The function of the nose in the aerodynamics of respiration

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SUMMARY

Resistance in the upper airway (Ra) is needed to maintain a sufficient Functional Reserve Capacity of the lung (FRC) and to build up a sufficient counterforce against the by a surfactant already lowered surface tension in the alveolar system. The Ra, when breathing through the nose is about 2.8 cm H_2O/LPS. Half of the resistance is supplied by the nose. The significance of the nose in this recpect lies in the fact that the nose forms an useful "additive resistance" in the total Ra. Adult persons need the physiological airway resistance of the nose especially in rest. In mouth-breathing forced by an obstructed nose, the breathing becomes deeper. In this larger breath excursions the mass of displaced air and the increased caused by the faster transport of air form a sufficient counterforce against the forces of the surface tension. Slightly exaggerated, one could say that the nose is more useful during sleep than when one is awake.

Especially acute obstruction (causing mouth breathing) or widening gives complaints. In the long run a compensation sets in by the augmentation of resistance in the mouth-lung part of the airway, when the obstruction is constant. When the obstruction is intermittent, a sufficient Raml cannot be built up and the patient remains shortbreathed. The lower the Raml is, the more complaints the patient has.

OBVIOUSLY, the nose has a function in the aerodynamics of breathing: an obstructed nose is felt as an annoying hampering of the breathing, especially if the obstruction is acute.

The question why this is so, has not been answered satisfactorily up till now. For always the fact remains that one can breathe just as easily through the mouth only, which is seen in patients with a chronically obstructed nose. They don't seem to be seriously hampered by it. So this function of the nose seems at first not entirely essential.

To answer the question: why is, from an aerodynamical point of view nose-breathing preferable to mouth-breathing?, we must concentrate on three phenomena, known to every rhinologist:

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1. An acutely obstructed nose is the more troublesome the less the person in question exerts himself. When walking or mountaineering, there is no difficulty while when in rest (sleeping or sitting) the obstructed nose is most annoying.
2. Too wide a nose, especially if the widening suddenly takes place, gives the same complaints as an obstructed nose.
3. Persons with a totally obstructed nose often have no more complaints about obstruction in the long run.

If these three phenomena can be accounted for, we are nearer to the solution of the problem.

SOME FACTS FROM THE PHYSIOLOGY OF THE LUNG

a. In adults the total respiratory epithelium, consisting mainly of the alveolar layer, must have an area of about 800.000 cm^2 to guarantee a sufficient gas-exchange. This can only be achieved if the alveolar ducts and the alveoli to some extent remain expanded by the fact that the lungs remain filled with air to a

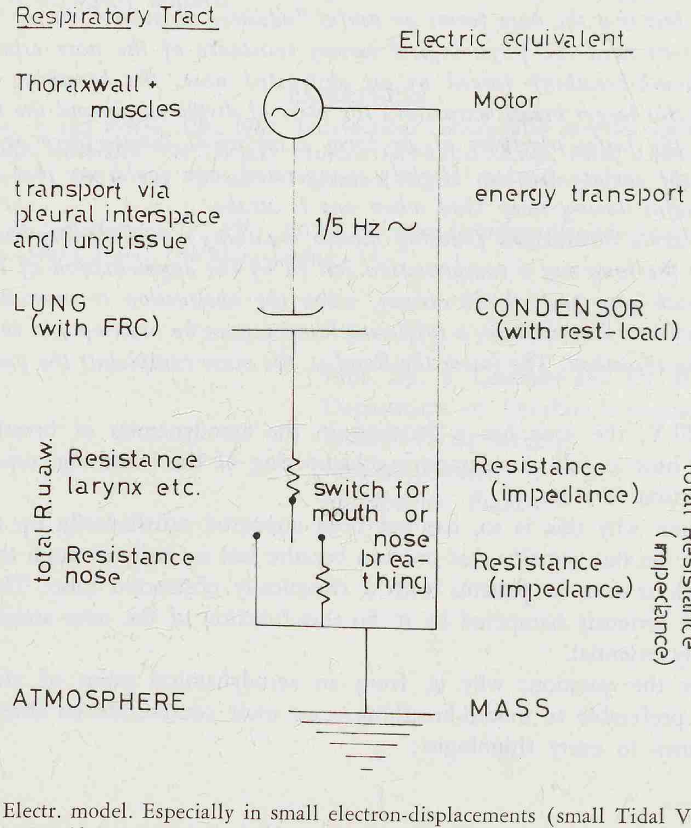

Figure 1. Electr. model. Especially in small electron-displacements (small Tidal Volume) and low frequencies (frequency of breathing) a large resistance to the mass (atmosphere) is required to maintain a sufficient rest-load (FRC) in the capacity (lung).

substantial degree even during expiration: the Functional Reserve Capacity (FRC) of about 2500 cm^2. Generally a rather stiff thoraxwall combined with the effect of the respiratory muscles will be sufficient to "pull open" the alveoli via the virtual intrapleural space and the lung-tissue.
Nevertheless, the airway resistance (Ra) has some influence, even in adults (Fig. 1) The higher the Ra, the bigger the FRC (Comroe and Nolte, 1962). Why this is so, can be demonstrated with the help of an electronic model (Fig. 1b). The greater the resistance to the mass (= atmosphere), the greater the rest-load in the capacity (= the FRC of the lung).
The Ra is indispensable when the muscles are weak and the thoraxwall is flabby, In this case the primary task of the larynx is to trap the air in the lung by closing the glottis. We see this mechanism e.g. in amphibians (Wind). This mechanism may also pay a role in men, especially in weak babies.

b. A relatively small, but regularly present positive pressure is absolutely necessary to prevent the lungs from filling with liquid by the influence of the surface-tension. The surface-tension is reduced by a surfactant but nevertheless always present. Van Neergaard (1929), Clements (1954) and Pattle (1957) were the first who stressed the function of these surface-tension in the lung.

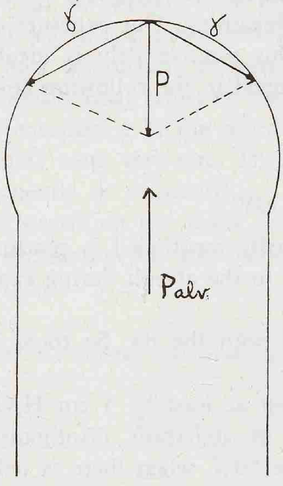

Figure 2. Scheme of alveolus and ductus. Pressure P caused by surfactant forces (γ) has to be neutralized by intra-alveolar pressure (i.e. PTP caused by Ra).

The surface-tension in a liquid lined cavity, here an alveolus, causes an inward directed tension (P) in this cavity if it is segment of a sphere (an alveolus is such segment) the formula $P = \frac{2\gamma}{R}$ (Law of Laplace) holds good. In the formula R = radius of the alveoli = 0.015 cm; γ = the surface-tension per cm. The γ of the alveolus-lining is low and changes between 5 and 40 dyne per cm and is subject to hysteresis. Consequently, this is a more or less changing pressure present in the alveoli, which, if this system is abandonned to its own fate, would effect that the alveoli becomes smaller and would fill themselves with liquid (atelectasis) in spite of the surfactant. To prevent this, an equivalent counterforce is necessary at regular intervals (the alveolar pressure (P alv) during expiration) (Fig. 2). This counterforce can only be furnished if the upper airways have a certain resistance (Ra).

As in all aerodynamic systems, also in the airway system, the law of Ohm holds good, that says the airway resistance is equal to the quotient of the pressure difference and the airstream. In the formula: $Ra = \frac{Palv}{\dot{V}}$

Palv = the difference between the atmosphere pressure and the pressure in the lung:

$\dot{V}$ = airstream in litres per second (LPS).

Ra is either the resistance between mouth and lungs (Raml) in mouth-breathers, or the resistance between the opening of the nose and the lungs (Ranl) in nose-breathers.

Ranl is of course greater than Raml, for in the Ranl the resistance of the nose takes part. This will say, in the formula of Ohm, that to maintain a sufficient Palv by decreasing airstream (LPS), the Ra has to increase. So, specially in shallow breathing a big resistance i.c. breathing through the nose with the help of the additional resistance of the nose (Ranl) is required. Indeed, as we all know, we especially in rest demand nose-breathing. Our exposure concerns especially the positive Palv in expiration. This positive Palv is identical with the positive pulmonary pressure (PTP), mentioned in the following animal experiments.

SOME FACTS FROM THE COMPARATIVE PHYSIOLOGY

The Transpulmonary Pressure (PTP) hence repeatedly mentioned is practically synonym with the positive pressure which is present in the alveoli during expiration in spontaneous breathing.

This pressure again as we have seen, is correlated with the Ra. So there is a positive correlation between the PTP and the Ra.

With dogs the transpulmonary pressure (PTP) must at least be 5 cm H_2O to avoid a decrease of compliance and the forming of atelectasis (Anthonissen, 1964). In rats the compliance is reduced to a more 50% when there is only a pressure of 3 cm H_2O (Williams c.s., 1966). With rabbits a PTP of at least 3½ cm H_2O was necessary under these circumstances. (Hilding, 1958) experimented with calves and rabbits. He too found that a great percentage of these animals developed atelectasis, when brought under narcosis. Williams (1966) and Hilding (1968) both proved that this atelectasis was not caused by tough mucus, but was entirely due to the low PTP, which itself was caused again by the shallow respiration.

Animals with a higher metabolic rate, generally smaller animals, have smaller alveoli to get a greater respiratory surface/body weight ratio. These are the animals

that need a higher PTP to cope with the evidently higher surfactant forces (Clements, 1962).
The smaller the alveoli, the higher the Ra has to be. Small mammals have complicated nose structures with much resistance. They seldom breathe through the mouth. This is only possible in very active breathing (panting). The big and fastly moving airmasses provide in this case a sufficient impedance (= resistance). A dog, when in rest and breathing with open mouth, always pants staccato-like.

THE FUNCTION OF THE AIRWAY RESISTANCE (Ra) ESPECIALLY IN RELATION WITH THE OBSTRUCTED NOSE IN MAN

The introduction of the body-plethysmography made the measuring of the airway resistance much easier and it can nowadays be done on an operational base.
The airway resistance is nearly almost measured in mouth-breathing.
The normal values of this Raml lies between 0.6 cm H_2O/LPS and 2.4 cm H_2O/LPS (average value 1,4 cm H_2O/LPS).
Ogura is one of the very few who measured the airway resistance in nose breathing (Ranl). He found an average value on Ranl = 2,7 cm H_2O/LPS.

OWN INVESTIGATION

In total 30 persons were investigated by body-plethysmography. All 21 patients included in this investigation were completely healthy, except for the occurrence of nose obstruction, so were the 9 persons of the control group. All 30 persons showed normal values of the lung functions (total capacity, vital capacity, residue, Tiffeneautest). In the control group complaints of nose obstruction (e.g. during a cold) were very rare. The 21 patients had complaints of nose obstruction very frequently or constantly.
We stresse on the word *complaints.* Not always the severity of the complaints of obstruction i.c. the feeling of shortness of breath with tendency to panting

Table 1. Airway resistance in the control-group without complaints of nose obstruction.

No.	Name	Sex	Age	Ranl in cm H_2O/LPS	Raml in cm H_2O/LPS
1	J.G.	♂	25	2.4	1.0
2	H.H.	♀	22	2.5	1.1
3	J.H.	♀	23	5.3	1.9
4	Y.M.	♀	21	1.7	0.7
5	E.S.	♂	25	2.6	2.0
6	R.S.	♂	24	3.5	2.2
7	R.V.	♂	27	2.7	1.1
8	F.W	♂	25	2.0	1.1
9	G.W	♂	60	2.1	1.5
average Ranl				2.8	
average Raml					1.4

and an annoying feeling of obstruction, accompanied with or without headache, runs completely parallel with the anatomic findings. Sometimes an anatomic obstructed nose will give no complaints and sometimes there are patients with severe complaints who, at least at the moment of investigation, have a rather patent nose passage.

Table 1 gives the data of the control group of 9 persons. The average value we found for Ra, measured from mouth to lung (Raml) = 1.4 cm H_2O/LPS; for Ra measured from nose to lungs (Ranl) = 2.8 cm H_2O/LPS.

In the control group (table 1) two persons (no. 3 and 6) with an obviously increased Ranl are remarkable. These two persons, however, have a rather increased Raml too. We can suppose that if in these persons the nose breathing is insufficient or becomes insufficient by the whole light disturbances, the breathing con switch over without difficulties in mouth breathing. The average values for Raml and Ranl the whole group are exactly of the same order as mentioned in literature (Ogura c.s., 1971).

Table 2. Airway resistance in patient with constant complaints of nose obstruction.

No.	Name	Sex	Age	Ranl in cm H_2O/LPS	Raml in cm H_2O/LPS
1	W.B.	♂	40	10.0	1.0
2	N.C.	♂	29	3.8	1.4
3	C.M.	♂	15	2.9	1.6
4	A.B.	♂	45	9.4	1.5
5	W.B.	♂	31	4.4	2.5
6	K.D.	♀	27	5.0	1.7
7	D.K.	♀	19	8.5	2.5
8	W.K.	♂	42	4.7	3.0
average Ranl				6.1	
average Raml					1.9

In table 2 the data of our investigations in 8 patients with complaints of constant nose obstruction are mentioned. Six of these eight patients have a Raml that is definitely higher than that the whole group. It is the same group in which the highest values for Raml are found (nrs. 5, 7, 8). One of the group (nr. 2) is a borderline case. Only one (nr. 1) has a definite low Raml. This strong sthenic patient was especially at night extremely hampered by his obstructed nose. This group had obviously built up an higher Raml for compensation. The Raml reaches here the value of 1.9 cm compared with 1.4 cm in the control group and 1.2 cm in the second group, mentioned below. The patients in the investigation of Ogura c.s. (1968) with an average Raml of 2.7 cm H_2O. LPS belonged mainly to this group. We called this group the *"adapted group"*.

The group of table 3 is formed by 13 patients who have severe complaints of obstruction which are, however, more *intermittent*. All patients of this group have a rather low Raml. The average value (1.2 cm) is even lower than the average value in the control group (1.4 cm).

Table 3. Airway resistance in patients with intermittent complaints of nose obstruction.

No.	Name	Sex	Age	Ranl in cm H_2O/LPS	Raml in cm H_2O/LPS
1	E.V.	♀	33	3.1	0.7
2	W.W.	♀	36	2.1	1.1
3	G.H.	♀	37	2.0	0.8
4	C.M.	♀	23	2.9	1.4
5	B.L.	♂	22	3.6	1.4
6	W.G.	♂	19	3.2	1.1
7	K.H.	♂	36	6.2	1.1
8	A.M.	♂	57	3.6	1.7
9	P.P.	♂	28	8.0	1.2
10	J.V.	♂	47	10.0	1.3
11	H.W.	♂	22	2.6	1.4
12	R.O.	♀	30	6.0	1.7
13	H.B.	♂	45	6.0	0.9
average Ranl				4.5	
average Raml					1.2

The intermittent character of the obstruction has obviously prevented to build up a bigger more compensating Raml. Possibly is it just their low Raml which is the cause of the severity of the complaint e.g. lack of breath and a tendency to panting. We called this group the *"not adapted group"*.

When we take the average value of the Raml of the whole group of 21 patients together we see that this value shows but little divergence from that of the control group, respectively 1.5 cm and 1.4 cm. Evidently, the average value of the Ranl in the group of patients is consistently higher (4.5 cm and 6.1 cm) than in the control group (2.8 cm). It is remarkable that in the "not adapted group" some patients have a low Ranl. The cause of this phenomenon will supposedly be the fact that the patients were investigated just at a moment that their noses were not obstructed.

As appears very clearly from the data or Ogura c.s., constant mouth breathers and nose breathers in the long run have the same Ra of about 2.5 cm H_2O/LPS at their disposal (for the respective airways they use). In our opinion this resistance of about 2-3 cm H_2O/LPS is necessary for an optimal functionering of the lungs, especially in the maintaining of the FRC and the regulation of the surface forces (see above).

It is in accordance with this conclusion that Ogura found that when the nose passage had been improved operatively and the resistance of the nose became effective again, the Ra over the distance mouth-lungs decreased after an adaptation period of about 4 months.

DISCUSSION

We will now try to answer the three questions which were put in the beginning:

1. *Why does an acutely obstructed nose cause more complaints during a period of rest?*

The shallower the respiration-excursions, the more a respiratory resistance is needed. In patients with an acutely obstructed nose the nose resistance has fallen off, while the resistance via mouth breathing has not been built up sufficiently yet. The patient is forced to take deeper breaths than is necessary and this gives him a feeling of oppression and sometimes even signs hyperventilation. The greater mass of air and the increase of resistance, caused by this deeper breathing, compensates for the lack of natural resistance.

2. *Why does too wide a nose give the same complaints as an obstructed one?*
The complaints appear especially when the nose is acutely and excessively widened, e.g. in a radical conchotomy. Fortunately ,this operation is relatively rare now compared with earlier days.
In those days it often happened that the patients came back with the same complaints as before, although their noses had been widened. This is quite understandable now, for they are to be compared with patients who are suddenly forced to breathe through their mouths. They too have initially too small a resistance, that must be built up to physiological values elsewhere, especially in the glottis and the pharynx.
Tracheotomized patients seldom have complaints in this field, for the resistance of the cannula with its "edgings" etc., lies in the same order as the nose resistance.

3. *Why persons with a totally obstructed nose often have no more complaints in the long run?*
The long continuous obstruction has allowed these mouth breathers to find a new equilibrium in building up the Raml from 1.4 cm H_2O/LPS normal to a higher value.

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ZUSAMMENFASSUNG

In ihrer Funktion als "Luftzufuhr" ist die Nase vorallem nützlich in ihrem Beitrag am Widerstand in den oberen Luftwegen. Dieser Widerstand, der total ungefähr 2 bis 3 cm H_2O/LPS beträgt, ist notwendig:

1. für die Aufrechterhaltung eines genügenden Luftvolumes (FRC) in den Lungen um eine ausreichende Respirationsoberfläche in den Alveolen sicher zu stellen.
2. als Antagonist der Oberflächenspannungskräfte der Alveolen, die sonst Verkleinerung und Vollaufen der Alveolen (Atelektase) verursachen würden.

Schätzt man die Bedeutung der Nase als Aufbauer eines Widerstandes gut ein, dann werden die Beschwerden von Atemnot bei einer obstruierten Nase besonders einer zu weiten Nase deutlich.

Bei Mundatmung versucht man nämlich den Mangel an Widerstand durch schnelleres, oberflächlicheres Atmen auf zu bauen. (Vergrösserung der Impedanz = Widerstand).

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