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Variations in nasal resistance in man: a rhinomanometric study of the nasal cycle in 50 human subjects

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SUMMARY

The alternating congestion and decongestion of the nasal mucosa, termed the "nasal cycle", was investigated with current mask (posterior) active rhinomanometric techniques. This communication reports variations in nasal resistance in 50 human subjects, each studied for about 7 hours. Approximately 600 resistance values (cm H_2O*/liter per second) were obtained from each subject. The nasal cycle defined in rhinomanometric terms was that alternating congestion and decongestion of the nasal turbinates which produced a change in pressure and airflow values calculated as resistance (comparing one side with the other) of 20% or greater for two consecutive observations (at least 15 minutes). The data demonstrated that 36 of 50 subjects (12 of 18 males and 24 of 32 females) had at least one nasal cycle during the period of observation.*

Those who look with curiosity and care soon recognize that the nasal mucosa is an active dynamic organ that is capable of reacting to various internal and external stimuli. This system of reactions is probably under autonomic nervous system influence and certainly is capable of responding to various chemical, electrical, and thermal stimuli. It has been known for some time that the internal nasal chambers are constantly in motion, changing their shape and configuration almost from moment to moment.

The German rhinologist Kayser (1895), just before the turn of the century, recognized the consistent reaction of congestion and decongestion of the nasal mucosa for which he coined the term "nasal cycle". Various workers have utilized various techniques to confirm the observations of Kayser. Clinical observations of this nasal cycle were made by Lillie (1923) and Heetderks (1927) during the middle portion of the twentieth century. To substantiate these clinical observations, we measured nasal airflow and pressure with the use of the current mask "flowmeter" rhinomanometric techniques, as first suggested by Mead (1960). The introduction of the mask flowmeter of Mead has given the rhinologist the equipment by which he can measure the pressure-flow relationship simultaneously through both nasal chambers. The main purpose of this communication is to report on variations in nasal resistance in man based on use of the mask flowmeter rhinomanometric technique in 50 human subjects.

METHODS AND MATERIALS

Thirty-two females 14 to 72 years old (mean age, 25) and 18 males 14 to 50 years old (mean age, 23) who had rhinoscopically normal noses and a negative history for nasal or paranasal sinus disease were selected for study. Examination followed an acclimatization period of about 30 minutes. The subjects were examined in the sitting position while they quietly breathed room air at 21 °C. The relative humidity varied from 25 ± 5%, in October through April, to 35 ± 5%, in May through September.

A schematic drawing of our investigational equipment is seen in Figure 1. A tight-fitting mask flowmeter was placed over the patient's face and secured with an elastic strap. Input to the mask was connected to a Statham PM 280 strain gauge (gas transducer) open to the atmosphere. This gauge, along with two pneumotachygraph mesh screens in the mask, was used to measure nasal airflow. A second input was used to record the pressure within the mask. This input was connected to a Statham PM 131 strain gauge (gas transducer), and the other end was connected to the mouth. The Statham 131 strain gauge with one input in the mask and the other in the mouth measured the transnasal pressure or pressure drop between the mask and the nasopharynx. The transnasal pressure really consitutes the driving pressure for nasal airflow. A con-

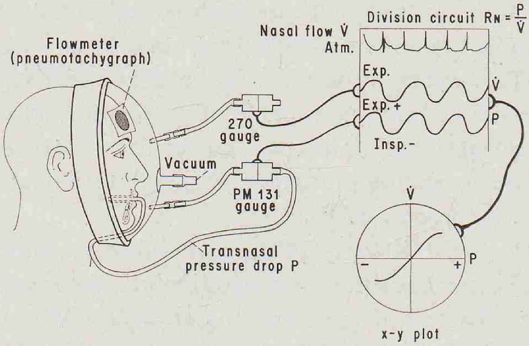


Figure 1. Equipment used in active posterior rhinomanometry. Inputs into face-mask flowmeter are connected to strain gauges to measure nasal airway and transnasal pressure. Output of gauges enters an amplifier and responses may be read out on recording paper. With this information, nasal resistance can be calculated or computerized division circuit can be used to calculate simultaneous nasal resistance. Another output may be led into an oscilloscope so that pressure-flow relationships may be visualized as an S-shaped curve resulting from changes in fluctuations in respiration, mainly inspiration and expiration.

stant-bias airflow (a vacuum could also be used) was also inserted in the mask to blow off or remove carbon dioxide and water vapor. The output of the gauge was entered in an amplifier, and the responses were read out on the paper of a Schuler-Packard Thermal Tip Recorder, Model 7414A. Another output was led into an oscilloscope (type 564B storage oscilloscope, Electronics, Inc.) so that the pressure-flow relationship could be visualized during inspiration and expiration, the result being an S-shaped curve. With this information (transnasal pressure and flow), nasal resistance was calculated and a computerized division circuit was used to calculate the nasal resistance simultaneously from the transnasal pressure-flow curves.

Only subjects who were able to relax the soft palate and breathe quietly so as to produce undistorted pressure-flow curves on the storage oscilloscope were included in this study. Two subjects had to be excluded on this basis. Subjects were asked to place their tongues between the upper and lower teeth against the buccal mucosa of the cheek to avoid obstructing the mouthpiece. Relaxation of the soft palate was facilitated by these maneuvers.

Patients were studied while breathing through both nostrils (binasal) and through each side (uninasal) after occlusion of the opposite side with cotton and surgical petroleum. While the subject was breathing through both nostrils, we calculated total binasal resistance. Uninasal – right and left – resistance was calculated with the opposite side obstructed. Examinations were made every 15 minutes and data were collected for total nasal resistance through both nostrils and then for the right and left sides alternately. This procedure was repeated for 7 hours with a 1-hour intermission at lunch. Figure 2 shows the equipment used in our experiments and a test subject in the sitting position.

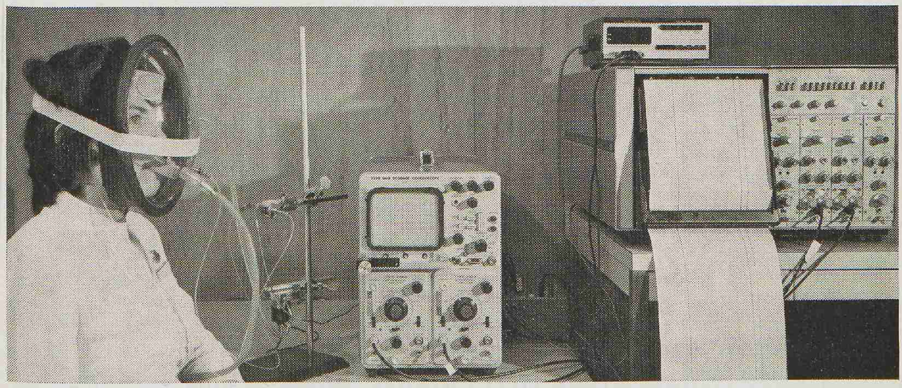


Figure 2. Arrangement of subject and equipment.

Figures 1–6 and tables 1–2 are from Hasegawa, M. and Kern, E. B., 1977: The human nasal cycle, Mayo Clin. Proc., 52, 28.

The value for nasal airway resistance was the mean of four breaths calculated at the peak inspiratory pressure and flow rates during quiet respiration. Nasal resistance (RN) is equal to the transnasal pressure (P) divided by the nasal flow rate ($\dot{V}$), $RN = P/\dot{V}$.

Resistance values obtained for both nostrils (total resistance) and for the right and left sides were plotted against time. For each subject, approximately 600 resistance values were obtained. The formula for nasal resistance that we have selected assumes laminar flow. It should be recognized, however, that other workers, including Masing et al. (1974), have used a formula for turbulent flow in which resistance equals pressure divided by flow squared, $RN = P/\dot{V}^2$. Air flow ranges from laminar to completely turbulent in the human nose. Certainly one can construct a cogent argument that resistance equals pressure divided by partly turbulent flow and therefore that resistance equals pressure divided by flow to the 1.75 power. Thus, $RN = P/\dot{V}^{1.75}$ is probably closer to what actually happens; however, the laminar flow formula was selected on the grounds that it has taken into consideration that the conditions of the experiment were standardized and that the comparison between subjects is permissible.

We did attempt to use fixed flow and even fixed pressure to calculate nasal resistance; however, this was not possible because of the physiologic variabilities that we noted in our subjects. For the purposes of this "physiologic" study, we recognized that not all subjects could reach the fixed flow rate, for example, of half a liter per second. The same problem exists when one attempts to utilize fixed pressure. Thus, it seems most appropriate for physiologic study to ask the subject to breathe quietly and to obtain a calculation of nasal resistance at the peak of inspiratory pressure and inspiratory flow. Each subject was able to produce a peak pressure and flow during every respiratory cycle. We think it is advantageous to utilize these active rhinomanometric techniques (the patient's own respiratory mechanism) during basic physiologic investigations, and by utilizing the mask flowmeter (also called posterior rhinomanometry), we avoid any instrumentation that could deform the nose itself. In addition, by the mask-posterior rhinomanometry technique, we have the opportunity to examine both nasal chambers simultaneously during these physiologic conditions.

RESULTS

Variations in nasal resistance were noted when pressure and flow were measured from each nasal chamber. This fluctuation in resistance was due to the alternating congestion and decongestion of nasal turbinates of sufficient magnitude to produce changes in resistance. The nasal cycle is the alternating congestion and decongestion of the nasal turbinates. Defined in rhinomanometric terms, it is that congestion and decongestion of the nasal turbinates which is sufficient

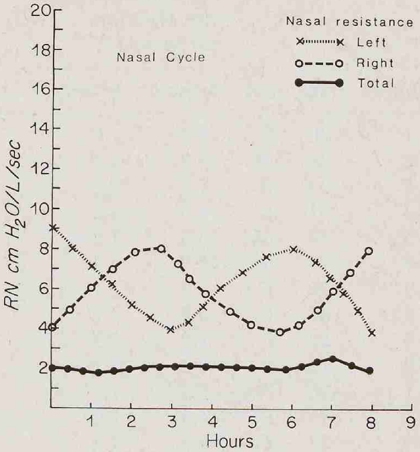


Figure 3. Plot of nasal resitance (*RN*) values in centimeters of water per liter per second against time in hours. Note right-sided and left-sided fluctuations in nasal resistance, whereas resistance through both nostrils (total nasal resistance) remains fairly constant. Also note that differences in resistance of 20% between two sides reversed or changed sides and thus demonstrated a complete nasal cycle.

to produce a change in resistance (comparing one side with the other) of 20% or more in two consecutive calculations (Figure 3).

With these criteria, 36 subjects (72%) – 12 males and 24 females – had at least one nasal cycle (again, alternating congestion and decongestion of the turbinates) during a period of observation. Forty-two complete cycles were observed, with a mean duration of 2.6 hours; including partial cycles, 102 cycles were detected. There were no apparent differences between right and left sides in frequency or duration of cycles. We evaluated the first complete cycle for those subjects who had complete cycles in order not to bias these results. Twenty-eight subjects (56%) had at least one complete cycle, whereas eight subjects (16%) had definite but only partial cycles. The estimated mean duration in this population was 2.9 hours, the 95% confidence interval being 2.4 to 3.4 hours. The longest cycle was 6 hours and the shortest was 1 hour. Table 1 summarizes the data in 36 patients who demonstrated variations in nasal resistance consistent with the nasal cycle. Table 2 is a summary of the data in all 50 subjects, including

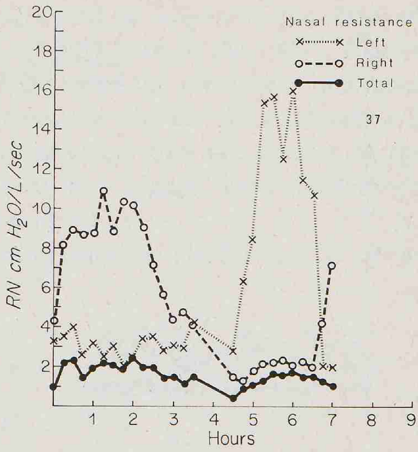
Table 1. Duration of Complete Cycles.

	No. cycles			
	23	19	42	28
	Right	Left	Total	First completed cycle
Hours				
Mean	2.7	2.4	2.6	2.9
SD	1.42	0.96	1.23	1.31
SE	0.29	0.22	0.19	0.25
Minimum	1.00	1.00	1.00	1.00
Maximum	6.00	4.50	6.00	6.00

Table 2. Rhinomanometric Data From 50 Subjects.

subject	age	sex	right side resistance (cm H_2O/liter per second)		left side resistance (cm H_2O/liter per second)		duration of first complete cycle (hours)	cycle	duration of study (hours)
			highest	lowest	highest	lowest			
1	20	F	9.7	1.0	12.4	1.6	1.75	+	6.00
2	26	M	13.3	1.8	5.7	1.3		−	6.25
3	33	F	7.2	2.2	8.3	3.2	1.25	+	6.50
4	21	F	8.0	1.8	15.7	2.8		−	6.50
5	14	M	13.3	1.2	15.3	1.2	1.75	+	6.25
6	14	M	10.7	1.3	8.5	1.4	4.75	+	7.00
7	20	F	2.5	1.2	3.3	1.9		−	6.75
8	45	F	4.7	1.2	4.9	1.0		+	6.75
9	28	F	2.9	0.9	2.7	1.1		−	6.00
10	18	F	6.2	2.3	8.0	2.0	2.00	+	5.00
11	18	F	6.4	1.7	6.4	3.3		−	5.25
12	19	F	4.3	2.2	5.9	2.5		+	4.00
13	23	F	3.9	1.3	4.4	2.6		−	6.75
14	24	F	10.4	2.3	20.6	1.5		+	7.00
15	20	F	6.1	1.4	4.7	1.0		−	7.00
16	16	F	4.5	1.2	8.0	2.9	4.50	+	7.00
17	14	F	10.6	1.8	5.2	1.5	2.00	+	7.00
18	42	M	4.6	0.9	4.2	1.1		+	7.00
19	17	F	14.5	2.0	16.3	3.7	2.25	+	7.00
20	23	F	5.2	1.6	4.5	1.7	1.50	+	7.00
21	25	F	5.8	2.4	6.6	2.5	2.25	+	7.00
22	27	F	7.5	3.5	7.9	2.9	2.75	+	7.00
23	26	F	3.9	1.0	4.0	0.9	1.00	+	7.00
24	23	F	4.7	2.4	3.1	2.1	2.75	+	7.00
25	41	F	3.3	2.0	3.5	1.5		−	7.00
26	53	F	5.9	1.4	4.0	1.4	3.25	+	7.00
27	72	F	3.2	0.6	8.5	1.9		−	7.00
28	23	M	4.0	0.9	8.0	0.7	4.00	+	7.00
29	33	F	3.5	1.3	3.8	1.5		+	7.00
30	30	F	18.1	2.5	6.3	2.0	6.00	+	7.00
31	34	F	5.7	0.9	3.2	0.6	1.00	+	7.00
32	15	F	9.7	2.9	8.0	2.8	3.75	+	7.00
33	36	F	7.9	2.2	8.6	2.4	4.00	+	7.00
34	24	F	9.8	2.9	11.7	1.5	4.00	+	7.00
35	67	F	3.7	1.8	4.3	1.8	3.75	+	7.00
36	28	F	4.2	2.3	4.1	1.8		−	7.00
37	26	F	10.8	1.3	15.9	2.0		+	7.00
38	19	F	13.0	2.5	10.2	2.5	4.00	+	7.00
39	23	M	5.2	2.5	9.5	2.9	2.25	+	7.00
40	25	M	7.3	3.4	7.5	2.3	2.25	+	7.00
41	22	M	15.0	2.4	6.2	2.5		−	7.00
42	26	M	6.8	2.1	10.9	2.5		−	7.00
43	19	M	30.0	3.2	13.4	1.6		+	7.00
44	25	M	37.5	2.3	7.2	1.4	1.50	+	7.00
45	23	M	5.1	2.3	11.9	3.5		−	7.00
46	19	M	5.0	1.8	12.0	1.9		+	7.00
47	50	M	3.5	1.2	4.7	2.3		−	7.00
48	17	M	9.5	2.1	10.7	2.5	2.50	+	7.00
49	19	M	8.5	1.3	5.6	1.2	4.25	+	7.00
50	19	M	8.8	3.0	9.6	2.6	4.50	+	7.00

Figure 4. Plot of nasal resistance (*RN*) values in centimeters of water per liter per second against time in hours for subject 37. Definite nasal cycle is present in which right side predominates for just over 4 hours, after which left side becomes dominant side.



the range from the highest to the lowest peak inspiratory resistance values obtained during this study. Several additional points were suggested by the results obtained. First, the older the person, the longer was the duration of the cycle. Two of seven subjects more than 40 years old who had nasal cycles had complete cycles; the five other subjects had long, incomplete cycles during the study. Secondly, younger subjects appeared to have greater nasal resistance values than did older subjects. Five subjects had repeat tests on subsequent days for study of the regularity of the cycle. Four subjects had one additional study and one subject had two additional studies, for a total of three separate observations of variations in nasal resistance.

Variations in nasal resistance are well demonstrated in Figure 4. Subject 37 demonstrates nasal resistance values in centimeters of water per liter per second

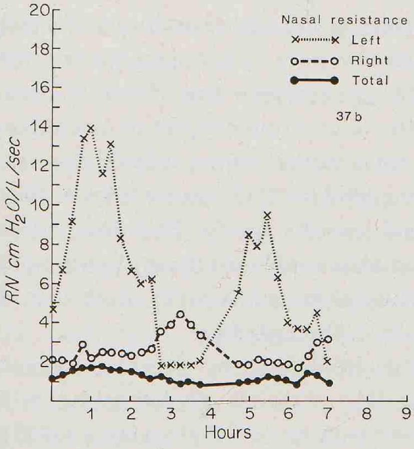


Figure 5. Plot of nasal resistance (*RN*) values in centimeters of water per liter per second against time in hours for subject 37 4 months after first study (Figure 4). Note difference in amplitude and duration of cycle.

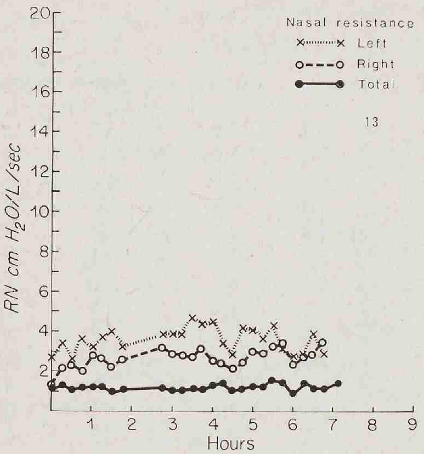


Figure 6. Plot of nasal resistance (RN) values in centimeters of water per liter per second against time in hours for subject 13. Note that there is no difference in resistance of 20% between two sides; hence, there is no evidence that a nasal cycle is present.

plotted against time in hours. A classical example of the nasal cycle occurred in this individual, with a predominant right side for just over 4 hours, after which the left side predominated. Four months later the same subject was retested. Figure 5 (same subject) demonstrates that the amplitude and duration of the cycle differed from the earlier values. Of the five subjects who had second studies, none had reproducible findings! The amplitude and duration of the cycles varied; the subject who had three separate studies did not demonstrate any nasal cycle on the second study but did have a cycle on a third study 1 month later. In Figure 6 (subject 13), no significant variation in nasal resistance is demonstrable; therefore, we concluded that this individual had no nasal cycle. This lack of the cyclic pattern occurred in 28% of our subjects.

DISCUSSION

Guillerm and associates in 1967 studied variations in nasal resistance and along with it the nasal cycle by rhinomanometric methods. They were among the first, along with Stoksted (1952, 1953a, b), to recognize that the total nasal resistance remains fairly constant despite the alternating congestion/decongestion of each side. The normal person does not complain of the subjective sensation of increased nasal resistance, because the total nasal resistance is lower than that of either one of the individual sides and remains steady. This observation was also made by Spoor (1963, 1965). Our studies confirmed these observations and substantiated the finding that the total nasal resistance is less than that of either one of the individual sides (see Figures 3 through 6).

We demonstrated the presence of a nasal cycle (defined by rhinomanometric standards as suggested under "Results") in 72% of the 50 subjects tested. It is interesting that these findings are consistent with those of Heetderks (1927), who estimated that the nasal cycle was present in approximately 80% of individuals after his direct observation in the early part of the 1900's. Flottes and associates, according to Williams (1972), noted the presence of the nasal cycle in 80% of 25 persons tested. It is interesting that the older subjects had lower resistance values. Perhaps one may speculate that the activity of the nasal mucosa decreases with age. The data strongly suggest that older subjects – more than 40 years old – have a longer nasal cycle.

The nose may be thought of as a set of parallel resistors. The formula for calculating total resistance is

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}\text{; therefore, } R_T = \frac{1}{\dfrac{1}{R_1} + \dfrac{1}{R_2}} \text{ or } R_T = \frac{(R_1)\,(R_2)}{(R_1 + R_2)}.$$

It is a simple matter to calculate nasal resistance by dividing the product of the right-sided and left-sided resistances by the sum of both resistances. For example, with a resistance on the right side of 4 cm/liter per second and a resistance on the left side of 2 cm/liter per second, the total resistance is the product of 2 and 4 which is 8, divided by the sum of 4 and 2 which is 6. Therefore, the total nasal resistance is 1.3 cm/liter per second, which is, of course, less than that of either of the individual sides. Functionally, it is the total nasal airway resistance that is the most important, and it would seem that the work of respiration would be less while breathing through both sides of the nose than while breathing through either the right or the left side.

Based on our rhinomanometric definition, we did not find the presence of a discrete cycle in 14 subjects (28%). There seemed to be three separate categories of subjects who had no cycles: one in which the right and left sides overlapped and neither side fluctuated, a second in which no fluctuations were noted on one side whereas there was a fluctuation on the opposite side, and a third in which there was fluctuation in nasal resistance on both sides which seemed to be in concert but without reversal or changes in dominance from one side to the other.

Keuning (1968) studied 17 men who were in their twenties and had rhinoscopically normal noses. He found that there were regular cycles in seven subjects which ranged from 2 to 7 hours. He also noticed that there were no reversals in patency, changes in dominance, or reversal in the nasal cycle in six subjects, and he further noted that there were regular cycles in four. He reported that the total nasal conductance (the inverse of resistance) remained essentially constant whether regular cycles, irregular cycles, or no cycles were present.

The mechanism by which the nasal cycle is controlled remains an enigma, for it is perhaps no better understood today than when Kayser first described it in

1895. He suggested that there was a dynamic shifting in the autonomic balance between the nasal chambers which allowed a constant change in blood flow to the erectile tissues of the turbinates and septum and thereby effectively caused a change in the uninasal resistance. It is known, however, that the nasal cycle is not present on a sympathetically denervated side (Horner's syndrome), but it may be present on a parasympathetically denervated side, according to Keuning (1968). Investigations have recently been carried out on pigs by Eccles and Maynard (1975) and Campbell and Kern (unpublished data). Because these investigators found that a nasal cycle does indeed exist in pigs, perhaps some day the questions about the function and control of the nasal cycle will be answered from studies in these animals.

There can be no doubt that our observations substantiate the existence of a nasal cycle and that fluctuation in nasal airway resistance is a normal physiologic phenomenon. We conclude that the nasal airway constitutes a dynamic, living, functioning organ. Biology is marked by variations among "normal" subjects and so it is in the case of the dynamics of the nasal cycle. Changes in uninasal resistance do not alter the total nasal airway resistance in a normal subject. This is a fascinating finding, which may have teleologic implications. Certainly, continued investigation in the development of more practical methods of studying nasal respiratory physiology is required before a more complete picture of nasal respiratory functions can be drawn.

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