On the Advantages of Specific Airway Resistance*

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Summary

The specific airway resistance (SR_{aw}) is a relatively precise parameter of bronchial quality and in normal children its relation with body length, although very significant ($P < 0.001$), is so poor that it can safely be disregarded (Fig. 4). Also the dispersion around the mean value remains stable at any body size (Fig. 4). Contrasting with the inverse relation between airway resistance (R_{aw}) and lung volume, SR_{aw} does not show any systematic variation with lung filling (Fig. 5). These data are consistent with the new formulas: $SR_{aw} = \text{tg } \beta (P_B - P_{H_2O})$ and $R_{aw} = SR_{aw} /$

TGV in which $\text{tg } \beta$ stands for the relation between the plethysmographic box volume and breathing flow fluctuations (Fig. 2); $P_B - P_{H_2O}$ represents the ambient pressure corrected for water vapor pressure at body temperature; TGV is the thoracic gas volume at mean expiratory level. In disease SR_{aw} varies more rapidly and markedly with any alteration of the airways than does R_{aw} (Fig. 6). Consequently, a normal value for SR_{aw} would indicate that both R_{aw} and TGV must be in a normal range.

Speculation

For those who operate with a whole body plethysmograph the authors purpose to use specific airway resistance more frequently for the study of lung mechanics in children. It is a reliable parameter which can be measured very quickly and this should enhance knowledge about the mechanism of many lung diseases in pediatrics.

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In a previous paper it has been shown that SR_{aw} can be established and calculated quickly without knowing either the R_{aw} or the TGV at which R_{aw} is measured (4). There would be no benefit to this finding if the knowledge of R_{aw} and TGV remained essential in order to appreciate the condition of the airways. Consequently it becomes important to judge the clinical value of SR_{aw} in comparison with R_{aw} and TGV in many situations, especially since in small children SR_{aw} will be often the only obtainable plethysmographic measurement (4).

MATERIAL AND METHODS

SUBJECTS

Two hundred and forty two non selected schoolchildren (23), i.e. all those for whom the parent's consent was acquired (70 % of the total schoolpopulation) served to calculate mean values and dispersions for SR_{aw} , TGV and R_{aw} . Most of the children were studied on two occasions to test individual reproducibility of each measurement. The age varied from 3 to 16 years and the height from 94.5 to 182 cm.

Thirty six of the normal children and seventeen asthmatic patients from an institution for respiratory disordered children (Astmacentrum - Zeepreventorium, De Haan) regularly undergoing lung function testing, were specially trained to breathe at different levels during the measurements (fig. 1). Fifteen of the latter performed also a histamine provocation test with a metered aerosol (Histamine acid phosphate 100 micrograms in each puff, Riker Laboratories, Loughborough, England). The number of puffs was gradually increased until a perceptible variation occurred in the β angle (fig. 2) which represented SR_{aw} and then Terbutaline (Bricanyl[®], Astra, Lund, Sweden) was administered. At each time SR_{aw} , TGV and R_{aw} were determined.

METHODS

A pressure compensated volume displacement whole body plethysmograph (Pulmorex[®] (24)) was used, equipped inside with a Douglas bag of about 60 liters and containing a water level heated by a thermostat to body temperature. This bag was connected to a heated Fleisch pneumotachograph no. 3 which was itself connected on the other side to a mouth piece to measure breathing flows (ΔV) at BTPS conditions. The integration of these flows served to record respiratory volumes. The integration of the flow signal of a second but unheated Fleisch pneumotachograph in the wall of the box was used for the measurement of the box volume variations (ΔV_b).

The calculations of SR_{aw} , TGV and R_{aw} were fully described earlier (4). The formulas used will be recapitulated here :

1. $SR_{aw} = \text{tg } \beta (P_{bar} - P_{H_2O})$ (fig. 2)
2. $TGV = \text{tg } \alpha (P_{bar} - P_{H_2O})$ (fig. 3)
3. $R_{aw} = SR_{aw} / TGV$

Equation 3 was obtained from the usual definition of $SR_{aw} = TGV \times R_{aw}$.

RESULTS

The relation between SR_{aw} and body length is very poor ($r = 0.13$, fig. 4) but nevertheless very significant as it is the result of a study in a large population ($p < 0.001$). The slope however is only 0.03, consequently we can safely disregard the increase of SR_{aw} with body size for normal children between 3 and 16 years of age and consider the mean value as constant. This confirms previous findings (6). The difference between the mean value of the first determinations and that of the second determinations is less than 0.02 $\text{cm}^3 \cdot \text{sec}$ and is statistically not significant ($p > 0.92$). The comparison of the differences between the first and second determination in each child separately shows an average intraindividual variation of only 13 %. As a result SR_{aw} can be regarded as a relatively precise parameter. The dispersion around the mean seems to be a biologic characteristic since it is stable for any height and is distributed according to statistical laws (fig. 4) (19). Simplifying we will consider the mean value for SR_{aw} to be 10 $\text{cm}^3 \cdot \text{sec}$ and the 95 % upper prediction limit as 16 $\text{cm}^3 \cdot \text{sec}$. The reason for the higher values in this study as opposed to others will be discussed.

TGV could not be measured for all the children because the Pflueger maneuver (breathing movements against a closed shutter in the mouth piece) was sometimes impossible. We obtained a TGV of 465 times with the 242 children. With these data we were able to calculate the predicted mean regression curve :

$$TGV = 90.5958 \times 1.0202^{\text{Height}} \quad (r = 0.86)$$

However, for small children the observed values were far more scattered than for the taller ones (table 1). The reason for this is chiefly a poorly performed Pflueger maneuver by the very small children as has been extensively discussed earlier (4).

There is no significant difference between the first and second determinations ($p > 0.15$) but the intraindividual variations average 18 %. Whenever TGV could be measured, it was possible to calculate R_{aw} (equation 3). The formula for the predicted mean regression curve is :

$$72.9146 \times 0.9832^{\text{Height}}$$

A statistically significant though relatively poor negative exponential correlation is found between R_{aw} and the height of the subjects ($r = -0.69$).

There is no significant difference between the first and second determinations, but the intraindividual variations also average 18 % which is clearly more important than for SR_{aw} . The diminished precision is only due to the difficulty with which TGV is obtained and thus concerns principally small children (table 1).

Starting from formula 1, SR_{aw} should not depend on the lung volume. The experiment on 34 normal and 17 asthmatic children who were asked to breathe at different lung volume levels (fig. 1) demonstrates this. In this experiment both SR_{aw} and R_{aw} were simultaneously measured ; R_{aw} varied inversely with the lung filling (fig. 5A), and SR_{aw} showed no systematic variation (fig. 5B).

The relative changes of SR_{aw} after histamine inhalation and after bronchodilator inhalation (fig. 6) are more important than the simultaneously measured R_{aw} deviations ($p < 0.001$).

DISCUSSION AND CONCLUSION

The tools used and the working methods applied by different authors can vary in many ways and therefore it is hard to overcome all possible difficulties in standardizing methods for the evaluation of normal values. This accounts for the large variations of the normal values obtained by different investigators (5, 9, 10, 18). For want of uniformity each inquirer should elaborate and fix his own standards which although they are not accurate should nevertheless be precise (20). In our study the mean value for SR_{aw} is larger than the means reported by others (2, 6, 12, 16). This can be explained primarily by the nor-

mal breathing rate at BTPS conditions with our non selected children. Clement et al. (3) demonstrated that during panting, a common technique to simulate BTPS conditions (7), the glottis opening is markedly wider than at low flow rates, thereby causing large variations in the airway resistance (8, 11, 14). In the second place the $\Delta V_b / \Delta V$ curves are S-shaped because resistive forces increase with flow. This sinusoid in the curves inevitably causes ambiguities in the determination of the slope and the β angle (1, 13, 15, 17, 21, 22). In our opinion the use of fixed inspiratory and expiratory flow points, for instance 0.5 l/sec. is not applicable in pediatrics. Indeed some small children will never reach this flow with tidal breathing ; other children will have their peak flows near 0.5 l/sec. and the tallest will have the 0.5 l/sec. point on the linear part of the curve (fig. 2). Confronted with this situation we decided to always join the extreme inspiratory and expiratory flow points and we expected that in this manner the curves of all the subjects at any age or any height could be analyzed in the same conditions. Further we have observed that the exaggeration of sinusoid of $\Delta V_b / \Delta V$ is an earlier indication of bronchial obstruction than the change of the linear part of the slope. Though this method could be criticized, we have found it very convenient as shown by the satisfactory reproducibility of our measurements. Furthermore any other calculation method is also arbitrary.

Our investigation corroborated that SR_{aw} is almost constant in a normal population after the age of 3 years (fig. 4) whatever the size of the subject or the volume of the lung (fig. 5B). This is consistent with the basic formula 1. On the other hand in disease, SR_{aw} varies more rapidly and more markedly with any alteration of the airways than does R_{aw} (fig. 6). We interpret this result in terms of formula 3, which indicates that in a measurement of R_{aw} , hyperinflation of the lungs reduces the effect of obstruction of the airways. Minor bronchial obstruction can escape notice by disregarding SR_{aw} . This can occur when the increase of either R_{aw} or TGV is insufficiently significant. We conclude that SR_{aw} is actually the best indicator of the quality of the airways which can be measured with a body plethysmograph and which needs very little cooperation of the patients.

SR_{aw} alone does not yield separate information on lung size and resistive forces that oppose air displacement. Therefore the single use of SR_{aw} in the appreciation of lung mechanics in older children will only result in saving some time, hence there is no other reason not to make the separate measurements of R_{aw} and TGV also. On the contrary in small children, it will often be the only reliable and sometimes the only available measurement obtained with a whole body plethysmograph because even when TGV and R_{aw} can be obtained, the considerable dispersion of the normal values and the poor individual reproducibility (4) make them useless for clinical application. However resulting from the greater sensitivity of SR_{aw} , a normal value would indicate that both R_{aw} and TGV must be in a normal range, whereas an abnormal value leads to conclude that at least one of them is abnormal.

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Table 1. Estimation of the precision of TGV and R_{aw} with respect to body size

Height (cm)	Mean TGV ^x (milliliters)	Coef.Var. ^{xx} (%)	Mean R_{aw} ^x (cm H ₂ O/l/sec)	Coef.Var. ^{xx} (%)
95	606 ± 175	29	14.58 ± 4.6	32
105	740 ± 323	44	12.31 ± 4.2	34
115	903 ± 223	25	10.39 ± 4.0	38
125	1104 ± 295	27	8.77 ± 3.7	42
135	1348 ± 205	15	7.40 ± 2.2	30
145	1646 ± 310	19	6.25 ± 2.0	32
155	2015 ± 332	17	5.28 ± 1.6	30
165	2455 ± 367	15	4.45 ± 1.1	25
175	3000 ± 425	14	3.76 ± 0.90	24
185	3663 ± 416	11	3.17 ± 0.62	20

x Values represent mean and 1 SD.

xx Coefficient of variation (SD/mean x 100).

The individual values are grouped in classes of 10 cm. The mean values for each class mark is calculated from this sample and is always very close to the value calculated from the exponential regression equation. The SD of each class mark is calculated from the dispersion of the individual values around the mean value of that class mark.

Fig. 1. Normal breathing (a) at spontaneous expiratory level (TGV); breathing at higher (b) i.e. TGV + V_1 , and at lower (c) i.e. TGV - V_2 expiratory levels. Lung volume is determined at any level (Pf) through a Pflueger maneuver (breathing movements against a closed shutter in the mouth piece). The volume is then calculated as shown in fig. 3.

Fig. 2. Measurement of SR_{aw} with a whole body plethysmograph. The relation between plethysmographic box volume variations (ΔV_b) and respiratory flow fluctuations ($\Delta \dot{V}$) during breathing at BTPS conditions.

$$\Delta V_b / \Delta \dot{V} = \text{tg } \beta \quad SR_{aw} = \text{tg } \beta (P_{Bar} - P_{H_2O}) \quad (4).$$

Fig. 3. Measurement of TGV with a whole body plethysmograph. A. Normal breathing is interrupted (Pf) at the end of some expirations by a shutter in the mouth piece. B. Recording of the breathing movements against the closed shutter or Pflueger maneuver. The lung volume (V) can be measured through the relation between the box volume variations (ΔV_b) and the static mouth pressure variations (ΔP_m) i.e. alveolar pressure at the exact moment of a Pflueger maneuver. ΔP_m is measured with an electronic pressure transducer (Fenyves & Gut).

$$\Delta V_b / \Delta P_m = \text{tg } \alpha \quad V = \text{tg } \alpha (P_{Bar} - P_{H_2O}) \quad (4)$$

If the shutter is closed exactly at the mean end expiratory level, V represents the sum of TGV and the volume of the mouth piece.

Fig. 4. SR_{aw} is poorly related to body length. The geometric mean is preferred since the frequency distribution is skewed (diagram at the right of the figure) (19). For all the measurements together this mean is 10.10 cm H₂O/sec. More important is the 95 % upper precision limit for the one tailed type I error test (19) which is 16 cm H₂O/sec.

Fig. 5. Relative change of R_{aw} (A) and SR_{aw} (B) in normal and asthmatic children with respect to the relative variations of the lung volume as shown in figure 1. The values at the end expiratory level during normal breathing are indicated in terms of 100 %.

R_{aw} and TGV are inversely related as shown by the hyperbolic regression of the observed data.

Fig. 6. Comparison of the simultaneous relative variations of SR_{aw} and R_{aw} in 15 asthmatic patients first after a histamine challenge (Hist.) and then followed by bronchodilatation with Terbutaline (Terbut.). The values at the onset are indicated in terms of 100 %.

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