INFLUENCE OF NOZZLES ON PRESSURE AND FLOW MEASUREMENT STUDIED BY MEANS OF THE ARTIFICIAL-NOSE AND THE CONDUCTIVITY-METER

Tomio Nakano, M.D.*

Introduction

Experimental investigations on nasal resistance were first done by Goodale (1896) (1). Many others, among them Zwaardemaker (1905) (2), Mink (1920) (3), van Dishoeck (1935) (4), Uddströmer (1940) (5), Stoksted (1952) (6), continued these studies. Recently in the Leyden Clinic, Keuning (1963) (7), and Spoor (1963) (8) have done important work.

Cottle (1958) (9) stated that the human respiratory system is unique anatomically and physiologically in that it regulates the nasal resistance in the fast varying respiratory depth by means of pulmonary reflexes. Attempts have been made to evaluate the part played by nasal chambers and valves in total nasal resistance. So in 1942, van Dishoeck (10) stated that the resistance in the wide nose is not caused by the conchae but exclusively by the ostium internum, whereas in the narrow nose the resistance of the conchae is predominant (II). Thus in the vast varying conditions of nasal patency an occasionaly evaluation is meaningless.

The resistance in the nasal air-pathway is caused by the nostril, vestibulum and chamber. In order to investigate the relationship between these structures, manometers, flowmeters and pressure transducers must be connected to one or even both nostrils by means of some kind of nozzle, in order to measure the nasopharyngeal pressure (resistance) while breathing with a certain ventilation (flow).

The pharyngeal pressure is measured through one nostril while the patient breathes through the other. In this case the size of the nozzles is of no importance as long as the other — active — nostril and valve are not distorted. In this arrangement the nasopharynx is connected to the manometer by a "canal" consisting of the nasal chamber, the nozzle and the tubes leading to the manometer. The diameter of these canals is of no importance, as there is no flow through them, but only transmission of pressure.

However in measuring flow, the diameter of the nozzle and tubes is highly important, as any obstruction in the connecting system will give an additional resistance.

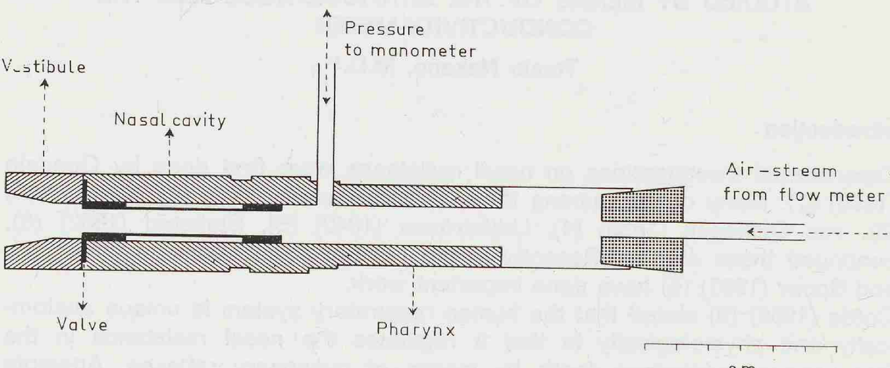
The purpose of this study is to find out experimentally which size of nozzle should be used.

---

* From the Department of Otorhinolaryngology, Faculty of Medicine, University of Leyden, Holland (Head: Prof. Dr. H. A. E. van Dishoeck).

Method

In test persons the swelling of the turbinates and the pulmonary ventilation is ever changing and consequently the resistance we measure often varies considerably from one moment to the other. Thus an artificial nose was used in order to achieve constant experimental conditions.
The artificial nose consisted of 3 parts (Fig. 1 a and b):



Scheme of the Artificial Nose

Figure 1a.

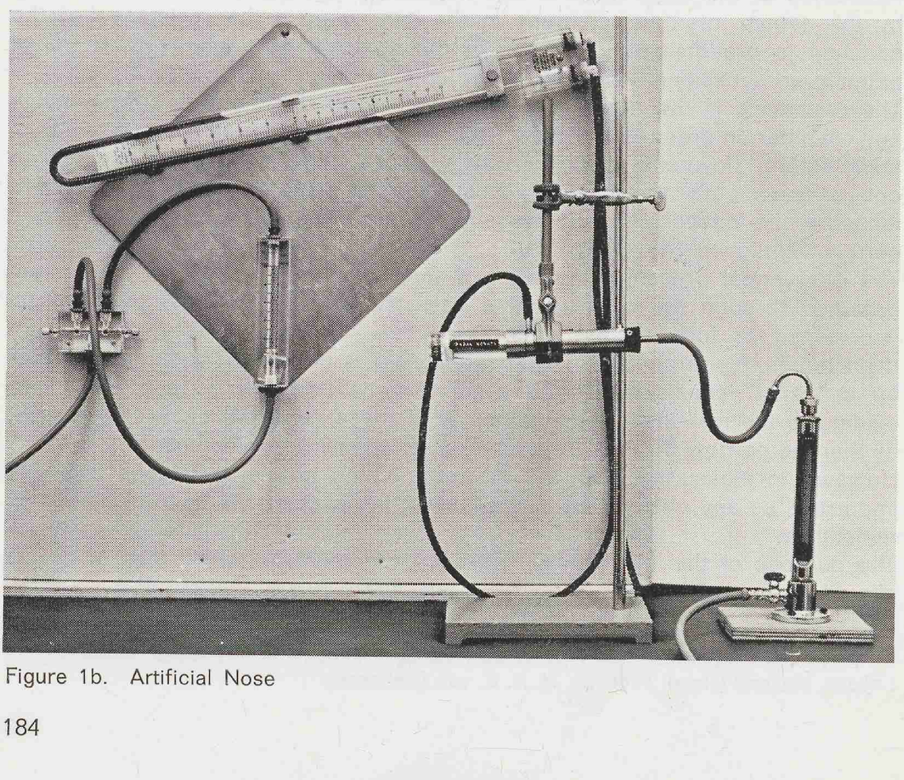


Figure 1b. Artificial Nose

A. The nose model which consists of;

I. a nasal chamber, with interchangeable tubes of different diameter, simulating the space between the turbinates;

II. in front of these metal discs with holes of different sizes simulating the valves;

III. a funnel shaped vestibulum:

The diameter of the artificial nasal chamber varies between 3.0 mm (surface 7.0 mm^2), 8.0 mm (surface 50.3 mm^2) and, 10.0 mm (surface 78.6 mm^2), the diameter of the opening of the artificial valves also varies between 3.0 mm (surface 7.0 mm^2), 8.0 mm (surface 50.3 mm^2), and 10.0 mm (surface 78.6 mm^2). By combining nasal chambers and valves of varying sizes, all kinds of noses can be expressed in the hydraulic radius (round tubes and openings) according to the formula:

$$Rh = 2 \frac{O}{F}$$

in which Rh is the "hydraulic radius" of the calculated round cross-section used in the artificial nose, 0 the irregular cross-section and F the circumference of this cross-section.

B. The airstream, which is blown into or sucked through the model and is measured by a flow meter immitates expiration and inspiration.

C. A sensitive manometer measures the resulting nasopharyngeal pressure. For this purpose a side-tube is mounted on the artificial nasopharynx.

In order to study the influence of nozzles on the pharyngeal pressure, the flow and the conductivity of the system, the conductivity-meter developed by Spoor (12) was used (Fig. 2).

In this device two strain-gauge electric transducers are built in. It records pressure and flow, making the division of these valuues such, that the conductivity curve is obtained. Conductivity is defined as the charged air volume in ccm per second, at a pressure of one cm of water, and is recorded

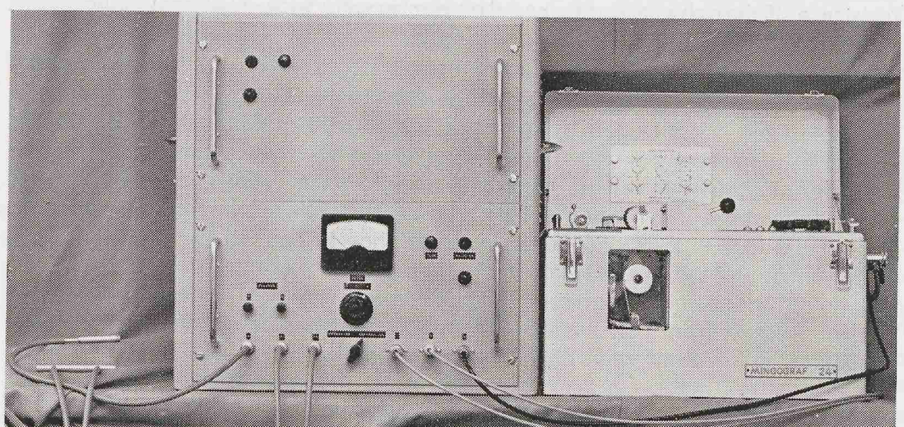


Figure 2. Conductivity-meter of Spoor connected to Mingograf-24 (on the right side) and to the nose (on the left side). Conductivity flow and pressure are recorded separately in three channels.

on paper of Mingograf-24 (Elema, Jarnh, Stokholm, Sweden). The measuring range for pressure is from 0 to 4 cm of water and for flow from 0 to 400 ccm/sec. In this apparatus the pharyngeal pressure is connected to one electric transducer, whereas the flow coming out of the nozzle is connected to the other transducer.

Results

I. The influence of different combinations of nasal chambers and valves on the pharyngeal pressure during a constant flow was studied. At a constant flow of 5L/Min. through the artificial nose, the changing patency of the nasal chambers in correlation with different sizes of valves was studied by reading, on a manometer, the pharyngeal pressures (Table I).

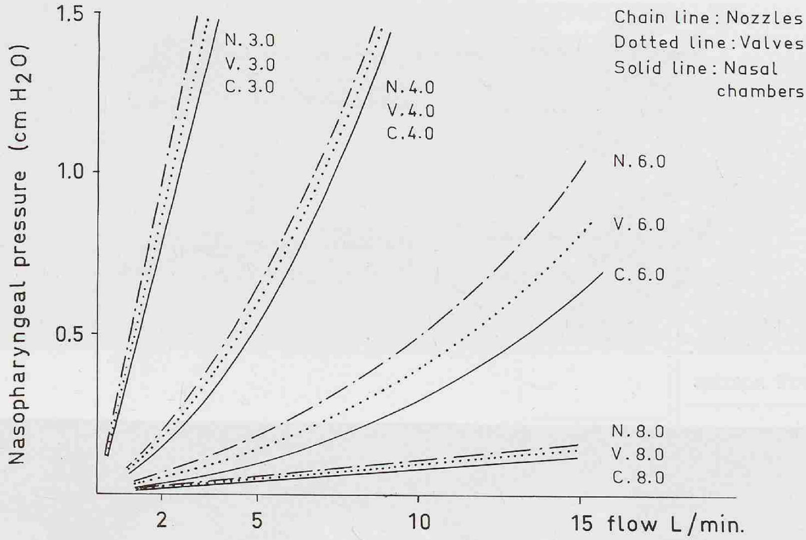
Chambers in mm		3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
Valves in mm					diameter				
					Control of valve				
3.0	Control of chamber	3.2	2.4	2.2	2.1	2.1	2.1	2.2	2.2
4.0		3.1	1.2	0.7	0.6	0.6	0.6	0.8	0.8
5.0		3.1	1.2	0.4	0.3	0.3	0.2	0.3	0.3
6.0		3.1	1.1	0.4	0.2	0.1	0.1	0.1	0.1
7.0		3.1	1.1	0.3	0.2	0.1	0.05	0.05	0-0.05
8.0		3.0	1.0	0.3	0.2	0.05	0.05	010.05	0-0.05
9.0		3.0	0.9	0.3	0.1	—	—	—	—
10.0		3.0	0.9	0.3	0.1	—	—	—	—
							(cm of water)		

Table 1. Combination of nasal chambers and valves and resulting pharyngeal pressure at a constant flow 5 L/Min. during simulated exspiration through the artificial nose. The highest resistance (3.2 cm of water) in measured when a very narrow chamber and valve (3 mm diameter) are combined. Here the friction in the chamber increases resistance. If the valve is narrow and the chamber very wide, resistance is somewhat higher, probably due to turbulence.

From table I it appears that if the nasal chamber is narrower than the valve, the resistance is controlled by the nasal chamber. So if the nasal chamber is 3 mm in diameter, the resistance is ± 3 cm of water, regardless of the diameter of the wider valves. The same holds for the valve if it is narrow, and if the chambers are wide. Consequently these experiments support the hypothesis that in the wide nose the resistance is caused by the valves and in the narrow nose by the turbinates.
On doing the same experiment with different flows it appeared that high pressure result from narrow nasal chambers and narrow valves and that low pressures result from wide chambers and wide valves (Fig. 3).

II. The nozzles

Nozzles (fig. 4) can be divided into:
1. Nostril nozzles: balloon shaped with controlled opening. They are mounted on a metal tube, which is applied by the patient with a slight pressure to the



Relationship between flow and pressure in the artificial nose (expiration). Hydraulic diameter in mm.

Figure 3. Pressure measured in narrow and wide valves and chambers at different flow-rates on the artificial nose.

outside of his nostril. Our standard nozzle is a wide nozzle of 10.0 mm in diameter.

2. Vestibulum nozzles (oval cone-shaped), which are introduced into the vestibulum of the patient. They may distort the valve.

3. Rim nozzles (shape of nostril with rim), which are introduced for ± 2 mm without distorting the valve.

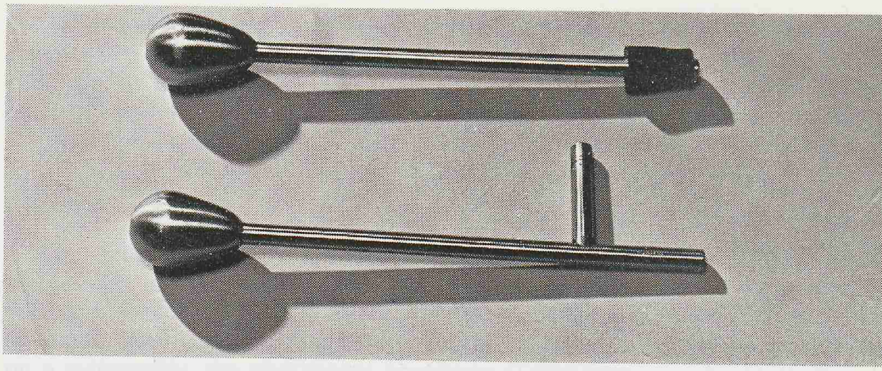
These different nozzles in varying sizes are compared with our standard nozzle with an opening of 10 mm, which measures the conductivity up to 400 ccm/sec. and one cm of water without increasing the resistance. In most patients this is satisfactory; only in very wide noses (Ozena) should a wider nozzle be used. The properties of nozzles are determined mainly by their orifices but also by the connecting tubes.

By means of the artificial nose the influence of the nozzle on the pharyngeal pressure (resistance) was studied by simply applying the nozzle to the nostril of the artificial nose, simulating what we do in our patients.

III. Orifices of nostril nozzles and the correlation between conductivity, flow and pressure.

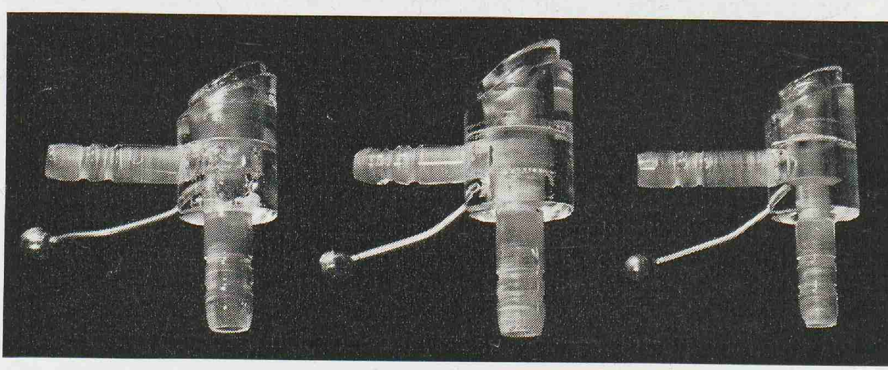
In a first experiment we compared a common nostril with the standard nozzle of the conductivity meter. The opening of a common type nozzle was 5 mm in diameter. Experiments were done with a flow of 10 L/Min. It appeared from these experiments that with an orifice of 5 mm, a considerable resistance was introduced, especially when measuring a wide nose (Fig. 5).

On comparing a wide nostril nozzle (8.0 mm) to a narrow nozzle (3.0 mm) it was seen that the narrow nozzle introduced into the wide nose gave a



Nostril nozzles

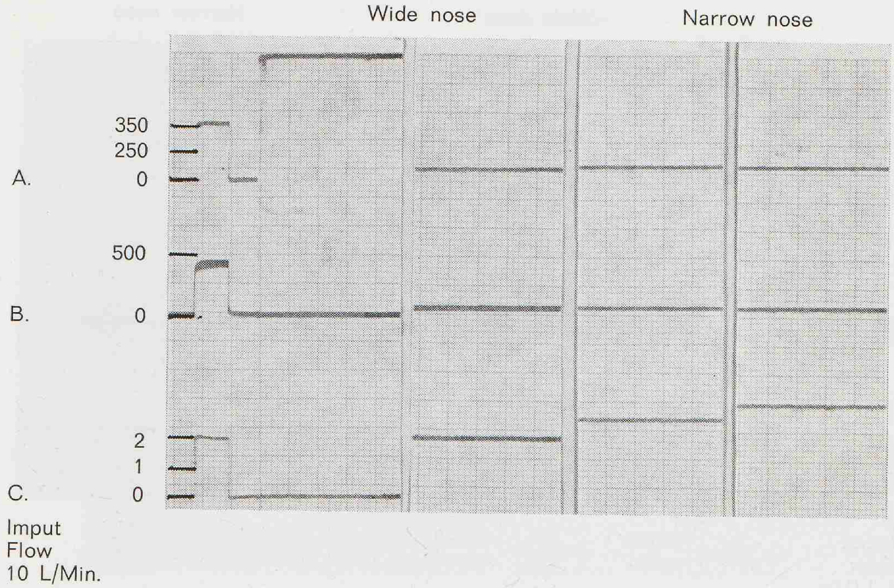
Vestibulum nozzles



Rim nozzles with side tubes (for measuring the inflow resistance)

Figure 4. Different kind of nozzles.

resistance which was highly siginificant. Indeed with such a narrow nozzle the resistance measured was not of the nose but in fact of the nozzle. In the narrow nose this objection is not so important. So in this case with a wide nozzle the actual resistance was measured and with a narrow nozzle the



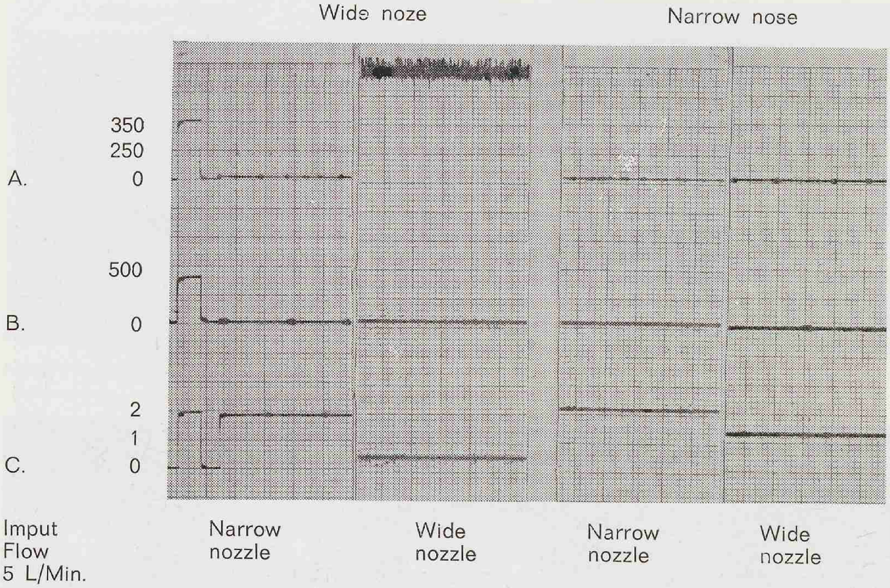
A. Conductivity : flow by 1 cm of pressure in ccm/sec
B. Flow : in ccm/sec by actual pressure
C. Pressure : in cm water

Figure 5. Correlation between pressure and conductivity when measured with the standard nozzle and a common nozzle in the wide and narrow nose.
1. Wide nose, standard nozzle: pressure at base line-conductivity maximum.
2. Wide nose, with 5 mm nozzle: pressure increased (2.0)-conductivity very low.
3. Narrow nose, standard nozzle: pressure increased (3.3)-conductivity low.
4. Narrow nose, with 5 mm nozzle: pressure high (3.7)-conductivity low.
Conclusion: the nozzle alters the conductivity significantly especially in the wide nose.

measured resistance proved to be only slightly different from this actual resistance (Fig. 6).
The conclusion is that a nozzle can only measure the conductivity of noses, which are the same or narrower than the opening in the nozzle. It does not matter if the narrow place of the nose is located in the nasal chamber or in the valve. The narrowest place will control the resistance, provided that the opening of the nozzle is not narrower than the hydraulic diameter of this place. According to our experiments the best opening for the nostril nozzle should be 8 mm in diameter (surface 50 mm^2).

IV. Vestibulum nozzles

The main objection against the use of vestibulum nozzles is that they disturb the size of the vestibulum. Consequently, experiments on the rigid artificial nose are not conclusive. For this reason tests were performed on test-persons. The vestibulum nozzles we used have openings from 25 to 80 mm^2; behind the opening they are of the same size. As they are oval-shaped the corresponding round hydraulic opening is somewhat smaller.
In these observations the same set-up was used as for the nostril nozzles. On



A. Conductivity : flow by 1 cm of pressure in ccm/sec
B. Flow : in ccm/sec by actual pressure
C. Pressure : in cm water

Figure 6. Influence of the width of different nozzles on conductivity, flow, and pressure in the wide nose and the narrow nose. Wide nasal chamber 8.0 mm. Narrow nasal chamber 4.0 mm. Diameter of the opening of the nozzles 4.0 and 8.0 mm.

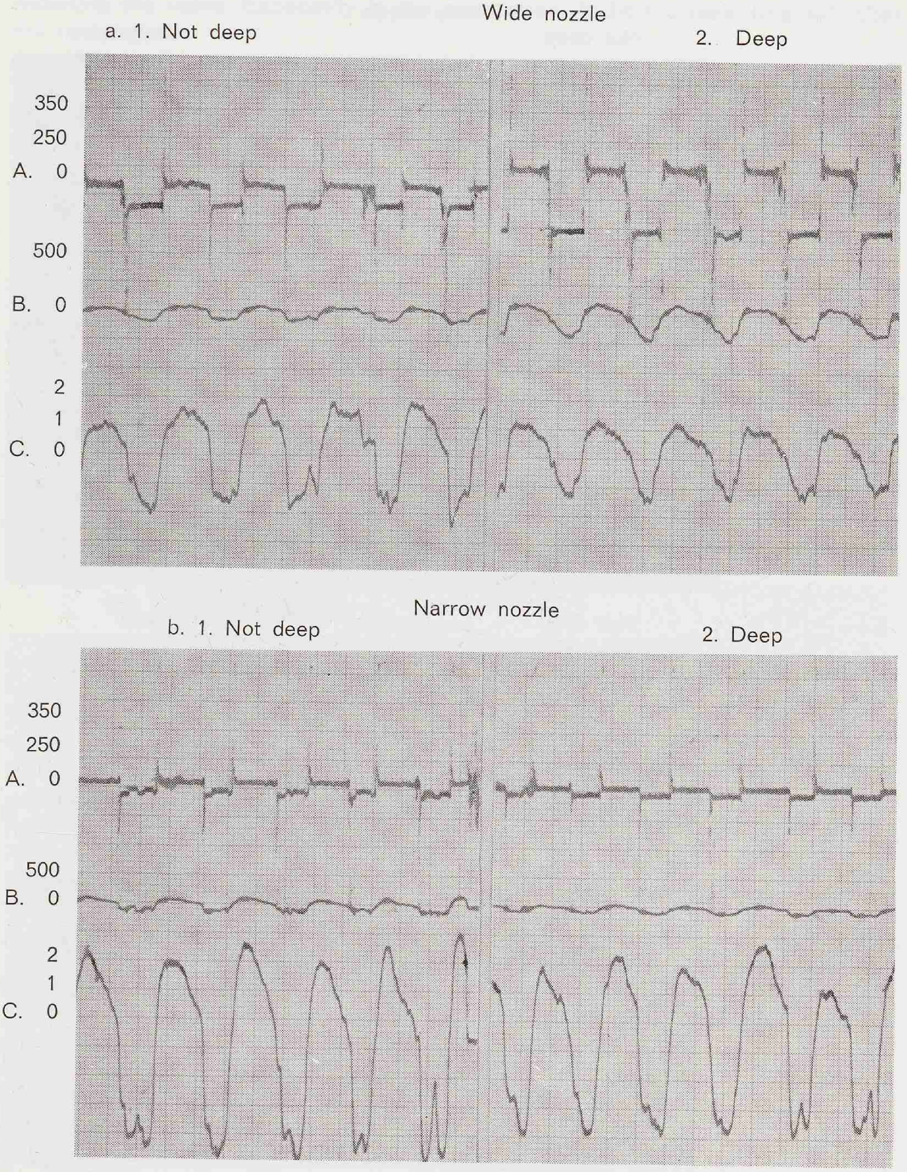
doing this, curves were obtained on in-and expiration. The values proved to be distinctly different for wide nozzles (8.0 to 10.0 mm) and narrow nozzles (3.0 to 6.0 mm).
Here again the optimal width of this kind of nozzles proved to be $\pm$ 50 mm^2. This is in agreement with the width we recommended for the opening of the nostril nozzles and also approximately the same width as of the normal valves.

V. Rim nozzles

The same holds for the rim nozzles. They can be listed as nostril nozzles, as the nostril supports the rim, being of the same size. They are only introduced for about 2 mm into the vestibulum. They are wide and have a diameter of 6-7 mm.

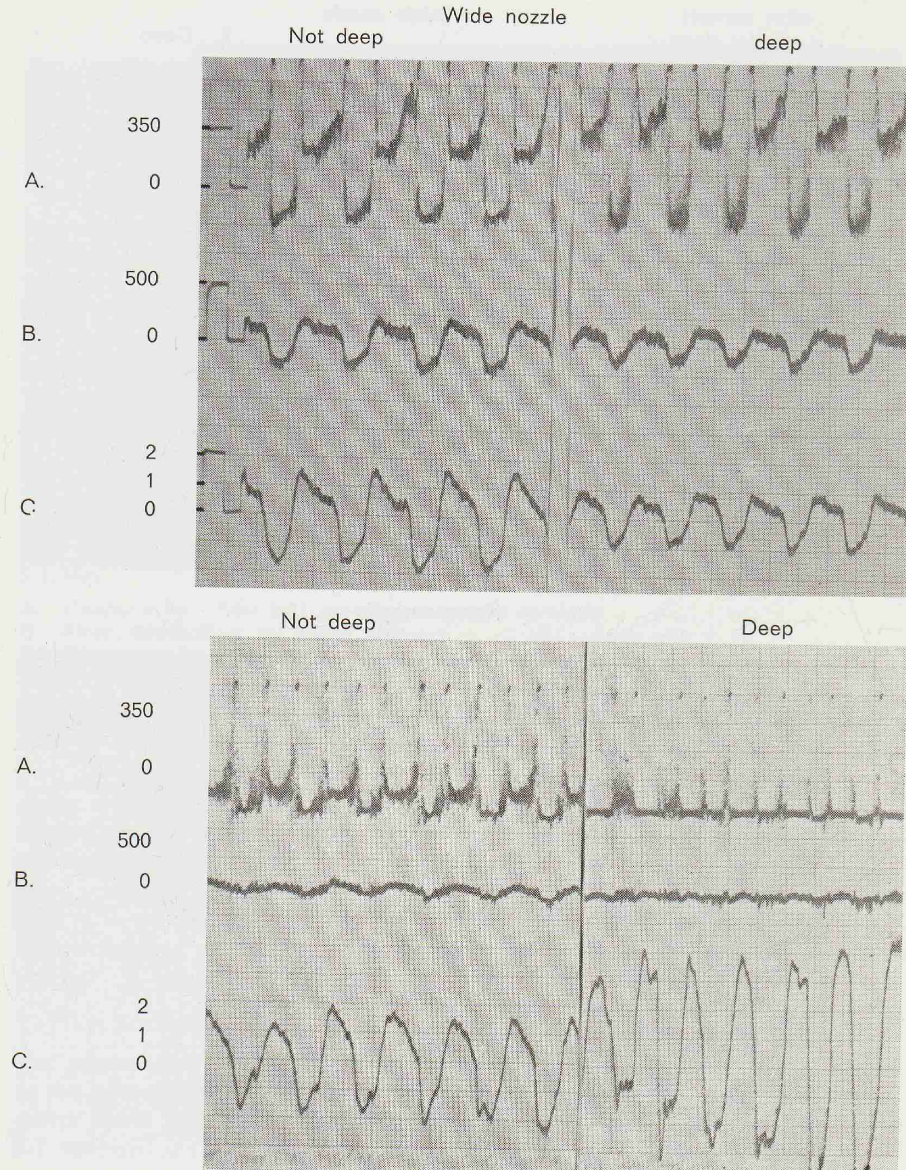
VI. Vestibulum nozzles and the valve

We mentioned above the fact that the introduction of these nozzles into the nose of patients might distort the valve area, especially if they are small and are introduced deeply.
In this case they will reach the cul de-sac and consequently they might press the upper lateral towards the septum narrowing the ostium. They might also extend the vestibulum and pull the upper lateral away from the septum, thus



A. Conductivity : flow by 1 cm of pressure in ccm/sec
B. Flow : in ccm/sec by actual pressure
C. Pressure : in cm water

Figure 7. Influence of a wide and a narrow vestibulum nossles on nasal resistance
a. 1. wide nozzle (80 mm^2), not deep.
2. same nozzle, deep.
b. 1. narrow nozzle (25 mm^2), not deep.
2. same nozzle, deep.
The resistance was decreased when nozzles inserted deeply.



A. Conductivity : flow by 1 cm of pressure in ccm/sec
B. Flow : in ccm/sec by actual pressure
C. Pressure : in cm water

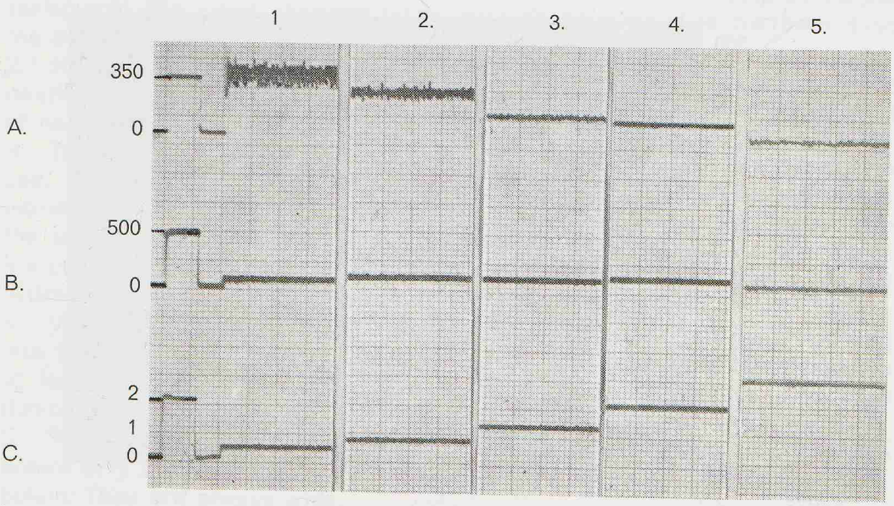
Figure 8. Influence of the insertion of a vestibulum nozzle on nasal resistance after spraying adrenaline and histamine.

1. wide nose, wide nozzle, not deep. After adrenaline spraying.
2. wide nose, wide nozzle, deep. After.
3. wide nose, wide nozzle, not deep. After histamine spraying.
4. wide nose, wide nozzle, deep. After.

widening the valve. Especially in the wide nose, in both cases, this will alter the resistance.
A wide nozzle will extend the vestibulum thus diminishing the resistance. Again in the wide nose this effect will be more clearly seen. This hypothesis was experimentally verified on test persons. For this experiment again vestibulum nozzles of different surfaces are used (Table 2).

Surface (mm^2)	Not deep Pressure difference		Deep Pressure difference	
25	3.0	3.8	2.3	3.1
43	2.2	3.1	2.0	2.5
50	2.0	2.6	1.8	2.3
66	1.7	2.3	1.5	2.0
80	1.5	1.8	1.2	1.4
				in cm H_2O

Table 2. Correlation of the width of vestibulum nozzles inserted not deeply and deeply on nasal resistance in test persons.



Imput
Flow
5 L/Min.

A. Conductivity : flow by 1 cm of pressure in ccm/sec
B. Flow : in ccm/sec by actual pressure
C. Pressure : in cm water

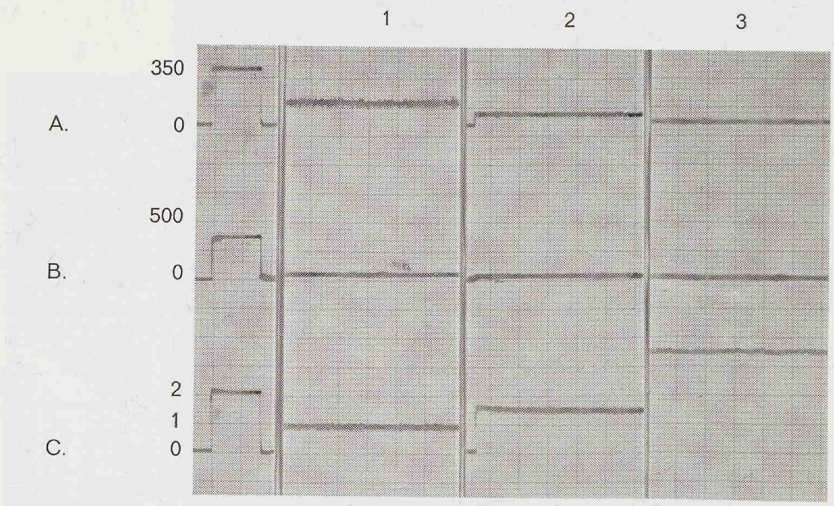
Figure 9. Influence of the length of the tubes wide opening (10 mm) of nozzle with tube (10 mm) of:
1. 20 cm
2. 100 cm
3. 300 cm
4. 600 cm
5. 20 cm (4.0 mm in a diameter)

Conclusion: The characteristic findings were present in all cases. The conductivity was remarkably high, low pressure at the length of 20 cm. The conductivity was low (200) and, pressure high (2.0) at the length of 600 cm.
At the narrow width (4.0))of the tube was the most high pressure (2.8).

It apeared that the narrow nozzle (25 mm^2), if introduced not too deeply, increases the resistance as compared to the wide vestibulum nozzle (80 mm^2). If the nozzle is introduced deeply, the resistance is decreased, indicating that the valve is somewhat opened. The same holds for the wide nozzle. (Fig. 7).

VII. Influence of adrenaline and histamine on nasal resistance

Spraying of adrenaline into a normal nose causes a considerable decrease of resistance. This also holds for a narrow or a wide nozzle. In these experiments the difference between an oval nozzle being inserted deeply or not deeply, is remarkable. In adrenalized noses deep insertion lessens the resistance and increases the conductivity. This might be due to the opening of the valve, which in this case controls the resistance — the nasal chamber being wide.
In the histaminized nose, on the contrary, deep insertion lowered the conductivity and increased the resistance, perhaps because the nozzle is pressed against the swollen turbinate (Fig. 8).



Imput
Flow
15 L/Min.
Length of the tubes 1 m

A. Conductivity : flow by 1 cm of pressure in ccm/sec
B. Flow : in ccm/sec by actual pressure
C. Pressure : in cm water

Figure 10. Correlation nozzle and tubing

1. wide opening of nozzle and wide tube (10.0 mm). low pressure, conductivity 230
2. narrow opening of nozzle and wide tube, medium pressure (1.4), conductivity 150
3. narrow opening and narrow tube (6.0 mm), high pressure (3.4), low conductivity, length of the tube 100 cm.

Conclusion: cross-section should be above 50 mm^2.

VIII. The tubing behind the orifice of the nozzle and the correlation between conductivity, flow and pressure.

The influence of the length and width of the tube was determined by connecting the standard nozzle to the conductivity meter. It was obvious that a tube of 6 M, 3 M, 1 M as compared with a tube of 0.2 M decreased the conductivity and increased the pressure (Fig. 9). The differences are comparatively small. This is in accordance with the law of Porseuille.

Of course, the width of the connecting tube is highly important. It was demonstrated that the resistance was increased in proportion to the width of this diameter (fig. 10).

Consequently the connecting tubes should be of the same diameter as the orifice of the optimal nozzles.

SUMMARY

From experiments by means of the conductivity-meter on the artificial nose and on test-persons, we concluded that:

1. If the nasal chamber is narrower than the valve (ostium internum), the chamber controls nasal resistance. The reverse is true if the valve is the narrowest place. So in the wide nose the size of the valve determines the resistance. The nasal chamber takes over as soon as it is narrower than the ostium (valve).
2. Nozzles can be divided into nostril nozzles, vestibulum nozzles and rim nozzles. They have their own special properties in relation to the measurement of nasal resistance.
3. The orifice of the nostril nozzle is highly important. Of most nozzles in use, the orifice is so narrow, that an additional unwanted resistance is introduced. Nozzles can only measure the resistance of noses, which are the same or narrower than the opening of the nozzle. The best opening is 8-9 mm in diameter, which corresponds to a surface of 50-65 mm^2 being the hydraulic cross-section of the normal internal ostium (valve).
4. Vestibulum nozzles are oval and cone-shaped. They can be introduced into the vestibulum more or les deeply. Their hydraulic diameter should be at least 8 mm. If they are introduced deeply they extend the valve thus diminishing the resistance in the wide nose.
5. Rim nozzles have the size of the orifice of the vestibulum and their rim enters only 2 mm. Thus they adapt perfectly without distortion of the vestibulum. They are always wide.
6. In the adrenalized nose the opening of the valve by inserting a vestibulum nozzle deeply is remarkable. On the contrary, in a histaminized nose under this condition the resistance increases. This is probably due to the pressure of the nozzle against the swollen turbinate.
7. The tubes which connect the nozzles to the apparatus also introduce resistance according to the law of Poiseuille. So the tubes should be as short as possible and their cross-section should be above 50 mm^2.

RÉSUMÉ

Des expérimentations faites à l'aide du mesureur de conductibilité de Spoor sur le nez artificiel et sur le sujet en expérience nous ont fait conclure que:

1. Si la fosse nasale est plus étroite que l'ostium internum, la fosse règle

la résistance nasale. Le contraire vaut si l'ostium internum est l'endroit le plus étroit. Donc dans le nez large la dimension de l'ostium détermine la résistance, tandisque la fosse nasale la détermine dès qu'elle est plus étroite que l'ostium.

2. Les applicateurs nasals doivent être divisés en: becs nasals, vestibulaires et de bord. A l'emploi ils ont leurs propres qualités particulières à l'égard du mesurage de la résistance nasale.

3. L'ouverture du bec nasal est hautement importante. De la plupart des becs en usage elle est tellement étroite qu'une résistance additionelle et indésirable est introduite. Les becs ne peuvent que mesurer la résistance des nez, qui sont pareils ou plus étroits que l'ouverture du bec. La meilleure ouverture mesure 8-9 mm en diamètre, correspondant à une surface de 50 mm^2, qui est la coupe en travers hydraulique de l'ostium interne.

4. Les becs vestibulaires sont en forme ovale et conique. Ils sont introduits dans le vestibule plus ou moins profondément. Leur diamètre hydraulique devrait être au moins 8 mm. S'ils sont introduits profondément, ils étendent l'ostium interne, ce qui diminue ainsi la résistance dans le nez large.

5. Les becs de bord ont la dimension de l'ouverture du vestibule et leur bord n'entre que 2 mm. Donc ils s'adaptent parfaitement sans contorsion du vestibule. Ils sont toujours larges.

6. Dans le nez adrénalisé l'ouverture de l'ostium, en insérant profondément un bec vestibulaire, est remarquable. Mais dans le nez histaminisé dans cette condition l'augmentation de la résistance est probablement due à la pression du bec contre le cornet gonflé.

7. Les tuyaux qui attachent les becs à l'appareil introduisent aussi de la résistance, d'après la loi de Poiseuille. Alors les tuyaux devraient être le plus court possible et leur coupe en travers devrait mesurer plus de 50 mm^2.

REFERENCES

1. Goodale, J. L.: An Experimental Study of the Respiratory Function of the Nose, Boston M. & S. J. 135: July, Dec. 1896. pp. 457-487.
2. Zwaardemaker, H. & C. D.: Ouwehand: Die Geschwindigkeit des Atemstromes und das Atemvolumen des Menschen. Onderz. ged. in Physiol. Laborat. d. Utrecht. Holland. Hoogesch. Vol. 5.1905. p. 250.
3. Mink, P. J.: Physiologie der oberen Luftwege, Leipzig, 1920.
4. v. Dishoeck, H. A. E.: Infra-Red Radiation and Nasal Obstruction, The Journal of Hygiene. Vol. XXXV. No. 2.4. June. 1935. pp. 185-198.
5. Uddströmer, M.: Nasal Respiration, A New Method of Diagnosis, Acta Oto-Laryngologica, Suppl. XLII. 1940. pp. 51-76.
6. Stoksted, P.: Rhinomanometric measurements for determination of the nasal cycle. Acta Oto-Laryngol. Suppl. 109. 1952. pp. 159-175.
7. Keuning, J.: Le cycle nasal. Int. Rhinol. I. (I). 1963. p. 57.
8. Spoor, A.: Aerodynamics, Intern. Rhinology. I. 1963. p. 19.
9. Cottle, M. H. et al: Correlating Nasal Examination with Respiratory Tract Function, Illinois State Medical Society, May. 1958. American Medical Association, June, 1958.
10. v. Dishoeck, H. A. E.: Inspiratory Nasal Resistance, Acta Otolaryngologica, Vol. XXX. Fasc. 5. 1942. 00.431-439.
11. v. Dishoeck, H. A. E.: The Part of the Valve and the Turbinates in total Nasal Resistance. Int. Rhinol. Vol. III. No. I. Jan. 1965. pp. 19-26.
12. Spoor, A.: A New Method for Measuring Nasal Conductivity, Int. Rhinol. Vol. III. No. I. January. 1965. pp. 27-35.

Tomio Nakano, M.D.,
Kamiyama-cho, Kitaku,
City of Osaka, Japan.