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Unilateral and bilateral nasal resistances

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SUMMARY

Plethysmographic rhinomanometric resistance measurements of combined and separate nasal cavities were made at a transnasal differential pressure of 100 Pa. The coefficients of variation over time of 40 consecutive total resistance values obtained at 1 min intervals from untreated noses of five healthy subjects averaged 11.0% measured directly and 11.8% calculated by application of Ohm's Law for parallel resistors. Measurements at 5 min intervals between sides increased variation of calculated total resistances markedly. The coefficients decreased to 4.7% and 5.1% respectively when the noses were decongested and by contrast with untreated noses these resistances varied independently from each other. Facial masking increased the coefficient of variation of resistance in the decongested nose ($p < 0.001$) to as much as 11.0% and the magnitude of averaged resistances was moderately increased also ($p < 0.035$). Measured values plotted against calculated values for total nasal resistance of 45 consecutive patients produced a regression differing insignificantly ($p = 0,94$) from the line of identity in the decongested nose but diverging from it (intercept 0.03 Pa/cm^3/sec and slope 0.83, $p < 0.03$) when the nose was untreated. Resistive variations associated with mucovascular instability and with use of a face-mask contribute substantially to differences between the results of anterior and posterior rhinomanometric assessments of total nasal resistance.

INTRODUCTION

Ohm's Law for parrallel resistors is widely employed to calculate total nasal airflow resistance by measurements obtained from each nasal cavity separately. A retrospective examination of our own clinical rhinomanometric results with a head-out body plethysmograph showed only approximate correlation between calculated and directly measured total resistances. Experimental attempts to improve on these results by traditional anterior and posterior rhinomanometry using an industrial type face-mask were unsuccessful.

This presentation is concerned with sources of variation in current methods of nasal resistance measurement.

METHODS

Subjects: Patients in the course of clinical rhinomanometric examinations and healthy volunteers.

Nasal airflow resistance: Respiratory airflow was measured by a head-out body plethysmograph leaving the face and nostrils unrestricted while concomitant transnasal pressures were measured through a fine per-nasal catheter to the nasopharynx (Cole and Havas, 1987). Each resistance value was determined at an inspiratory transnasal differential pressure of 100 Pa.

Statistical analysis: Data management and analyses were accomplished using the Statistical Analysis System (SAS User's Guide, 1982). The association between measured and calculated total nasal resistances (untreated and decongested) was assessed using least-squares regression analysis. Statistics with associated p-values of 0.05 or less were deemed significant.

Experiments: In experiments 1 and 2(b) resistances were averaged from five measurements of two consecutive breaths (20 data points) and in 2(a) and 3 they were averaged from two consecutive breaths (four data points). Unilateral measurements were made with the opposite side occluded.

1. *Effect of duration of time interval between measurements*

Initial resistance values were obtained from right and left nasal cavities separately in 12 healthy subjects, the interval between left and right measurements was <1 min. The measurements were repeated in each subject after an interval of 5 mins. The results enabled total nasal resistances to be calculated from right and left measurements <1 min and 5 mins apart and compared.

2. *Effect of decongestant*

(a). Measurements were obtained from the combined nasal cavities and from each side separately. The sequence was repeated each minute until 40 sets of results had been accumulated in each of five subjects.

I Nose untreated

II Following topical application of 0.1% xylometazoline hydrochloride.

(b). As (a) I and II from 45 consecutive referred clinic patients.

3. *Effect of face masking*

Three different masks were employed, an anaesthetic mask, a modified scuba mask and a full-face industrial mask, each with the airflow port open to the atmosphere. Resistance measurements were obtained while the mask was carefully applied and alternated with measurements during which the face was unmasked. All measurements were obtained from a single decongested nasal cavity to minimize sources of intrinsic variation, the opposite nasal cavity with the pressure detecting catheter in situ remained occluded throughout the experiment. Measurements were repeated until 40 pairs of alternating results (masked and unmasked) had been accumulated with each mask in turn.

RESULTS

Table 1 shows that in untreated noses an increase of the interval from <1 to 5 mins between left and right measurements increased the coefficient of variation of total nasal resistances calculated from Ohm's Law significantly. Table 2 demonstrates that untreated noses exhibited much more variation of resistance over time than noses which were decongested but, in contrast with untreated noses, decongested measured and calculated values varied independently from each other. Averaged measured and calculated resistances showed inconsistent but small differences. It may be noted also (Tables 2 and 3) that an unidentified source of variation (coefficient = 5% approx.) remains in the decongested measurements.

Table 1. Calculated total nasal resistance $Pa/cm^3/sec$

Interval between Left and Right measurements			
<1 min		5 mins	
Initial	5 mins later	L&R	L&R
0.143	0.146	0.155	0.135
0.199	0.181	0.238	0.158
0.224	0.244	0.210	0.263
0.108	0.119	0.122	0.106
0.117	0.127	0.108	0.139
0.170	0.179	0.175	0.174
0.193	0.205	0.217	0.183
0.114	0.125	0.109	0.121
0.189	0.190	0.205	0.229
0.121	0.133	0.133	0.137
0.126	0.119	0.157	0.180
0.172	0.183	0.192	0.221

Table 2. Coefficient of variation of total nasal resistance in % (N = 40)

Subject	1	2	3	4	5
Untreated measured	14.3	11.0	10.4	9.3	9.8
Untreated calculated	15.1	12.0	9.3	11.3	11.3
Decongested measured	5.6	3.8	3.9	4.6	5.4
Decongested calculated	6.2	4.1	4.3	4.7	6.1

Table 3. Coefficient of variation of nasal resistance in % (N = 40)

Mask type	1	2	3
Masked	9.3	8.5	11.0
Unmasked	5.8	4.5	6.1

The effect of decongestant is illustrated further in Figure 1 as a boxplot and in Figure 2 from regressions of measured on calculated total resistance values of a group of consecutive patients. The regression of the untreated level of the measured total nasal resistance on the calculated level of total nasal resistance produced a highly significant correlation coefficient ($r=0.92$, $p<0.0001$). However, analysis of the regression parameters revealed that the estimate of the intercept, namely 0.033 Pa/cm^3/sec, was significantly different from zero ($p<0.03$). Furthermore, the estimate of the regression slope, 0.83, was found to deviate significantly from unity ($p<0.03$). When the analysis was repeated using decongested levels of measured and calculated total nasal resistances, a correlation coefficient virtually identical with the first analysis was obtained ($r=0.91$, $p<0.0001$) but both the estimate of the intercept (0.009 Pa/cm^3/sec) and the slope (0.99) were found to be insignificantly different from 0 and 1, respectively ($p>0.50$).
The masking experiments (Table 3) demonstrated that each of the different types of mask amplified variation ($p<0.001$), in addition masking tended to elevate the magnitude of resistance ($p<0.035$).

DISCUSSION

The investigations demonstrate two major sources of variation in rhinomanometric measurements. They are intrinsic, associated with mucovascular instability and extrinsic, associated with application of a face-mask (Cole and Havas, 1987). In sum or even individually these variations contribute substantially to apparent discrepancies when the results of Ohm's Law calculations of total nasal resistance to respiratory airflow are compared with direct measurements.
The resistive effect of mucovascular instability over time is demonstrated in Tables 1 and 2. Figures 1 and 2 show that variations in nasal resistances and consequent anomalies in the application of Ohm's Law are reduced when the mucosa is stabilized by decongestion of vascular tissue (Bende and Löth, 1986).
Although it would be desirable for the regression of the measured level of nasal resistance on the calculated level of nasal resistance to produce an intercept of 0 and a slope of 1, as was the case with the decongested measurements (Figure 2), a result which almost suffices is one in which the intercept is not zero but the slope is equal to unity. Such a scenario would suggest a constant systematic error in the measured level of nasal resistance which could be corrected by subtraction of the y-intercept from the measured level of total nasal resistance. However, a regression slope which deviates significantly from unity, irrespective of the value of the y-intercept and which was characteristic of the measurements obtained prior to the application of decongestant, is the least desirable of scenarios as any correction on the measured level of nasal resistance is complicated appreciably.

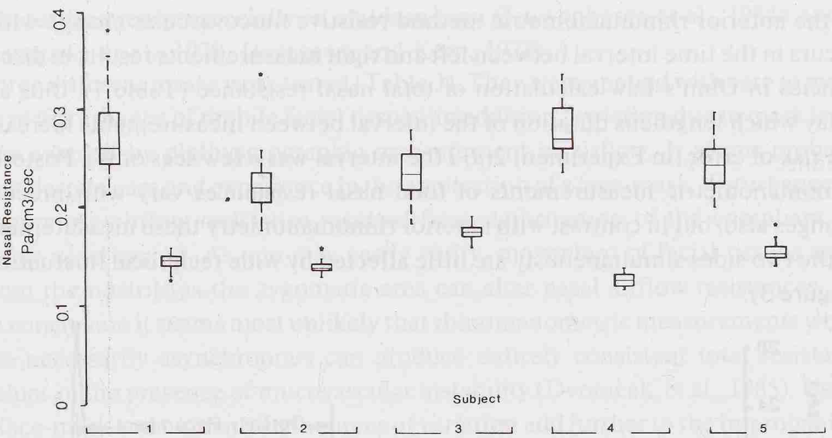


Figure 1. Boxplot of nasal resistance values (For explanation see Appendix). Five subjects before and after decongestion.

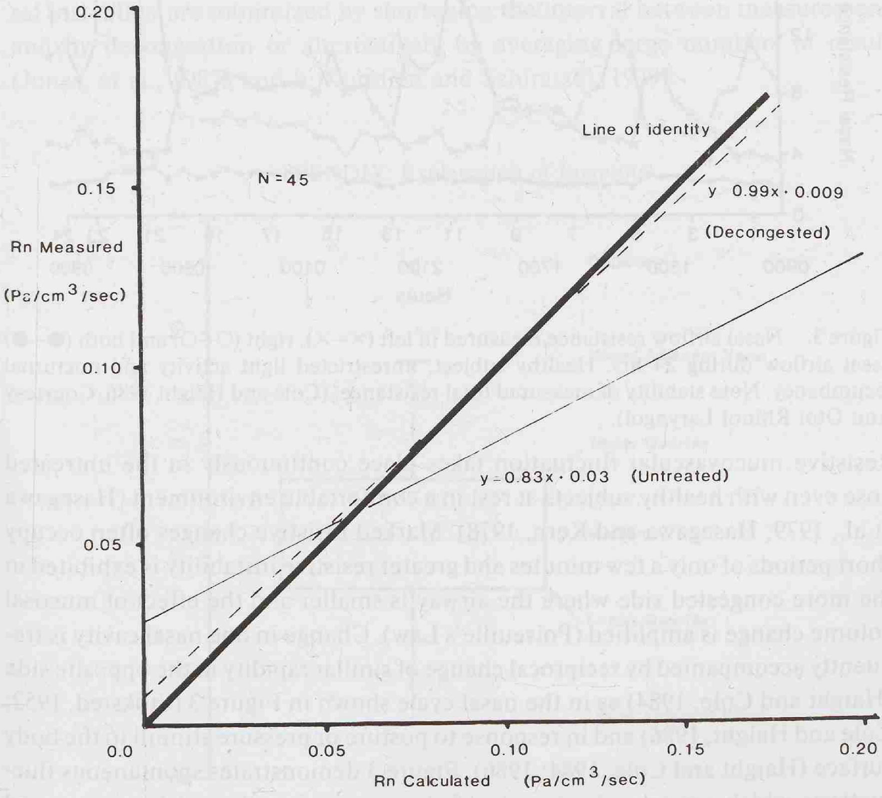


Figure 2. Linear regressions of measured on calculated nasal resistance values for 45 patients before and after decongestion.

In the anterior rhinomanometric method resistive mucovascular change which occurs in the time interval between left and right measurements results in discrepancies in Ohm's Law calculation of total nasal resistance (Table 1), thus any delay which lengthens duration of the interval between measurements increases the risk of error (in Experiment 2(a) i the interval was a few secs only). Posterior rhinomanometric measurements of total nasal resistances vary with mucosal changes also, but in contrast with anterior rhinomanometry these measurements of the two sides simultaneously are little affected by wide reciprocal fluctuations (Figure 3).

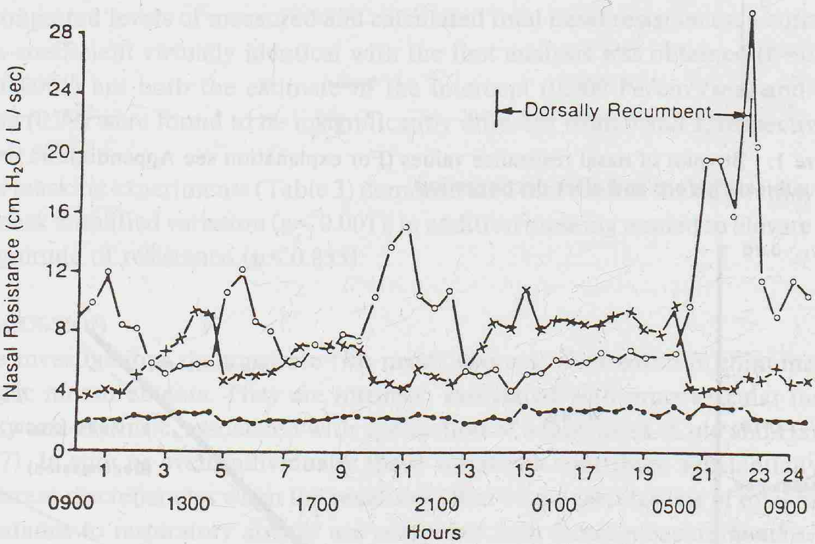
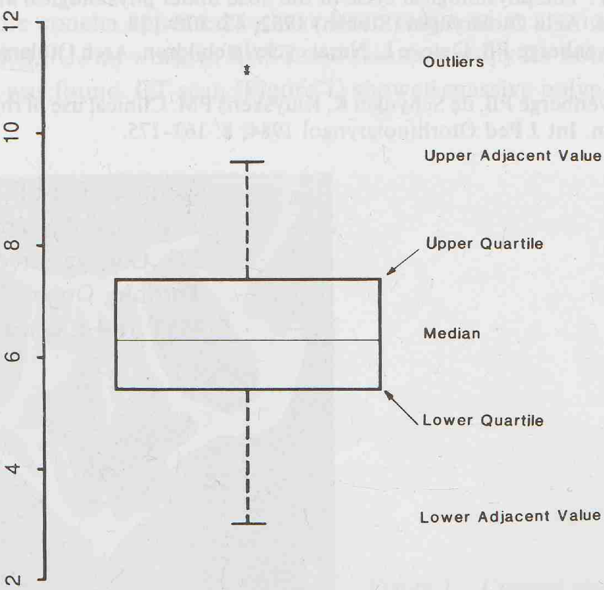


Figure 3. Nasal airflow resistance measured in left (×–×), right (O–O) and both (●–●) nasal airflow during 24 hrs. Healthy subject, unrestricted light activity and nocturnal recumbency. Note stability of measured total resistance. (Cole and Haight 1986, Courtesy Ann Otol Rhinol Laryngol).

Resistive mucovascular fluctuation takes place continuously in the untreated nose even with healthy subjects at rest in a comfortable environment (Hasegawa et al., 1979; Hasegawa and Kern, 1978). Marked resistive changes often occupy short periods of only a few minutes and greater resistive instability is exhibited in the more congested side where the airway is smaller and the effect of mucosal volume change is amplified (Poiseuille's Law). Change in one nasal cavity is frequently accompanied by reciprocal change of similar rapidity in the opposite side (Haight and Cole, 1984) as in the nasal cycle shown in Figure 3 (Stoksted, 1952; Cole and Haight, 1986) and in response to posture or pressure stimuli to the body surface (Haight and Cole, 1984; 1986). Figure 3 demonstrates spontaneous fluctuations which are irregular in rate of change, magnitude and frequency and other investigators have reported marked resistance shifts and phase reversals of

greater frequency especially in children (van Cauwenberge et al., 1984a and b; Hasegawa et al., 1979; Hasegawa and Kern, 1978).
Three different masks were tested (Table 3). They were applied with care to minimize disturbance of mobile facial tissues, in addition, variation due to mask leaks was avoided by plethysmographic measurement of airflow. It seems probable that despite care and experience in the application of a face-mask, disturbances of respiratory airflow resistance resulted from deformation of the compliant anterior nasal region. As one may easily verify, movement of facial tissues as far from the nostrils as the zygomatic area can alter nasal airflow resistances.
In conclusion it seems most unlikely that rhinomanometric measurements which are necessarily asynchronous can produce entirely consistent total resistance values in the presence of mucovascular instability (Dvoracek, et al., 1985). Use of a face-mask and unidentified sources of variation add further to the improbability of precise agreement. Nevertheless, although the result of an Ohm's Law calculation of total nasal resistance to respiratory airflow usually differs from a direct measurement the law appears increasingly appropriate as variations due to mucosal instability are minimized by shortening the interval between measurements and by decongestion or alternatively by averaging large numbers of results (Jones, et al., 1987a and b; Kumlien and Schiratzki, 1979).

APPENDIX: Explanation of Boxplots



Note: If the data is normally distributed, 95% of it should lie between the adjacent values.

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