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Exact measurements of nasal resistance with the oscillation method

S. Ullmer and H. Enzmann

Dept. of O.R.L., Ruprecht-Karls-Universität Heidelberg, West-Germany

SUMMARY

It is demonstrated how it is possible to obtain a certain determination of the nasal resistance with the oscillation method respecting the whole airway resistance while measuring the flow. The 68 measurements with 17 probands under varying situations indicate that the values obtained are exactly the same with the two methods. There are only a few values which are outside the confidence limits. These are caused by interference from the regulation mechanism of the airway resistances e.g. in the nasal pharynx, larynx and bronchioli by augmentation of functional residual volume, which cannot be avoided. The averages of the two measurements are identical. There is no systematic error.

INTRODUCTION

At the second International Congress of Rhinology in Mexico, W. Ey presented whole body plethysmographic loops of nasal breathing from which the coefficient of nasal resistance could be calculated. In the whole body plethysmographic loops, the curved lines characterize nasal function during respiration. The curves bend enables computation and differentiation of nasal resistance from total airway resistance (Ey, 1970). Because of the disadvantages of the method, i.e. much calculation or inaccuracy, it has not yet been introduced in routine rhinomanometry.

Other methods for determining airway resistance data as a physical parameter in pulmonary medicine have been developed. Since Siemens built an apparatus based on the oscillation method which is easy to operate, pulmonologists, allergologists and rhinologists (Berdel and Gast, 1979; Berdel and Koch, 1980; Thiel and Fuchs, 1978; Kroidl, 1978) are again using this method. The possibility of estimating the upper airway or nasal resistance was investigated (Berdel and Koch, 1980), but exact calculation methods have not been published up to now. Above all, it was not mentioned in the calculations that the resistance of the nose increases with the flow, rather than the resistance of the lung.

Can the oscillation method replace rhinomanometry and under what conditions can such an oscillation unit be recommended for rhinomanometric measurements? Most pulmonologists and even some rhinologists believe that naso-pulmonary function tests render rhinomanometry superfluous (Berger and Nolte, 1979). The difference between the data of mouth breathing and those of nasal breathing reflects the function of the nose. Habitual mouth breathers, however, are able to form an adequate upper airway resistance by means of laryngeal, pharyngeal and even bronchial control mechanisms (Enzmann and Voelcker, 1981). Moreover, the units of measurement are not the same. These are the reasons why the simple difference method mentioned above is not sufficient for determining nasal respiratory function.

THE INSTRUMENT

The small Siregnost FD 5 unit permits a simple determination of the airway resistance. The proband breathes practically unhindered through a reference resistance, which is realized here by a flexible PVC tube.

At the mouthpiece, by means of a second tube; a small air volume pulsating at 10 Hz is impressed, which 'divides' in accordance with the resistance ratio between the airway and the reference resistance. The alternating pressure thus resulting, which is a measure of the airway resistance, is detected via a second tube connection, and evaluated in the equipment.

In reality, the functional principle is of greater complexity: properties of the lung such as compliance alter the complex respiratory impedance. In addition to the real component of total respiratory resistance (not only airway resistance!) the phase-angle is therefore also of importance. But in the range of 0–0.7 Pa*sec/cm^3 the phase angle can be ignored owing to the mechanization which is used for the needle instrument, too (Siemens: operating instructions, page 10). For our special purpose, the PVC tube is connected at its end with a pneumotachograph with a low resistance. The two values, flow ($\dot{V}$) and airway resistance (R), obtained in this way, are plotted by an X/Y plotter.

METHOD

The Siemens equipment is connected to a direct print-out plotter, so that the resistance can easily be read on the ordinate and the flow on the abscissa (Figure 1). Though the mechanisms of measurements are highly complicated, electronics can provide one simple value for resistance. However, the resistance is performed with a certain inertia, so that only a single value is calculated by the machine during one breathing movement. Nevertheless, you can see that in nasal breathing and with an arbitrarily chosen flow rate (for example 0.2 l/s = 200 cm^3/ s, 0.4 l/s = 400 cm^3/s and 0.8 l/s = 800 cm^3/s), the resistance increases with increasing flow rate (Figure 2).

The apparatus describes only one value for expiration and one value for inspiration. This is based on the inertia of the apparatus. Therefore, the direct print-out tracings only oscillate from the expiration resistance figure (with a negative flow

Figure 1a. The equipment manufactured by Siemens, supplemented by a pneumotachograph (interface included) and a X-Y plotter.

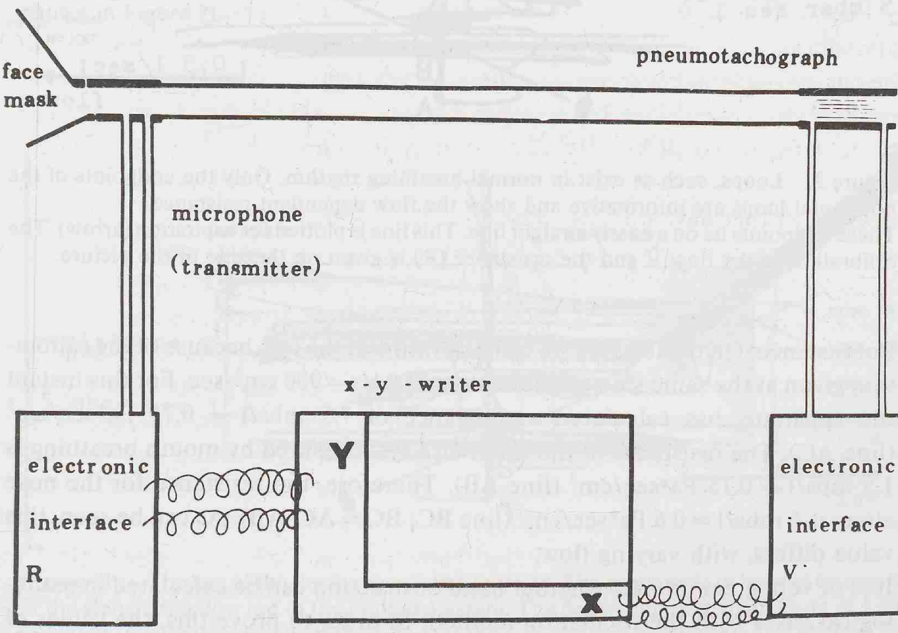

Figure 1b. Schematic model of the equipment.

value) to that for inspiration (with a positive flow value), except when very special breathing manoeuvres were done.
In the existing equipment the value for resistance and that for the flow can be read. Resistance is not a constant value because of the non-linear pressure-flow relationship in the nose as we know from rhinomanometry, body plethysmography and now the oscillation method. Since resistance is the ratio of pressure and flow, the pressure of these data recorded can always be calculated.
In spite of the variation, the endpoints of the loops (with varying flow) nearly form a straight line (Figure 2). This confirms the relationship already mentioned between flow and pressure as well as flow and resistance. Nasal resistance can be determined from this line as well as from recording pressure-flow relationships recording (Figures 3a, 3b).

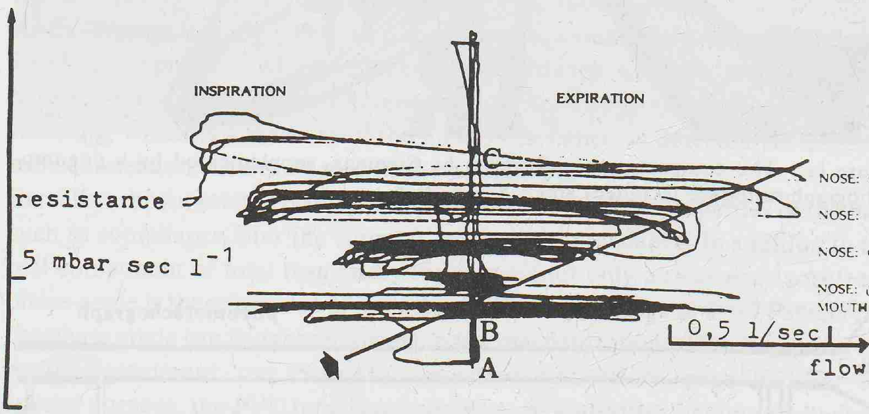

Figure 2. Loops, such as exist in normal breathing rhythm. Only the endpoints of the horizontal loops are informative and show the flow dependant resistance.
These endpoints lie on a nearly straight line. This line is plotted for expiration (arrow). The calibration of the flow $\dot{V}$ and the resistance (R) is given on the side of the picture.

For instance: On the left side we can determine at the top, because of the calibration given at the same side on the bottom: 0.9 l/s = 900 cm^3/sec. For this instant the apparatus has calculated a resistance of 7.5 mbs/l = 0.75 Pa*sec/cm^3 (line AC). The resistance of the lower airways measured by mouth breathing is 1.5 mbs/l = 0.15 Pa*sec/cm^3 (line AB). Therefore, the resistance for the nose alone is 6 mbs/l = 0.6 Pa*sec/cm^3 (line BC; BC = AC–AB). As can be seen, this value differs, with varying flow.
It is of very great interest whether nasal obstruction can be calculated in pathological cases with the oscillation method. In order to prove this, the values of patients in varying position with and without the influence of alcohol were com-

pared (Manz, 1985). For these statistical problems, by the means shown below, we calculated the figure of the flow (cm^3/sec) through both nostrils at an pressure of 1 mb = 100 Pa in the nasal pharynx.

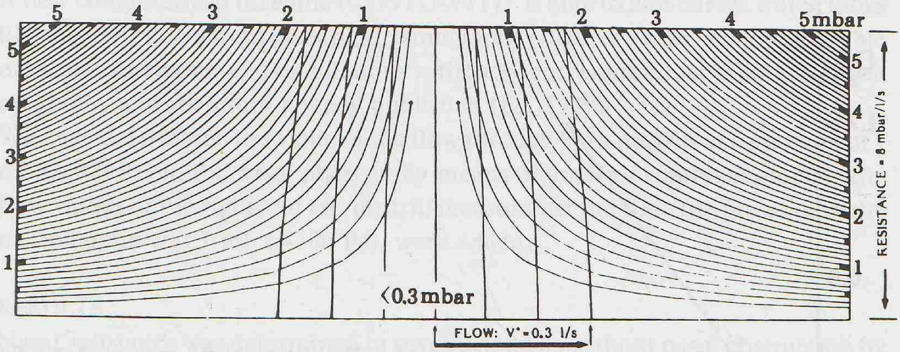

Figure 3a. Hyperbolic curves, which are connecting points of same pressure, calculated by the formula $P = R^*\dot{V}$. Using these curves as stencil (Figure 3b), you can read pressure (in millibar or hectopascal) at once and the corresponding flow from the plotted line or curves. If you wish to use the mathematical, circle orientated model of Broms, this is possible too. The circles are equivalent to the three nearly vertical lines. All other lines and figures represents pressure values. Flow has to be read out of the plotted diagram (e.g. the diagram shown in Figure 2).

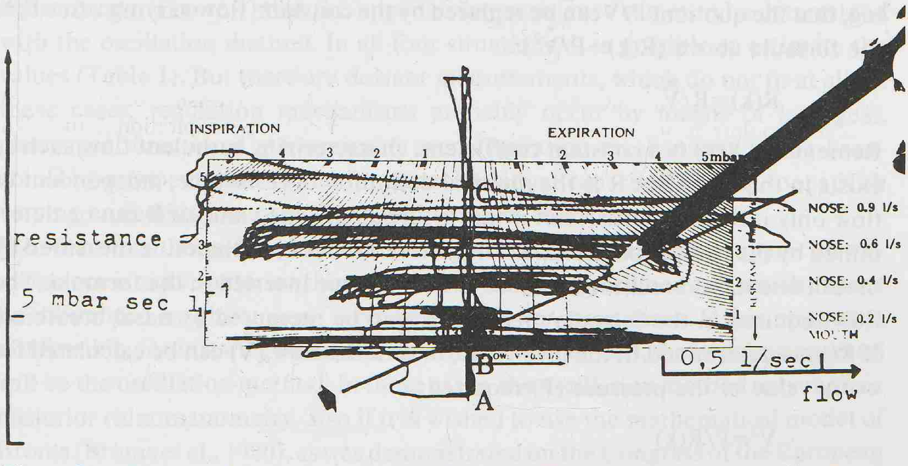

Figure 3b. The use of the device shown in Figure 3a. The pressure is to be read by means of the stencil, the flow out of the plotted diagram. The pencil points at an pressure of 1 mb (= 100 Pa) (calibration on the stencil) and for this you can read a value of 0.4 l/s (400 cm^3/s) for the flow (calibration given on the diagram).

THE MATHEMATICAL MODEL

The calculation is based on following considerations: The pressure in the nasopharynx is proportional in the square of the flow:

$$R(k)=P/\dot{V}^2$$

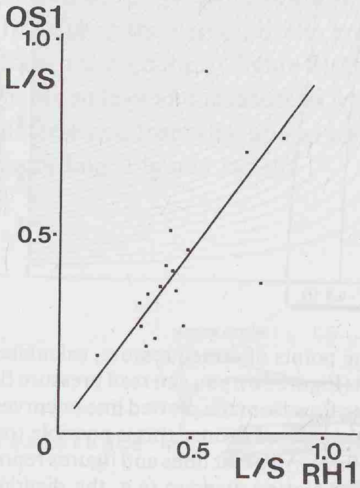

Figure 4. The flow values measured by the oscillation method and rhinomanometry, show a good correllation. As you can see in Table 1 the two deviant values are manifest errors, as they do not appear in the subsequent measurements (subjects 7 and 17).
OS = Oscillation. RH = Rhinomanometry.

Therefore R(k) is a constant value which is not influenced by variations of the flow as in the resistance ($R=P/\dot{V}$). The resistance increases with the flow. Assuming, that the quotient $P/\dot{V}$ can be replaced by the constant, flow varying value R in the formula above ($R(k)=P/\dot{V}^2$):

$$R(k)=R/\dot{V}$$

Remember: R(k) is a constant coefficient, characterizing turbulent flow such as exists in the nose. But R is the physical definition of resistance, independent of flow only if this is laminar, not if this is turbulent. The value of R can be determined by the oscillation method. The difference between the value measured by mouth and nasal breathing is equal to R, the value inserted in the formula. The flow required in the formula mentioned is to be measured by nasal breathing. If R(k) is determined in the given way, in turn the flow ($\dot{V}$) can be calculated for every value of the pressure (P) required:

$$\dot{V}^2=P/R(k)$$

If P is replaced by the value 1 mb (or 100 Pa), the flow which exists if the pressure in the nasopharynx has the value 1 mb (= 100 Pa) is calculated.
An example: The resistance (R) breathing through the widely opened mouth was

2.0 mbs/l = 0.2 Pa*s/cm^3. The total resistance (nasal breathing) at an flow of 0.6 l/s (= 600 cm^3/s) was 7.0 mbs/l (0.7 Pa*s/cm^3). Assuming, that the flow of the nose is turbulent, $R(k)=P/\dot{V}^2$ should be a constant value. R(k) = (0.7 Pa*s/cm^3 – 0.2 Pa*s/cm^3) / (600 cm^3/s) = 8.33*10^{-4} Pa*s^2/cm^{-6}. Now we can calculate the value for $\dot{V}$ at any nasal pressure we want, e.g. at 100 Pa. $\dot{V}^2 = P/R(k)$. $\dot{V} = 346$ cm^3/s. A new computerized machine (CUSTO-VIT)[1)] is able to plot curves which looks like those we know from body plethysmography (Figures 5a, 5b, 5c). The possible nasal measurements and calculations with these curves are equal to body plethysmography and therefore already published (Ey, 1979).

We have determined the value of the flow through both nostrils at a pressure of 1 mb (=100 Pa) in the nasal pharynx by means of anterior rhinomanometry: the flow values of the right and left nostril, measured at the time the pressure in the nasopharynx was 1 mb (=100 Pa), were added.

RESULTS

Nasal resistance was determined in several persons without nasal obstruction by the oscillation method as described before, and by active anterior rhinomanometry. Of course, there is a major variation in this functional biologic data, but the mean value did not show any difference (Table 1).

The measurements were done with 17 probands in varying positions: lying, sitting and once again in the same position under the influence of alcohol (red wine). As already published, alcohol alters nasal resistance (Eccles, 1988). There is no difference in the flow for the two methods. Moreover, we can demonstrate (Figure 4) that the upper airway resistance can even be determined with the oscillation method. In all four situations, it is possible to estimate the values (Table 1). But there are deviant measurements, which do not fit at all. In these cases, regulation mechanisms probably occur by means of laryngeal, pharyngeal functional stenoses and even regulation mechanisms in the bronchioli by augmentation of the functional residual capacity. Tracing loops with varying endpoints can probably avoid some of these errors.

We therefore consider that the best method for measuring upper airway resistance is active anterior rhinomanometry. It is a direct measure which cannot be influenced by pharyngeal, laryngeal and lower resistances. If this method is not feasible, for instance when one nostril is totally closed, the next best method will be the oscillation method. In these cases, the oscillation method may replace posterior rhinomanometry, also if it is wished to use the mathematical model of Broms (Broms et al., 1980), as was demonstrated on the Congress of the European Rhinologic Society in Bologna in 1978 and is now published here. The problems

[1)] Address: Firma Custo Med GmbH, Heiglhofstr. 1, 8000 München 70

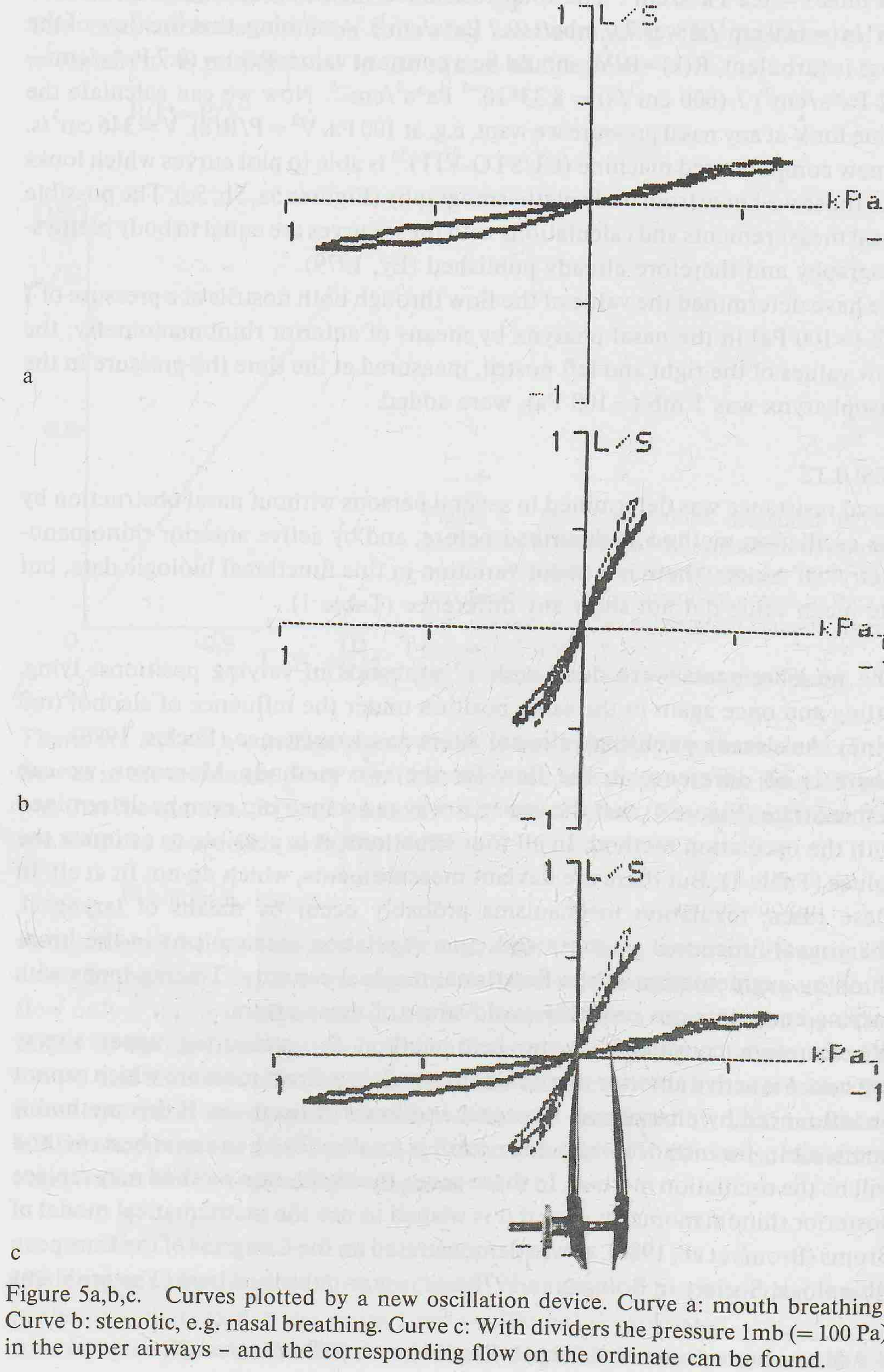

Figure 5a,b,c. Curves plotted by a new oscillation device. Curve a: mouth breathing. Curve b: stenotic, e.g. nasal breathing. Curve c: With dividers the pressure 1mb (= 100 Pa) in the upper airways – and the corresponding flow on the ordinate can be found.

Table 1. Nasal flow (cm^3/s) at 100 Pa in the nasal pharynx

	experimental situation							
	OS1	RH1	OS2	RH2	OS3	RH3	OS4	RH4
person:								
1	340	330	330	160	310	260	290	140
2	210	330	260	350	220	340	230	390
3	350	440	330	370	400	340	390	260
4	230	360	390	390	330	310	350	260
5	320	310	320	210	–	–	–	–
6	260	310	250	340	360	380	260	290
7	910	550	570	510	420	490	420	440
8	–	260	–	–	080	–	210	110
9	360	380	360	260	270	350	360	260
10	400	430	530	450	290	320	340	290
11	740	850	470	820	670	740	420	620
12	410	400	350	280	370	280	320	330
13	–	560	660	570	670	410	690	490
14	500	420	260	360	250	370	170	350
15	450	490	480	390	560	390	650	280
16	700	710	530	570	510	530	520	590
17	370	760	480	450	570	580	370	400
mean:	437 +/–200	464 +/–170	411 +/–123	405 +/–161	393 +/–166	406 +/–129	374 +/–145	344 +/–142

OS1 = oscillation method, sitting position
RH1 = rhinomanometry, sitting position
OS2 = oscillation method, recumbent position
RH2 = rhinomanometry, recumbent position
OS3 = oscillation method, sitting position, after red wine ingestion
RH3 = rhinomanometry, sitting position, after red wine ingestion
OS4 = oscillation method, recumbent position, after red wine ingestion
RH4 = rhinomanometry, recumbent position, after red wine ingestion

Listed are the values of the flow, passing both nostrils the nasal pressure beeing 1 mb = 100 Pa.
In all four situations, the mean value of the flow (at 1 mb = 100 Pa in the nasal pharynx), determined once by rhinomanometry (RH), the other time by oscillation method (OS) is the same.

with the oral pressure measurements in posterior rhinomanometry, when the patients are not able to breath through the nose with the pressure tube in the mouth and relaxed soft palate do not occur using the oscillation method.

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Prof. Dr. H. Enzmann
Universitäts-Hals-Nasen-Ohrenklinik
(University ENT Hospital)
Im Neuenheimerfeld 400
69 Heidelberg
West Germany