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Some physical data about Passive Anterior Rhinomanometry (P.A.R.)

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SUMMARY

The authors studied the physical data of the passive anterior rhinomanometry (P.A.R.). The values obtained from thirty normal test subjects made it possible to make a statistical analysis (ANOVA) of the different variables involved with the P.A.R..
By measuring "Δp" with successively changing flows, it was possible to determine that the airstream was mainly laminar.

In the literature of the past decenia, the importance of functional tests for the upper respiratory tract is stressed. It is amazing to see on one hand, how familiar every physician is with the most sophisticated lung function tests, and on the other hand, how seldom ENT specialists use as a routine nose function tests. Many operations at the level of the nose are performed by ENT specialists, stomatologists and plastic surgeons, without being informed about the permeability of the nose. The aim of this study will be to present a simple method of testing the patency of the nose and to discuss some physical data about this method.

INTRODUCTION

Although most otolaryngologists don't use functional nose tests as a routine, many methods for doing so have been developed.
One can measure the permeability of the nose by active (during active respiration) or passive (without breathing) rhinomanometry, by anterior (at the level of the nostrils) or posterior (at the level of the oro-rhinopharynx) rhinomanometry, by unilateral or bilateral (one or both nostrils) rhinomanometry.
According to Melon (1973) and Kern (1977), advantages of the anterior rhinomanometry (Courtade, 1903; Stoksted, 1953; Cottle, 1960; Guillerm et al., 1960) are:

1. easy and fast to handle.
2. possible with every test subject.

The disadvantages are:
1. possibility of deformation on the internal ostium
2. difficulty in obtaining an airtight seal
3. one can only measure one nostril at the time. The total resistance of the nose wil then be:

$$\frac{I}{R_{tot}} = \frac{I}{R_{left}} + \frac{I}{R_{right}}$$

R_{tot} = total nasal resistance
R_{left} = resistance of the left nostril
R_{right} = resistance of the right nostril

4. measuring only one nostril (the other is plugged off) can alter the respiration, because the patient feels oppressed (dyspneic)
5. not possible to use in cases of septal perforation

The posterior rhinomanometry (Spiess, 1900; Scheideler, 1939; Seebohm et al., 1958) has the following advantages:
1. respects the physiological respiration (no disturbance of the valve area)

The disadvantages on the other hand are:
1. impossible to perform with all test subjects (25 to 50% failure)
2. with this method it is impossible to measure the nasal cycle
3. laborious and time consuming

The most well known rhinomanometer using the anterior method is the rhinosphygmo-manometer according to Cottle (1968); the one using the posterior method is the rhinomanometer according to Masing (Solomon et al., 1965; Masing, 1965; Bachmann, 1973, 1974, 1976; Naumann et all., 1977). The disadvantages of most of these methods are that it needs a rather sophisticated and expensive electronical equipment. This must be one of the reasons why most ENT specialists are reluctant to start rhinomanometry, as it is time consuming especially when the apparatus is not in constant use.
A third method of rhinomanometry is by means of the body plethysmograph which is not free of artefacts (Schumann et al., 1976), and is completely useless in a routine ENT practice.

INSTRUMENTATION AND METHOD

The method we advocate has been developed by H. A. E. van Dishoeck (1935). Although it is not as accurate as the other methods, it has the advantage of being very simple (no recording device is needed) and fast (a few seconds). It can be constructed easily by oneself (H. A. E. van Dishoeck et al., 1970; Ramey et al., 1971). It consists of a suitable nozzle with a side tube. A stationary air stream, provided by an ordinary office airpump, is blown through the nozzle.

The flow of the air stream can be controlled to 15 liters a minute by an ordinary turbometer (accuracy of about 5%) which is very commonly used by the anaesthesiologists. The side tube of the nozzle is connected to a water manometer. This manometer is made more sensitive by inclining one leg 60° and by replacing the other leg by a balloon with a broad surface. One millimeter of lowering of this surface will result in an important excursion of the water in the inclined leg. At the end of the inclined leg is another balloon which is a simple provision against spilling the fluid by too high pressures. This manometer can be calibrated from 0 to 20 cm H_2O pressure by a simple *U* tube water manometer (Figure 1, Figure 2A).

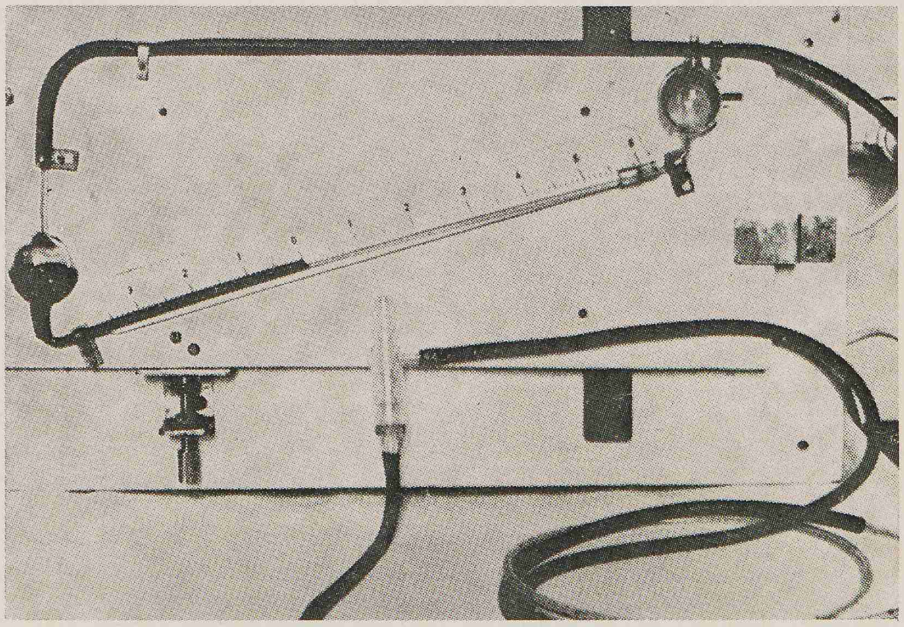

Figure 1. The nozzle and watermanometer of the P.A.R. from H. A. E. van Dishoeck's publication (1935).

The nozzle has a oval shaped opening (existing in 5 sizes), so hat it will fit, with a minimum of pressure, the nostril to be examined.
The innerside of the tubing and the nozzle must be very smooth as it should not disturb the laminar flow of the airstream. It is advisable by a special device to saturate the airstream with water and heat it to body temperature before it enters the nozzle. This special device will avoid undesirable reactions of the nasal mucosa caused by the airstream. At the same time, it will prevent microscopical oil particles to enter the nose. There exists also a more sophisticated commercial version of this rhinomanometer made by the Heyer Company* (Figure 2B).

* Heyer Company: Carl Heyer GMBH - Bad Ems.

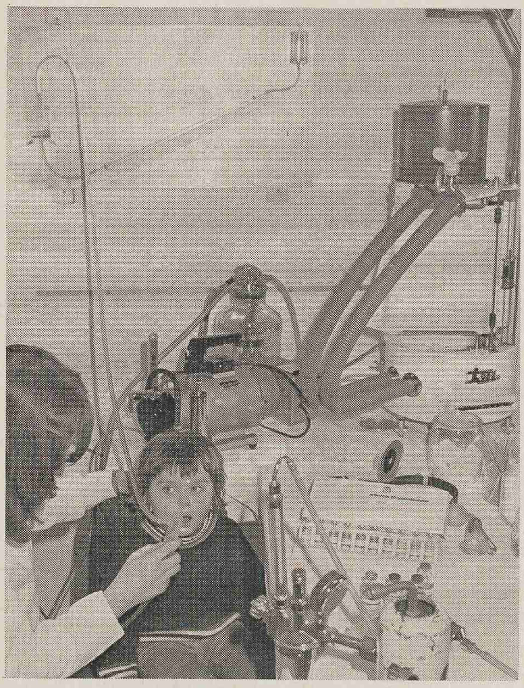

Figure 2A. The original P.A.R.

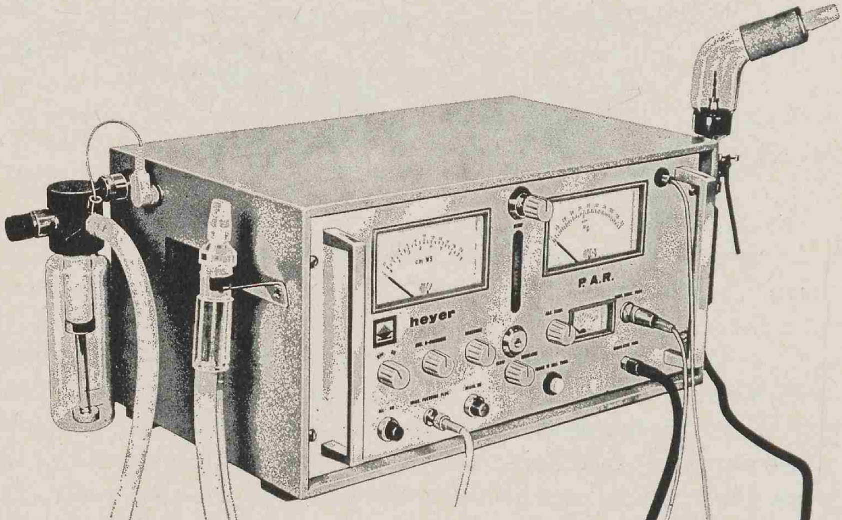

Figure 2B. The Heyer-version of the P.A.R.

According to H. A. E. van Dishoeck (1970) one can obtain with this set up 14 different values depending on: the side of inblow (right of left nostril) and the mouth open of closed; or the inblow by the mouth (both or one nostril open). Usually, however, one measures the permeability of one nostril when the patient is in apnoea with the mouth open. Because the patient is not breathing (passive rhinomanometry) the fourth disadvantage of the anterior rhinomanometry does no longer exist. This method is called passive anterior rhinomanometry (P.A.R.).

PHYSICAL DATA ABOUT PASSIVE ANTERIOR RHINOMANOMETRY

From physics one knows (Rosenberg, 1974 and Fischer, 1969) that in an ideal situation (i.e. for a straight glass pipe and a laminar airstream) the law of Poiseuille goes:

$$\Delta p = \frac{64 L \varrho \dot{V}^2}{Re\, D 2 S^2} \tag{1}$$

Re = Reynold's number
L = length of the pipe
ϱ = density
S = surface (πr^2) of the cross section
r = radius of the pipe
D = diameter ($2r$) of the cross section

In formula (1) every factor is known except the Reynold's number (Re)

$$Re = \dot{V} \frac{4\varrho}{\pi D \eta} \tag{2}$$

η = dynamic coefficient of viscosity
(1)+(2)

$$\Delta p = \frac{8\eta L}{\pi r^4} \dot{V} = R\dot{V} \tag{3}$$

R = resistance
$R = I/C = C$ = conductance

or:

$$R = \frac{\Delta p}{\dot{V}} = \frac{8\eta L}{\pi r^4} \tag{4}$$

Reynold's number has no dimension. When a certain critical value of this

number is exceeded, then a laminar airstream can or will change in a turbulent airstream. This will happen if "$\dot{V}$" exceeds a critical value "$\dot{V}_k$".
For a turbulent airstream the law of Venturi applies and

$$\Delta p = \frac{0{,}316 L \varrho \dot{V}^2}{Re \frac{1}{4} D 2 S^2} = R \cdot \dot{V}^2$$

Δp = pressure gradient
$\dot{V}$ = flow

or:

$$R = \frac{0{,}316 L \varrho}{Re \frac{1}{4} 4\pi^2 r^5} = \frac{\Delta p}{\dot{V}^2} \tag{5}$$

If the pipe has no constant diameter and no stationary airstream exists (like in the nose), then no critical value for Reynold's number can be calculated and this value must be determined experimentally. Furthermore, in the nose the abrupt change from a laminar flow into a turbulent flow, like in a pipe, does not exist (Fischer, 1969). Localised turbulences cause the occurence of a gradual change. This fenomenon is very dependant on the flow ($\dot{V}$) as follows from formula (4).
Melon (1973) stated that in the nose the resistance equals:

$$R = \frac{\Delta p}{\dot{V}_1^n} \tag{6}$$

from which follows that in the nose, undependently from the flow, there always exists a mixed airstream and $1 < n < 2$.
The fact that one never knows exactly the value of "n" makes the determining of the resistance very difficult and time comsuming. Therefore we think it is better to work with a stationary flow and keep "n" constant so that "Δp" is directly proportional to the resistance.
The measurement of "Δp" (pressure gradient) means the measurement of the difference betweens two pressures. If one of the pressures equals the atmospheric pressure, and the second pressure equals the atmospheric pressure plus an extra pressure, then it will suffice to measure that extra pressure to be informed about the pressure gradient (Δp).
Therefore the system to be measured must be adapted in such a way that on one end of the system the pressure always equals the atmospheric pressure. On the other end of the system, one measures the extra pressure generated by a flow of 15 liter a minute. This can be achieved in the following way:

a. mouth open and the pressure is measured on one nostril while the other is sealed off. The system consists of: one nostril, choana, pharynx, mouth.
b. mouth closed: the system consists: one nostril, choana, rhinopharynx, other choana, other nostril.
c. open mouth: the system consists of: one nostril, choana and then the system splits in
   - pharynx, mouth
   - other nostril

From the literature follows that the most narrow cross section of the upper respiratory tract exists at the level of the internal ostium (van Dishoeck, 1935; Solomon, 1965; Melon, 1964; Bachmann, 1972) and of the turbinates if the latter are congested.

$$R_{tot} = R_{int} + R_{turb} + R_{rest}$$

R_{tot} = total resistance
R_{int} = resistance of the internalostium
R_{turb} = resistance at the level of the turbinates
R_{rest} = resistance of the rest

compared to R_{int} and R_{turb} one can neglect the influence of R_{rest}.

OUR EXPERIMENTS

Thirty normal subjects (aged between 15–35 years) were tested. Before every test program the nose was inspected by an ENT specialist, who wrote down his findings in a file (i.e. existence of anomalies, situation of turbinates, presence of secretions).
The test program consisted in:

A. FIRST the measurement of the permeability of the nose (with a flow of 15 l/min) in the following way:

a. in every test subject *3 different sizes* of nozzles were used according to the judgement of the size of the nostril by the experimentator.
b. in every test subject *the right and the left side* were measured alternately.
c. the pressure at the level of the nostril was measured in *4 different situations*:
   - mouth open
   - mouth open and saying softly "a"
   - mouth open and the other nostril gently sealed off by the thumb of the investigator
   - mouth closed
d. every measurement was performed *three times successively.*

This makes 72 measurements a test subject:
2 (left or right) × 4 (4 different situations) × 3 (every measurement in triplo) × 3 (3 different sizes of nozzles) = 72 mesaurements.

B. SECONDLY: in one test subject the permeability of one nostril was determined with mouth open and *successively changing flows* (i.e.: 15 – 13 – 11 – 9 – 7 – 5 – 3 – 1 L/minute).
The first part of the experiment was done to have some information about the influence of the nozzle, difference between right and left side, influence of the situation and the reproducibility of the measurements.
The second part of the experiments was done to have some idea about the exponent "*n*" which can be calculated from formula (6)

$$R = \frac{\Delta p}{\dot{V}_i^n} \quad \text{or} \quad n = \frac{\log(\Delta p)_2 - \log(\Delta p)_1}{\log \dot{V}_2 - \log \dot{V}_1} \tag{7}$$

All the measurements were done with the new type P.A.R. rhinomanometer (Heyer Company) on the most sensitive scale (from 0–20 mm H_2O).
Five different sizes of nozzles were used with the following cross section:

no. 1 = 60 mm²
no. 2 = 88 mm²
no. 3 = 108 mm²
no. 4 = 140 mm²
no. 5 = 180 mm²

All the nozzle cross sections are oval shaped, to fit well at the level of the nostril. The diameters of the cross sections of each nozzle are:

no. 1 = 0,4 × 1,1 cm
no. 2 = 0,6 × 1,3 cm
no. 3 = 0,6 × 1,6 cm
no. 4 = 0,8 × 1,7 cm
no. 5 = 0,9 × 2,0 cm

RESULTS AND STATISTICAL ANALYSIS

Before a statistical analysis was performed, all measurements which were too high to be measured by the most sensitive pressure scale of 0–20 mm H_2O were excluded from the analysis. It is a well known fact that most nasal septa show anomalies. Whenever these anomalies give too extreme values, it will considerably alter the mean values of our results. These extreme values make it necessary to use a less sensitive scale with a different standard error so that comparison between the values for statistical analysis is no longer possible.

Last but not least from the results it was very clear that measurements (76%) done with one nostril sealed off, gave values higher than 20 mm H_2O. Mostly it was because the palatum molle interfered with the measurement (Fischer, 1969). Therefore this situation was not analysed statistically and considered as not suitable for measurement of the pressure gradient. In 18 out of the 30 test subjects, all measured values were in the range of the most sensititve scale and therefore suitable for statistical analysis.

An analysis of variance (ANOVA) to study the influences of different variables was applied. An "F test" was performed on the variances given by the ANOVA.

Table 1.

	F (distribution)	degrees of freedom
V_A/V_R	0,373	1,306
V_B/V_R	14,491	2,306
V_C/V_R	8,937	2,306
V_{AB}/V_R	0,027	2,306
V_{AC}/V_R	0,374	2,306
V_{BC}/V_R	0,522	4,306
V_{ABC}/V_R	0,074	4,306

ANOVA with 3 controlled factors to study the influences of different variables was applied. The three factors that were considered were:

A = right or left nostril (2 variables)

B = situation of measurement (3 variables)

C = size of the nozzle (3 variables)

From the statistical data (Table 1) follows that:

1. there exists no significant influence on the nostril to be measured (right or left): $F = 0,373$
2. there exists a clear cut influence of the size of the nozzle used: $F = 14,491$
3. there exists a clear cut influence of the situation in which the permeability is measured: $F = 8,937$
4. there exists no significant interaction between the different variables (V_{AB}, V_{AC}, V_{BC} and V_{ABC}).

Table 2.

	$\overline{X}$	S^2	S
mouth open	8,79 mm H_2O	16,45	4,06
mouth open, saying "a"	7,68 mm H_2O	9,56	3,09
mouth closed	10,25 mm H_2O	11,43	3,38

The mean values ($\overline{X}$) and standard deviation (S) are given in Table 2 from which follows that the situation with the mouth open and saying "a" gives the best results.

Although one can measure with an accuracy of 0,5 mm H_2O on the most sensitive scale, an unbiased estimator of variance has been calculated and is equal to 1,88 mm^2 H_2O. So the standard error of the 324 in triplo measurements is 1,4 mm H_2O.

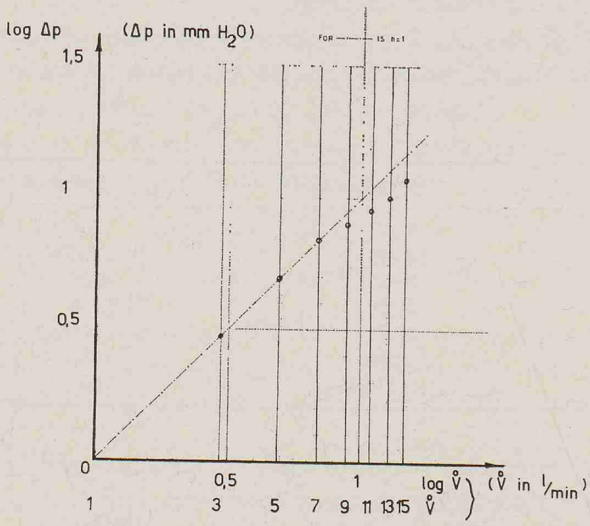

Figure 3.

The second part of the test program consisted in determing the value of exponent "*n*" according to formula (7). Therefore the pressure gradient with successively changing flows of one nostril was determined. The different values of "Δp" were logarithmically plotted on the ordinate and the different flows were plotted in the same way on the absissa (Figure 3). The slope of the resulting graph equals very much the slope of the bisective line for which $n = 1$. From this graph follows that – for flows of 15 liter a minute or less – the airstream is mainly laminar.

DISCUSSION

For every test subject, 72 measurements were performed. These 72 measurements took about 10–15 minutes per person which proves how fast this method works. Especially when one wants to study the effect of a drug or allergens, the measurements may not be too time consuming if one wants to rule out any influence of the nasal cycle. The P.A.R. is especially practical in nose provocation tests (van Dishoeck et al, 1975; Clement et al., 1977) and is used with succes by many authors (Horak et al. 1976; Bazin et al., 1976; Pas et al., 1977). On the commercial version, the P.A.R. is combined with an aerosol device. The whole procedure of rhinomanometry combined with nose provocation test takes as an average 15 min. and can be plotted on a graph (Figure 4). In this graph one sees on the absissa the different concentrations of mites and on the ordinate the value of the corresponding rhinomanometrical values.

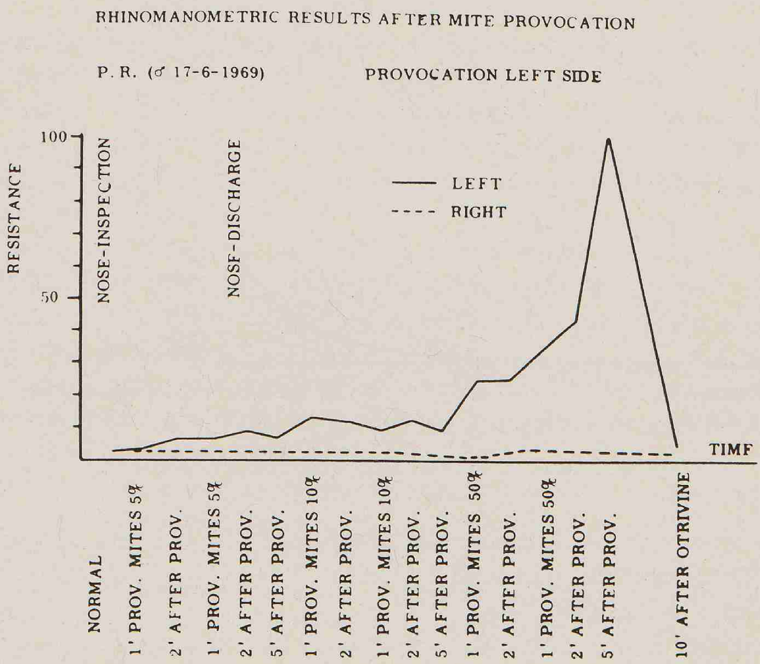

Figure 4. Graph of a nose provocation test.

In (Figure 5) one sees the increase of the pressure gradient when a constant airstream is forced through a diafragm with decreasing cross section, an experiment which was carried out by H. A. E. van Dishoeck in 1935 with the P.A.R. The course of the graph is characteristic for a 4th or 5th power function.
The same course can be seen in Figure 4 where a higher concentration of mites corresponds with a reduction of the radius of the cross section at the level of the turbinates. This is a fine illustration of the formula's (4) and (5) from which follows that the resistance of the nose is a 4th or 5th power function of the radius.
The mean value of the pressure gradient at the level of a nostril with the P.A.R. method was according to Table 2 about 8 mm H_2O (i.e. usual way of measurement with mouth open or with mouth open and saying "a").

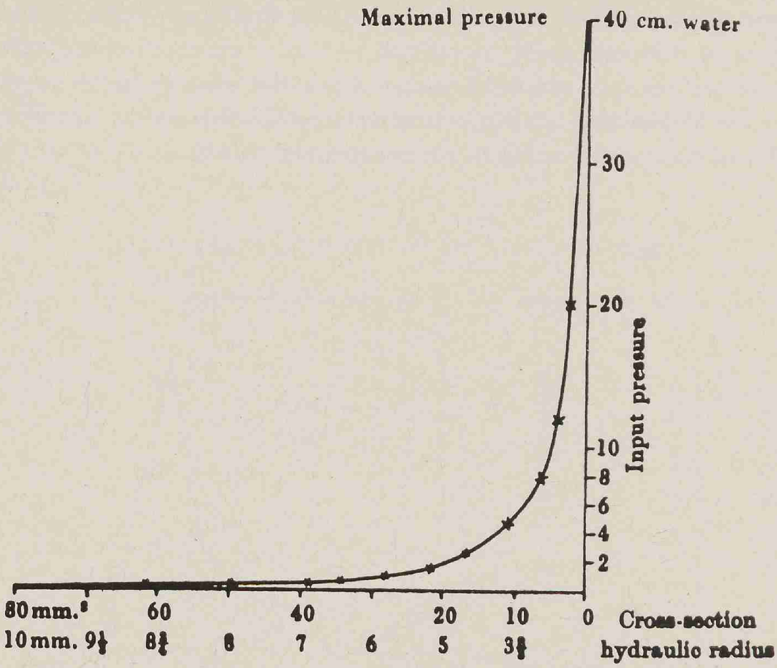

Figure 5. H. A. E. van Dishoeck experiment (1935) see text.

This figure corresponds with the value of the "Δp" with unilateral rhinomanometry (Cottle method), calculated by Melon (1973–1974) who found 0,5–6 cm H_2O with $\dot{V} = 0{,}25$ l/sec.

The resistance of one nostril with a flow of 15 liter/minute ($= 0{,}25$ l/sec) will be (formula 2) :

$$R = \frac{8 \text{ mm } H_2O}{15 \text{ l/min}} = 0{,}53 \frac{\text{mm } H_2O}{\text{l/min}} = 32 \frac{\text{mm } H_2O}{\text{l/sec}}$$

The total resistance of the nose will be:

$$\frac{I}{R_{tot}} = \frac{I}{0{,}53} + \frac{I}{0{,}53} = \frac{I}{3{,}8}$$

or

$$R_{tot} = 0{,}26 \frac{\text{mm } H_2O}{1 \text{ l/min}} = 0{,}26 \times 60 \frac{\text{mm } H_2O}{1 \text{ l/sec}} = 15 \frac{\text{mm } H_2O}{\text{l/sec}}$$

This figure corresponds fairly well with the figures found by Schuman et al., (1976) with their alternating pressure principle (i.e. 18,7–15,4 mm H_2O l/sec) and their body plethysmograph (11,5 mm H_2O l/sec).

To convert the units used here into the international MKS units, the following key can be used:

MKS	Units used here
Δp (Newton/m^2)	$1{,}02 \times 10^{-1}\ \Delta p$ (mm H_2O)
$\dot{V}$ (m^3/sec)	$6 \times 10^4\ \dot{V}$ (liter/min)

Concerning the type of flow (laminar or turbulent), our findings correspond with the finding of Melon (1973) who stated that for flow smaller than 1 liter/sec (= 60 l/min) "n" = 1,15 or the airstream is of a mixed type but mainly laminar. A flow of 15 l/min has been chosen because it corresponds to the flow wich exists under phsysiological conditions during, rest or light labor, i.e. 15–30 l/min (Fischer, 1969).
According to Naumann et al., (1977), a normal ventilation consists of 12–24 respirations/min of 500 to 1000 cm^3. According to the same authors, the pressure gradient becomes too high if "$\dot{V}$" exceeds 50–70 l/min and one is forced to breath through the mouth.
The surface of the cross section of the nozzle (from 60–180 mm^2) can be very well adapted to the external ostium of the nose whose surface ranges from 50–130 mm^2 (Naumann et al., 1977).
When changing the size of the nozzle, one must always readjust the manometer to its zero position (between size no. 1 and size no. 5 exists an adjustment of 5 mm H_2O).
In conclusion the authors state that the P.A.R. is an easy and reliable test for rhinomanometry, which has proven its usefullness especially for allergic diagnosis.

RESUMÉ

Les données physiques de la rhinomanométrie antérieure passive (P.A.R.) ont été étudiées par les auteurs.
A l'aide de valeurs obtenues chez 30 sujets normaux, il était possible de faire une analyse statistique des différentes variables concernant la "Rhinomanométrie antérieure passive".
En mesurant "Δp" avec des débits changeant successivement, il a été possible de déterminer que le courant aérien était principalement de type laminaire.

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