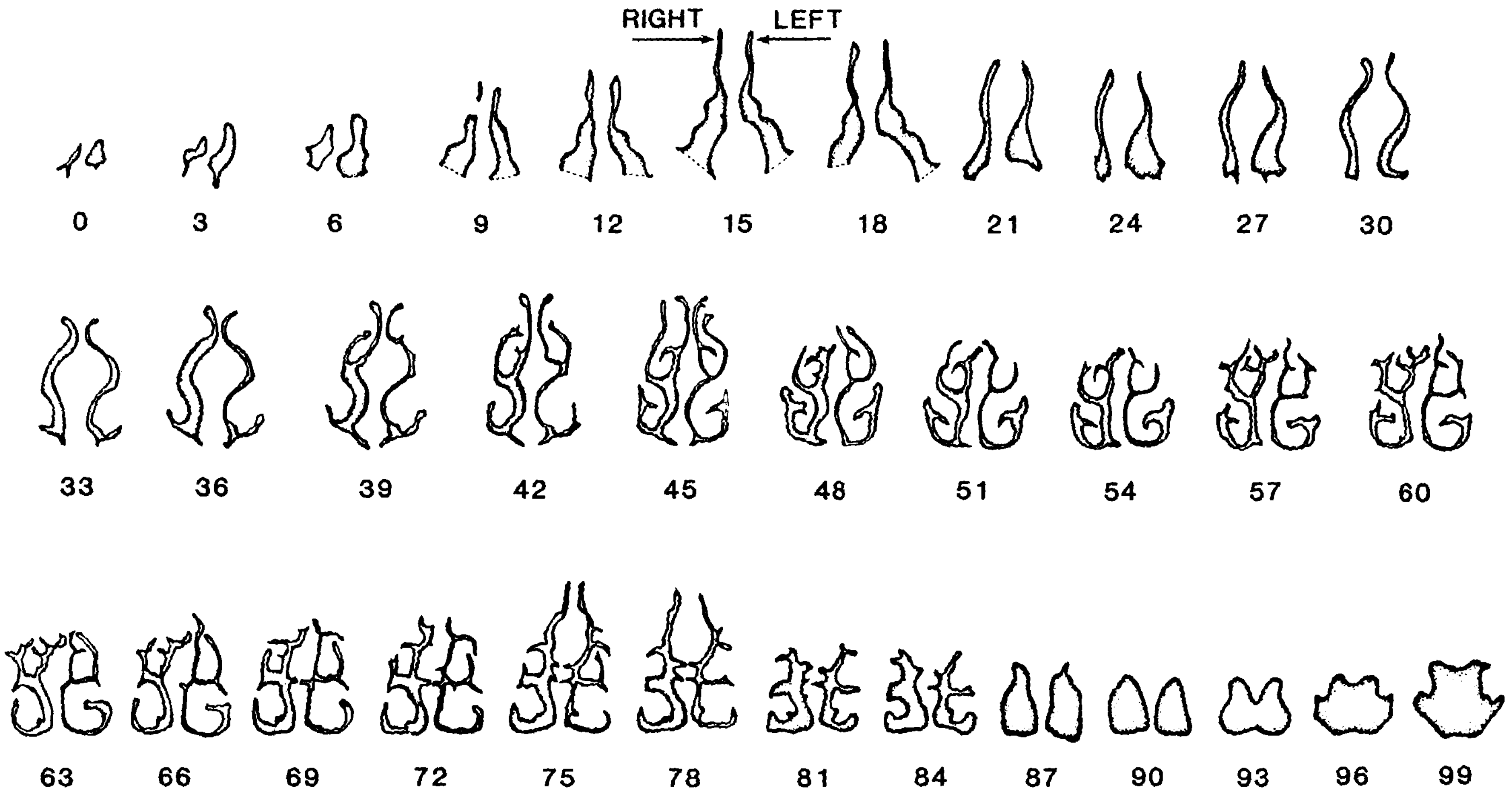

Figure 1. Tracings of the coronal images of the nasal airways of a human subject obtained by magnetic resonance imaging. Numbers on each tracing represent the distance in mm from the anterior nares.

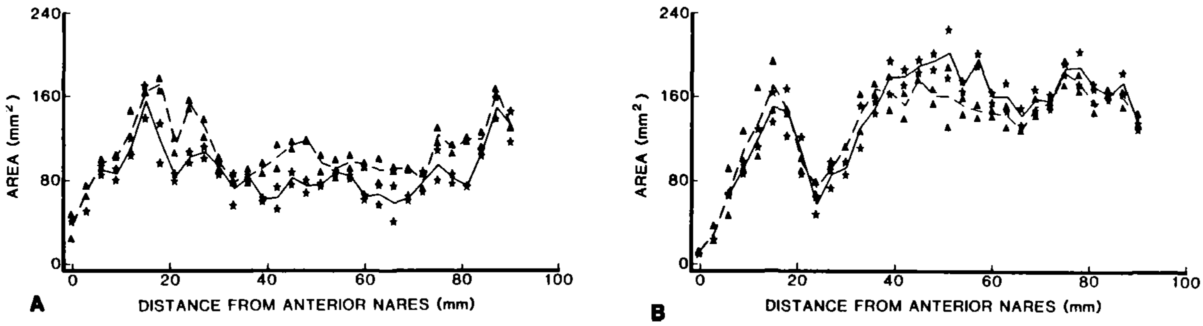

Figure 2. Cross-sectional areas of coronal sections of the left (a) and right (b) nasal airways of a human subject. Triangles are for right-side patent measurements; stars are for left-side patent.

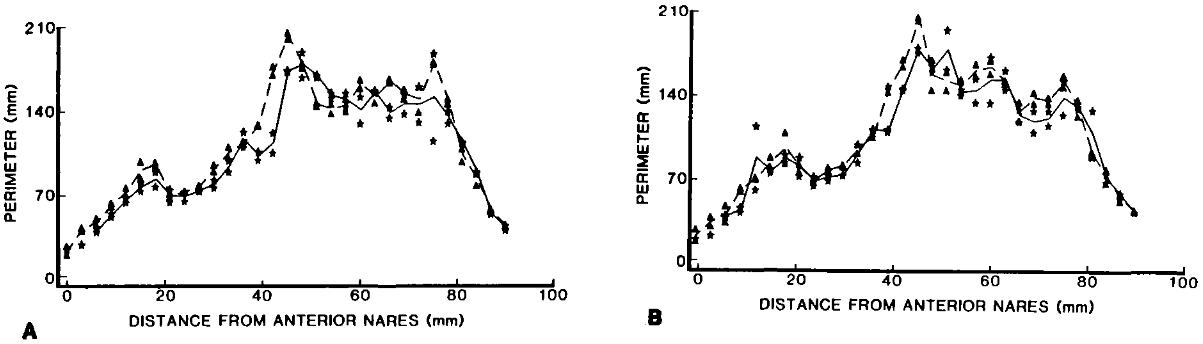

Figure 3. Perimeters of coronal sections of the left (a) and right (b) nasal airways of a human subject. Symbols are the same as for Figure 2.

the nasal resistance for the given side was measured to be at or near the minimum measured resistance. As such, the "right-side patent" scans were performed at right-side resistances of 7.65 and 8.85 cm H_2O sec L^{-1} and the "left-side patent" scans were done at left-side resistances of 5.86 and 6.19 cm H_2O sec L^{-1}.

In terms of cross-sectional area, there was a correlation between relative airway size and patency status, but the patterns were different for the left and right airways. For the left nasal airway, there was a consistent pattern of increased cross-sectional area during the left-side patent measurements. The increases in area were largest in the vestibular region (sections 18-27), ranging from 23 to 55 mm^2. There was a generalized increase in area averaging 25 mm^2 in the turbinate regions (sections 39-87). This amounted to an average relative increase of 30 ± 14%. In comparison, the cross-sectional areas of the right side showed both positive and negative changes in airway areas. There were decreased areas measured in the vestibular and anterior turbinate regions (sections 6-36); the decreases in area ranged from 0.5 to 20 mm^2. Posterior to section 36, the airway cross-sectional areas increased from 2 to 49 mm^2. The reasons for these contradictory changes in area are not known. In general, however, it can be seen that the changes in the areas of the left airway were larger than those for the right side. On the other hand, the areas of the right side were consistently larger than those of the left, with the exception of the region 18-27.

In terms of perimeters, there were differences in the relative changes for the left and right airways. For the left airway, there was a generalized increase in the perimeter of the airways going from right-side to left-side patency. However, the magnitude of the changes were mostly on the order of 10-15%. On the other hand, for the right-side, there were generally decreased perimeter values going from left-side to right-side patency. Again, the magnitude of the decreases was on the order of 10-15%. Except for the anterior region of the turbinates (sections 39-45), where there were consistent sizeable increases in perimeter for both right and left sides, the other changes may not be significantly different.

DISCUSSION

The objective of this study was to determine the extent of the changes in nasal airway dimensions that occur as a result of the normal congestion/decongestion of the mucosa. This latter phenomenon leads to both unilateral and bilateral changes in nasal airway patency such that, in normal individuals, airflow is neither constant nor equally distributed between the two nasal airways. We used posterior rhinomanometry to measure the resistance of the nasal airways, and made MRI scans at points in time when the resistance of the nasal airways was measured to approximate the minimum over a four-hour test period. Two scans were done for minimum resistances on the right side, two for the left side. Although this approach appears to be conceptually simple, there are several important factors that may have confounded the interpretation of the results obtained here, i.e., that the changes in the relative airway sizes, as reflected in the cross-sectional area measurements, did not appear to be as large as might be expected given the measured changes in nasal airway resistance. In addition, there were inconsistencies between the right and left airways. For example, the range of nasal resistances for the left airways were from 5.86 to 10.85 cm H_2O sec L^{-1}, a ratio of 2.0. The measured changes in the major portion of the left airway averaged 35%, but had a range of 2 to 62%. In comparison, the nasal resistance for the right side ranged from 9.5 to 23.8 cm H_2O sec L^{-1}, a ratio of 2.5. Yet, with the larger relative change in airway resistance, the relative increase in the cross-sectional areas for the right side were less, about 13% with a range of 1 to 33% for the turbinate regions. To further confuse the interpretation, the cross-sectional area of the vestibular region of the right side actually decreased at the time that the nasal resistance of the right side was minimal, presumably corresponding to maximum patency of the right side.

One possible explanation for the apparent paradox in the relationship between resistance and airway area for the right side, i.e., involving both increases and decreases in airway areas, may be due to the length of time needed to acquire the MR images. The total amount of time needed to acquire a single scan was about 60 min. Although the subject used in this study did not manifest a well-defined nasal cycle, there were indications that his nasal resistance tended to change within 45-min periods. Since the technique of acquiring the MR images involved two separate scanning sequences beginning with the most posterior locations, it is possible that the subject's right nasal airway may have become congested during the scan itself, and that only the second half of the scan, which encompassed the anterior half of the airways, showed the change. However, with the variability in the results, it is more likely that the differences are truly not significantly different.

More important to this analysis is the attempt to explain changes in measured nasal airway resistance in terms of changes in the structure and/or size of the airways themselves. The fluid dynamics of the nasal airways are not well understood despite studies that have been done using hydrodynamic models of these airways. Several points can be mentioned, however. It is clear that the complexities of the nasal airway structure do not permit the use of models with simple pipelike analogs. Additionally, the fluid flow within the airways is very dependent on the flow rates and pressure gradients within them. At low flow rates (~ 0.2 L sec^{-1}), flows can be approximated as laminar. However, at significantly higher flow rates, i.e., 1.0 L sec^{-1}, the flows become substantially more turbulent, leading to nonlinearities in the pressure-flow relationships. The resistance measurements made in this study were most likely made in the turbulent flow regime.

A second factor that must be considered in interpreting nasal resistance changes relative to structural changes is the fact that the resistance elements are not uniformly distributed along the nasal airway. In fact, studies have shown that most of the resistance can be defined to occur in a very short segment of the nasal airway that is situated in the bony cavum near the anterior end of the inferior turbinate.[1] In this study subject, this point corresponds to section 24 (Fig. 1). It can be seen that this particular point is markedly asymmetric, with the cross-sectional area of the left side being twice that of the right. Thus, if resistance were to be inversely related to the cross-sectional areas, then it would be expected that at section 24, the right side would present the most significant resistance. Conversely, this would not be as likely for the left side, where minimal cross-sectional areas occurred more posteriorly (sections 33-42).

In summary, the relationship between measured nasal airway resistance and nasal airway structure has not been explained by the results of this study. It is clear that measurements on other subjects are needed. Additionally, resistance measurements need to be made at considerably reduced flows compared to those used here. Only then will it be possible to identify what are the important resistive components of the nasal airways and how changes in their size and configuration affect measured resistance, and presumably also airflow patterns.

REFERENCES

1. Haight, J. S. J. and P. Cole. The Site and Function of the Nasal Valve, Laryngoscope 93: 49-55, 1983.