Rhinology, 24, 163–173, 1986

Resistance to respiratory airflow of the nasal passages: comparisons between different common methods of calculation

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SUMMARY

Computer assisted active posterior rhinomanometric determinations of resistance were made with four adult subjects.

A face mask and pneumotach were used to measure respiratory airflow. The magnitude and variation of six different instantaneous and time averaged methods of calculation of resistance resulting from simultaneous measurements were compared. Over a resistance range of 1–6 cm $H_2O/l/sec$ (0.1–0.6 $Pa/cm^3/sec$) time averaged results approximated those computed at 75 Pa and were 20–25% less than those at 150 Pa. Over the same range of nasal patencies, the coefficients of variation averaged 6–8% in 144 series of 10 measurements which were obtained from six modes of resistance computation in four subjects (total 1440). Time averaged results showed the least variation. A frequency range of 10–26 breaths/min increased the coefficient of variation only to 9% and a ventilation range of 7–24 l/min increased it to 11%, quantitative relationships between resistances and pattern of breathing were not evident. Mask positioning was critical, small maladjustments resulted in large resistive changes.

INTRODUCTION

In this communication contemporary methods which are commonly employed for assessment of nasal patency are examined and discussed.

In many centres, nasal patency is quantified reciprocally in terms of resistance and it is expressed as a ratio between transnasal pressure and respiratory airflow, the concept of resistance is firmly established and widely recognised. Although other valid measures have proved useful to individual investigators and for specific projects none has achieved as general an acceptance as resistance (Clement and Hirsch, 1984; Masing, 1979; Graamans, 1981; Hamilton, 1979; Kern, 1973; Melon and Daele, 1979; Pallanch, 1984).

Our paper is concerned with variously calculated resistance values. These values may be obtained conveniently from co-ordinate points on the curve traced by concurrent recording of transnasal pressure and respiratory airflow, a form of recording advocated by the International Standardization Committee on Rhinomanometry (Clement). The Committee (ISCR) recommends further that published rhinomanometric data include resistances calculated at transnasal pressures of 75 and 150 Pa and expressed in S.I. units as Pa/cm^3/sec (conversion factor for cms H_2O/l/sec to Pa/cm^3/sec $= 0.98 \times 10^{-1}$).

Differing choices of co-ordinates by investigators who use this form of pressures: flow recording complicate comparison of results. In order to provide a yardstick we have compared computations of resistances from simultaneous recordings (Hamilton, 1979; Hamilton and Christman, 1977) which include the designated values recommended by the ISCR together with those obtained at other commonly designated respiratory flows of 0.2 and 0.4 l/sec, and in addition two forms of time averaged resistances. This communication presents comparisons of the magnitude and variation of these resistance values (Cole et al., 1980a; Kumlien and Schiratzki, 1979).

METHODS

Subjects

Four adult Caucasian volunteers in whom histories of recent nasal symptoms and pathological findings were absent.

Nasal resistance

Respiratory airflow – subjects breathed through the nose into a Scuba mask with a Fleish #2 pneumotach mounted in the face piece (Hamilton, 1977; Niinimaa et al., 1981).

Transnasal pressure – differential pressures between pharynx and anterior nares were obtained through a per oral tube to the oropharynx and a tube to the interior of the mask, i.e. posterior rhinomanometry (Williams, 1970).

Coaching and biofeedback enabled all four subjects to produce acceptable pressure: flow curves on the screen of an x-y oscilloscope (Solow and Greve, 1980). Pressure and flow signals were sensed by reluctance transducers (Validyne MP 45) and their amplified electrical analogues were sampled every 20 msecs by the A/D converter of a programmed IBM/PC microprocessor. Digitized values were stored in the computer memory and several respiratory variables, which included resistances, were computed on completion of a chosen sequence of breaths (Cole et al., 1980b).

Resistances were computed as follows:

(i) $\Delta_p/\dot{V}$ at 0.2 l/sec flow
(ii) $\Delta_p/\dot{V}$ at 0.4 l/sec flow
(iii) $\Delta_p/\dot{V}$ at 75 Pa transnasal pressure
(iv) $\Delta_p/\dot{V}$ at 150 Pa transnasal pressure

(i–iv). These designated pressure and flow values were retrieved by programmed computer scanning of stored digitized data. Instantaneous resistances at the respective pressure and flow points were then computed (designated data points are recorded four times in every breath unless they are situated beyond the pressure: flow curve limits) and the resistance values (about 20) from the chosen sequence of breaths were averaged.

(v) Resistance was computed from the ratio between averaged consecutive 20 msec pressure values and averaged 20 msec flow values from the chosen sequence of breaths. (Time average #1 in tables).

(vi) Resistance was computed from averaged consecutive 20 msec pressure: flow ratios from the chosen sequence of breaths. (Time average #2 in tables).

Experimental

1. Comparisons between magnitude and variation of resistances in four subjects (M 67, F 27, 29, 34). Computer assisted simultaneous measurements of all the above variables were recorded at 10 consecutive 60 sec intervals from each of four subjects in six different resistive situations as listed below:
   (a) Nose untreated:
      (i) both nasal cavities combined
      (ii) left nasal cavity (right occluded)
      (iii) right nasal cavity (left occluded).
   (b) Nose decongested (topical 0.1% xylometazoline):
   (i)–(iii) as in (a).
   (This range of patencies extended well beyond the extremes of normal noses).
2. Effect of minute ventilation on nasal resistance in two subjects (M 67, F 21). A series of 10 computer assisted measurements was obtained from each of 2 resting subjects. Their breathing frequency was metronome paced at 12/min and ventilation was varied voluntarily from 7 to 24 l/min.
3. Effect of breathing frequency on nasal resistance in two subjects (M 67, F 21). As in 2, but breathing frequency paced by metronome ranged from 10 to 26 l/min and ventilation approximately 17 l/min.
4. Effect of mask adjustment on nasal resistance (one subject, M 67). A Scuba mask was used. Most of the transparent plastic face piece had been excised so that obstructive cotton plugs could be inserted and removed from the nasal vestibules without changing the position of the mask. It was placed on the subject's face and adjusted as described in Table 6. In the absence of a complete mask face piece airflow was measured by means of a "head-out" body plethysmograph (Niinimaa et al., 1979; Griffin and Zamel, 1979) and pressure by posterior rhinomanometry. A series of five nasal resistance values was obtain-

ed in each case, the highest and lowest were rejected and the resistance recorded resulted from averaging the three intermediate values – this method sampling and averaging is employed in most of our rhinomanometric studies.

RESULTS

Comparisons between differently calculated resistances in terms of magnitude and variation are shown in the accompanying tables. Table 2 demonstrates a similarity in variation of other respiratory parameters which were computed simulta-

Table 1. Typical series of resistances and variations (subjects breathing spontaneously at rest).

	time average #1 (a)	time average #2 (b)	flow 0.2 l/sec (c)	flow 0.4 l/sec (d)	pressure 75 Pa (e)	pressure 150 Pa (f)
resistance in cm H_2O/l/sec						
1.	2.39	2.21	2.01	2.44	2.32	-
2.	1.98	1.88	1.61	2.11	2.06	-
3.	2.43	2.33	2.11	2.70	2.48	3.19
4.	2.55	2.35	2.11	2.73	2.51	-
5.	2.39	2.23	2.05	2.56	2.29	-
6.	2.49	2.30	2.21	2.78	2.46	2.62
7.	2.51	2.35	2.22	2.78	2.52	2.92
8.	2.28	2.15	2.03	2.55	2.30	2.68
9.	2.47	2.24	2.18	2.75	2.45	3.05
10.	2.61	2.39	2.24	2.81	2.54	-
mean resistance N = 10						
	2.41	2.24	2.09	2.63	2.41	2.89
coefficient of variation N = 10						
	7%	6%	9%	8%	6%	8%

Single subject. Sampling period 5 breaths for each series (a)– (f). Repeated at 1 min. intervals 1–10.

N.B. The pressure of 150 Pa is not achieved in several determinations, it is close to the limits of the pressure: flow curve.

Table 2. Typical series of other respiratory parameters: magnitude and variation.

variable	mean of 10	coefficient of variation %
breaths/min	18.2	6
minute ventilation – litres	11.4	7
mean insp. press cm H_2O	0.88	7
mean exp. press cm H_2O	0.80	10
mean insp. flow l/sec	0.38	7
mean exp. flow l/sec	0.33	8
time insp. secs.	1.44	7
time exp. secs.	1.86	5

Respiratory parameters computed simultaneously with the resistances in Table 1.

Table 3.

		mode of computation					
range of resistance	means	average #1 (a)	average #2 (b)	0.2 l/sec (c)	0.4 l/sec (d)	75 Pa (e)	150 Pa (f)
$2>$ cms H_2O/l/sec	(N = 80) mean nasal resistance*	1.44	1.39	1.49	1.56	1.56	1.93
	mean relative proportion %	100	96	103	108	108	131
	mean coefficient of variation %	6	7	9	8	6	5
2–3 cms H_2O/l/sec	(N = 80) mean nasal resistance*	2.34	2.24	2.31	2.56	2.47	2.85
	mean relative proportion %	100	95	99	109	105	123
	mean coefficient of variation %	6	7	8	7	7	8
$3<$ cms H_2O/l/sec	(N = 80) mean nasal resistance*	4.12	3.93	4.25	4.48	4.24	4.97
	mean relative proportion %	100	95	103	109	103	121
	mean coefficient	6	6	9	8	7	7

* Each resistance value was averaged from 8 series of 10 measurements. The results are arranged to provide a comparison of magnitude and variation of the 6 modes of computation over 3 different ranges of resistance.

neously with resistance in Table 1. As a result of the sigmoid shape of the pressure: flow curve resistances calculated from co-ordinates of points near the origin were smaller than those from the extremities. In the series of patencies in which resistances ranged from 1–6 cms H_2O/l/sec (0.1–0.6 Pa/cm^3/sec), the magnitude of time averaged results approximated instantaneous resistances at a flow of 0.2 l/sec and a pressure of 75 Pa, they were about 25% less than those calculated at 150 Pa (Table 3).

Coefficients of variation were 6–8% with the four subjects breathing spontaneously at rest. They demonstrated little difference between subjects, between patencies, or between the various computations of resistance, and decongestion which would be expected to minimize vascular disturbances of nasal resistance (Cole and Haight, 1985a) did not reduce variability (Cole et al., 1980a). Time averaged resistance showed less variation than the instantaneous values. With a range of 10 breathing frequencies between 10 and 26 breaths/min at a constant minute ventilation of approximately 17 l/min the coefficient of variation was 9% and a constant frequency of 12 breaths/min and a range of 10 ventilations between 7–24 l/min increased it to 11%, in neither case was a clear quantitative relationship with resistance evident (Tables 4 and 5).

Table 4. Effect of minute ventilation on nasal resistance (breathing frequency 12/min).

minute ventilation l/min	time average #1 (a)	time average #2 (b)	flow 0.2 l/sec (c)	flow 0.4 l/sec (d)	pressure 75 Pa (e)	pressure 150 Pa (f)
resistance in cm H_2O/l/sec						
24	1.38	1.41	1.79	1.62	1.62	1.72
23	1.69	1.68	1.84	1.76	1.76	1.94
17	1.51	1.55	1.71	1.64	1.74	1.81
16	1.49	1.49	1.80	1.53	1.61	1.68
14	1.13	1.35	1.19	1.28	1.33	–
12	1.56	2.10	1.77	1.76	1.52	–
12	1.37	1.57	1.48	1.54	1.61	–
11	1.42	1.71	1.81	1.82	1.76	1.99
10	1.19	1.86	1.50	1.35	1.36	–
7	1.64	1.88	1.65	1.58	1.61	–
mean. N = 10						
	1.44	1.66	1.65	1.59	1.59	1.83
coefficient of variation. N = 10						
	12%	14%	12%	11%	10%	8%

Single subject. Five breaths sampled simultaneously in each series (a)–(f).

Table 5. Effect of breathing frequency on nasal resistance of a single subject (minute ventilation 17 l/min).

frequency breaths/ min	time average #1	time average #2	flow 0.2 l/sec	flow 0.4 l/min	pressure 75 Pa	pressure 150 Pa
26	2.13	2.08	2.23	2.23	2.20	2.33
24	2.09	2.05	2.27	2	2.21	2.37
20	1.72	1.72	1.91	1.81	1.81	1.98
17	1.77	1.67	1.80	1.67	1.69	1.81
15	1.98	1.88	1.90	1.98	1.96	2.21
15	1.83	1.83	2.08	2.09	2.01	2.13
10	2.11	2.08	2.11	1.98	1.96	2
10	1.86	1.86	1.84	1.68	1.79	2.00
10	1.72	1.72	1.91	1.81	1.81	1.98
10	2.22	2.17	2.14	1.98	1.95	2.31
	mean N= 10					
	1.94	1.91	2.02	1.94	1.94	2.13
	coefficient of variation N= 10					
	10%	9%	8%	10%	9%	9%

Single subject. Five breaths sampled simultaneously in each series (a)–(f).

Table 6. Effect of mask adjustment on nasal resistance. Example of a single subject.

	nasal resistance in cms H_2O/l/sec (mean values $N=5$)		
	combined nasal cavities	left nasal cavity	right nasal cavity
no mask	1.2	1.9	1.9
mask well adjusted	1.2	2.3	1.8
tension left harness	1.7	2.8	5.5
tension right harness	1.3	3.9	1.8
mask too high	2.5	–	–

Mask positioning was critical (Table 6). Asymmetrical adjustment of the harness produced only a small effect on resistance of the combined nasal cavities, whereas large reciprocal changes were induced in the separate vestibules and bunching of the upper lip by the mask markedly increased resistance of both. At resting ventilation and low nasal resistance a pressure of 150 Pa was not always achieved, by contrast in cases of high resistance resting flow sometimes failed to reach 0.4 l/sec.

DISCUSSION

This communication is concerned with the magnitude and variation of empirical measurements of nasal resistances to respiratory airflow. Comparisons were made between six differently calculated resistance values under widely ranging conditions of nasal patency and pattern of breathing. In addition untoward resistive artefacts which can result from distortion of facial tissues by masking were demonstrated.

Our methods for creating six different resistances in each subject which may, at first sight, appear unduly artificial and invasive do not depart very far from the effects of spontaneous nasal cycling. Indeed, severe obstruction to one nasal cavity occurs frequently as a normal but seldom noticed physiological event especially in recumbent subjects and it is accompanied by vigorous reciprocal decongestion and increased patency in the opposite side (Cole and Haight, 1984; 1985b).

Differences in nasal patency are indicated by inclination of transnasal pressure: flow curves toward pressure (decreased patency) or flow axes (increased patency) and Broms et al. have found that a series of curves representing different patencies can be arranged in radial order, i.e. they rarely cross. The concept of describing these curves mathematically is attractive, each curve portrays resistance throughout a complete breath. Rohrer's equation and constants (1915) have been used by many investigators since 1915, and attempts to improve on this approach have led to development of several mathematical transformations and polynomial descriptions of the curve. These models are subjected to critical examination by Pallanch (1984), Eichler and Lenz (1985) and Schumacher, Gaines and Bescript (1985), but general agreement has not yet been achieved. In the absence of agreement on mathematical treatments many different empirical methods for assessment of nasal patency are employed and although any one of them may appear practical, valid and promising, resistance as a ratio between transnasal pressure and nasal respiratory airflow is most widely used. It may be conveniently calculated from rectangular or polar coordinates of points on the sigmoid pressure: flow curve. As a result of this sigmoid shape the magnitude of instantaneous resistance increases with the distance at which it is measured from the origin. Between 0.2 l/sec flow and 150 Pa pressure our empirical results indicated an increase of about 25% and time averaged resistances occupied the lower end of this range.

Coefficients of variation were remarkably similar, they approximated 6–8% for the differently computed resistances over a wide range of nasal patencies and they were similar to the variations of other respiratory parameters (Tables 1–3). Time averaged values showed less variation than instantaneous values. The coefficients increased to 11% when spontaneous resting ventilation was disturbed by a range of voluntary alterations which far exceeded the spontaneous changes of resting breathing patterns and no definite relationships between resistances and breathing frequency or minute ventilation were recognised (Tables 4 and 5). The results provide an interesting comparison with several series which ranged over extended periods of hours to months in which the coefficients of variation of individual subjects increased only to 15–20% (Cole et al., 1980a).

A designated transnasal pressure of 150 Pa as recommended by the ICSR is, in many cases, beyond the resting level of spontaneous breathing in subjects with low nasal resistance and a flow of 0.4 l/sec is frequently not achieved when resistances are high. Some workers avoid these deficiencies by designating a low pressure or flow value for their calculations of instantaneous resistance: and Broms et al. select appropriate pressure: flow radii in their polar co-ordinate technique (Broms, 1980) while other investigators urge their subjects to breathe more vigorously. By contrast, time averaged resistances are independent from these limitations. In our experiments, they were averaged from 1000 (or more) consecutive, digitized values of pressure and flow distributed equally in time at 20 msec intervals throughout any chosen sequence of pressure: flow curves (usually 5 breaths). Time averaged values are representative of complete breathing cycles since their computation takes into account the distribution in time of the instantaneous resistances from which the pressure: flow curves are composed. As will be noted from tracings of pressure and/or flow plotted against time or respiratory pressure: flow recording with an X–Y oscilloscope, the moving spot spends its time nearer the extremities of the curve than the origin, this is reflected in time averaged measurements.

The instantaneous resistance values we present result from a simpler form of computer averaging, in that pressure and flow at designated points are achieved four times in each breath. Thus 20 measurements or more were averaged from each chosen sequence of breaths, and this may explain their greater reliability than the results which we had derived previously from direct measurements of photographed pressure: flow curves – a laborious technique we abandoned in favour of computer averaging.

A rather disturbing feature demonstrated by our experiments was the critical resistive effect of slight malpositioning of the Scuba face mask (Table 6). Scuba type masks are widely used in nasal airflow studies and although other types of mask preferred by some investigators may reduce the risk of distorting the soft and mobile tissues of the face, great care must be taken in all cases to minimize these risks. Pressures exerted on facial tissues, even when they are remote from the nasal vestibules, can alter airflow resistances very markedly as one may readily verify by obstructing a nasal cavity and exerting pressures on the cheek of the opposite side. Nevertheless, a carefully adjusted mask is less invasive than a vestibular probe which some investigators have used for measurements of nasal airflow. Almost half the airflow resistance of the normal nose resides in the compliant vestibule (Cole and Haight, 1985a; Haight and Cole, 1983) this resistance and its abnormalities are abolished by use of a probe.

We prefer to avoid the risks of vestibular distortion and use a "head-out" body plethysmograph (Niinimaa et al., 1979) in most of our rhinometric studies. This technique has additional advantages in extending the range of clinical and pathophysiological investigations; it facilitates visual, photographic and video observation, E.M.G. recording, alar retraction, jaw and lip movement, assessment of oronasal breathing, etc. Useful investigations of this nature are hampered by the restrictions of facial masking.

CONCLUSIONS

1. We found a range in magnitude of about 25% between different common empirical methods which are used for determination of nasal resistance to respiratory airflow.
2. Coefficients of variation were similar to those of several other respiratory parameters at about 8%.
3. Moderate changes in breathing pattern affected results minimally.
4. Careful choice and positioning of a face mask is an absolute sine qua non if it is to be used for reliable assessment of nasal patency.

RÉSUMÉ

On a effectué sur quatre sujets adultes, avec l'aide d'un ordinateur, des déterminations de résistance active au rhinomanomètre dans les fosses nasales postérieures.

On a mesuré le débit d'air respiratoire à l'aide d'un masque appliqué sur le visage et d'un pneumotachymètre. On a comparé l'importance et les variations des résultats obtenus à partir de mesures instantanées selon six méthodes distinctes de calcul instantanées et pondérées dans le temps. Sur une gamme de résistances de 1 à 6 cm $H_2O/l/s$ (0,1 à 0,6 $Pa/cm^3/s$), les résultats pondérés sans le temps ont été approximativement égaux aux résultats calculés à 75 Pa et inférieurs de 20 à 25% aux résultats obtenus à 150 Pa. Sur la même gamme de patences nasales, les coefficients de variation ont été en moyenne de 6 à 8% dans 144 séries de 10 mesures obtenues chez quatre sujets grâce à six modes de calcul de la résistance (total de 1440 mesures). Les résultats pondérés dans le temps ont affiché la variation la plus faible. Une gamme de fréquences de 10 à 26 respirations par minute n'a fait augmenter le coefficient de variation que jusqu'à 9%, tandis qu'une gamme de ventilations de 7 à 24 l/min l'a fait passer à 11%. On n'a pas constaté de rapports quantitatifs évidents entre les résistances et le rythme respiratoire. Le placement du masque s'est avéré critique, car de faibles erreurs de réglage ont entraîné d'importantes modifications de la résistance.

ACKNOWLEDGEMENT

We wish to express our thanks to Miss Au Yeung for her patience and generous secretarial support.

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This project was supported in part by grants from The Physicians' Services Incorporated Foundation of Ontario and the Ontario Thoracic Society.

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