A Method for Ventilatory Measurements in Subjects 1 Month-5 Years of Age: Normal Results and Observations in Disease

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Extract

Using the total body plethysmograph, a method for the measurement of lung volume and airway resistance was developed for infants and young children of 1 month-5 years of age. The subjects were studied in a supine position using a reproducible method of sedation. The procedure providing the most consistent results involved use of a Rendell-Baker mask directly controlled by the operator while the subjects were breathing through the nose. Availability of an oscilloscope permitted immediate detection of pressure leaks, artifacts, and abnormal patterns during each determination and minimized potential errors during the study of each subject. Care was required to avoid pressure on the tip of the nose because an abnormally high airway resistance resulted.

The logarithmic relation of thoracic gas volume (TGV) at functional residual capacity (FRC) to body length for 52 normal subjects compared well with results obtained on newborn infants and with those obtained on older subjects. The equation was: $\text{TGV at FRC, liters} = 1.57 \times 10^{-5} \times \text{length, cm}^{2.238}$ (correlation coefficient = 0.948). The logarithmic relation of airway conductance to TGV was: $\text{conductance, liters/sec/cm H}_2\text{O} = 0.1431 \text{ TGV, liters}^{0.6441}$ (correlation coefficient = 0.835). Comparison with older subjects was limited by the difference in airflow rates at which the airway conductance was determined (0.06-0.28 liters/sec versus about 0.5 liters/sec for adults) and by the use of sedation and nasal breathing in this study; adults are studied awake and during mouth breathing. Comparison of our conductance values with those obtained on unsedated newborns suggests that either sedation alters the airway resistance or that some change occurs in the airway size-lung volume relation during the first weeks of life.

Examples of the application of this method to patients with asthmatic bronchitis and cystic fibrosis of the pancreas are provided.

Speculation

It is possible that an airflow-lung volume-airway resistance relation exists throughout life; however, the results presented in this study, combined with those previously presented on newborns for airway resistance, suggest that a change may occur in the relation of the size of the airways to lung volume during early infancy, or that sedation alters airway resistance. Development of this and other methodology should permit more adequate studies of the early changes in pulmonary physiology associated with growth and the acute and chronic pulmonary conditions seen during the first 5 years of life.

Introduction

Although techniques for measuring lung volume and airway resistance in adults and older children have been available for some time and have recently been reported for newborn infants [6], very little information is available for subjects from 1 month to 4 or 5 years of age. The studies reported by KRIEGER [12, 13] and more recently by WOHL *et al.* [19] utilizing different techniques, indicate the difficulties encountered, the need for more information in normal subjects, and the need for more observations in infants and young children with obstructive pulmonary disease.

The total-body plethysmograph method of DuBois and co-workers [8, 9] was modified to permit the measurement of lung volume and airway resistance in infants and young children under sedation. It is the purpose of this report to present the relations of these two measurements to those for age, body length, weight, and surface area, and to relate these results to those obtained in newborns and older children and adults.

Materials and Methods

A modification of the total-body plethysmograph method of DuBois *et al.* [8, 9] was used to measure lung volume and airway resistance. The plethysmograph used in this study was described previously [6]. A 5-cm circular-cuffed opening in the side of the plethysmograph permitted entrance of the operator's hand and forearm for application of the face mask. The monocellular rubber gasket cuffing the opening was flexible enough to permit entrance of the hand and provide an airtight fit around the forearm, yet rigid enough to withstand the pressure changes that occur during the procedure.

Early in the development of the method, a face mold of each child studied was made of plaster and from that mold a custom, clear acrylic mask was made. The nares were blocked and an oral airway used. The mask was sealed to the face lightly with Vaseline and held in place from outside the box by a rod as described by POLGAR [17]. The child was studied in the supine position and with sufficient sedation to permit useful measurements. In these early studies, the tongue tended to obstruct the posterior pharyngeal airway. The slight pressure applied through the rod to keep the mask in place tended to push the lower jaw back, thus interfering with the measurements by increasing obstruction. The box was then modified to allow the operator's hand to control the face mask and pull the mandible forward to maintain patency of the pharyngeal airway. Because normal subjects were not available to us long enough for individual masks to be made,

size 1 or 2 Rendell-Baker masks, sealed to the face with a light coating of Vaseline, were used since they allowed adequate space for the nose and seemed to minimize any tendency to produce nasal obstruction. Attempts to utilize oral breathing while using a Rendell-Baker mask were unsuccessful because the oral airway caused gagging or accumulation of excess secretions in the posterior pharynx. Consequently, all measurements of airway resistance and lung volume in this study were made during nasal breathing. Use of other types of masks, particularly the flat circular type, produced wide variations in airway resistance and erroneously high results due to the obstruction produced by pressure on the tip of the nose. Care was necessary even with the hand-held Rendell-Baker masks to avoid this pressure.

Attached to the mask was a monel wire-mesh pneumotachometer (2 cm in diameter) with a linear flow response to 0.3 liters/sec. The resistance of the pneumotachometer screen, 0.1 cm H₂O/liter/sec, was subtracted from all airway resistance measurements. The pneumotachometer was calibrated with a flowmeter [20], the calibration of which was verified using a spirometer [21]. Differential pressure transducers [22] were used to measure the box pressure and airflow changes and a differential transducer [23] was used for the airway pressure measurement. A direct writing recorder [24] was used and a modified oscilloscope [25] provided a visual display. A cable-release manual shutter, which could be operated from outside the plethysmograph and closed at end-tidal expiration, was positioned between the mask and flowmeter. The dead space from the mask to the shutter (15 ml) was subtracted from all lung volume measurements. The box pressure changes were calibrated by the rapid introduction and withdrawal of 30 ml of air delivered from a calibrated pump while the subject was in the plethysmograph.

Because cooperation cannot be expected from subjects in this age group, some degree of sedation was required to obtain a regular respiratory pattern and even tidal flow rates. Oral chloral hydrate gave variable results and intramuscular injections of phenobarbital required too long a period to act and the period of sedation was prolonged. Methohexital sodium (Brevital) given intramuscularly, 5–7 mg/kg body weight [10], produced somnolence in 4–8 min. The sedation produced was mild enough so that most subjects still responded to tactile stimulation. Most were alert and active within 30–45 min. Occasionally one-half of the initial dose had to be repeated after 15 min. No untoward effects or reactions were observed.

Using this method, the respiratory rates and breathing patterns observed provided very good oscilloscope tracings for lung volume determinations. In the earlier

studies, though lung volume measurements appeared to be valid, adequate flow data were often not obtained as a result of compression of the nasal airway produced by pressure on the tip of the nose. If repositioning was not successful in relieving the obstructive pattern, the airway resistance data were not used. In all cases, the airflow-box pressure relation was measured first, and then the airway was closed at the end of tidal expiration and the mouth pressure-box pressure relation determined. This was repeated until 10 measurements of airway resistance and lung volume at functional residual capacity were obtained. Erroneous results due to air leak or pressure on the nose were readily detectable from the oscilloscope tracing and permitted repositioning of the mask. Measurements of tidal volume, respiratory rate, and inspiratory and expiratory flow rates were obtained before the subjects were stimulated by airway closure. Despite this attempt to minimize stimulation the values observed cannot be considered basal.

Fifty-two normal infants and children from 1 month to 5 years of age were studied. They were the normal siblings of patients with cystic fibrosis of the pancreas (CFP) or other pulmonary problems, or were patients hospitalized for repair of inguinal or umbilical hernias. The former subjects were all hospitalized prior to study; the latter patients were obtained from the private and staff pediatric surgery division [26] and were studied immediately prior to surgery. None of the subjects had current, recent, or significant remote pulmonary disease. Once the method was established, measurements were obtained on patients with CFP, bronchial asthma, and other conditions. Informed consent was obtained in each case [27] and no complications were encountered.

Results

The results of the measurements obtained in this study of 52 normal subjects are shown in table I. Their lengths ranged from 54 to 118 cm and their weights from 4.1 to 25.2 kg. The thoracic gas volume (TGV) per kilogram of body weight averaged 32.4 ± 5 ml; the tidal volume per kilogram averaged 8.8 ± 2.6 ml; and the minute volume per kilogram averaged 234 ± 77 ml. The specific conductance (conductance/TGV) averaged 0.221 ± 0.070 liter/sec/cm H_2O /liter TGV. The ratio of tidal volume to TGV, in liters, averaged 0.279. The mean values for conductance, inspiratory and expiratory flow rate, tidal volume, and respiratory rate are also shown in table I.

Thoracic gas volume at functional residual capacity (FRC) and conductance were related to body length, weight and surface area, to age, and to each other, in

logarithmic and linear fashion by the method of least squares. The resulting coefficients, exponents, standard deviations, and correlation coefficients for the logarithmic relations are shown in table IIA and C, and the slopes, standard deviations, and correlation coefficients for the linear relations in table IIB and D.

In deriving the lines of best fit for the data graphed on figures 1 and 2, logarithms of TGV and length or conductance were used.

The equation for the fitted line for TGV at FRC versus length is:

$$\log \text{TGV} = \log \text{coefficient} + \text{exponent} \times \log \text{length, or} \\ \log \text{TGV} = \log 1.57 \times 10^{-5} + 2.238 \log \text{length} \pm 0.1538$$

On taking antilogs of both sides of this equation:

$$\text{TGV, liters} = 1.57 \times 10^{-5} \times \text{length, cm}^{2.238}$$

Fig. 1. Individual results for the relation of FRC to length on a logarithmic basis for 52 subjects. The solid line represents the line of best fit and the dashed line represents two standard deviations on either side of the line. The equation for this line is $\text{FRC, liters} = 1.57 \times 10^{-5} \times \text{length, cm}^{2.238}$. The cross represents the mean results obtained on 51 newborn infants by the same method [6]. The upper solid line represents the line of best fit obtained in our laboratory on 88 subjects, aged 6–18 years, when the total-body plethysmograph method was used but with the subjects seated and awake [7]. The equation for this line is $\text{FRC, liters} = 1.292 \times 10^{-5} \times \text{height, cm}^{2.352}$.

Similarly, the equation for conductance versus TGV, liters, is:

$$\log \text{conductance} = \log 0.1431 + 0.6441 \times \log \text{TGV} \pm 0.2042$$

On taking antilogs of both sides of this equation:

$$\text{conductance, liters/sec/cm H}_2\text{O} = 0.1431 \times \text{TGV, liters}^{0.6441}$$

The standard deviations refer to log TGV and log conductance (to base e) and are not directly transferable to a standard deviation for the variables. The equations of best fit for the relation of log TGV and log conductance to the other variables in table IIA and C can be derived in similar fashion. The correlation coefficients obtained when the logarithms were used are slightly better than those obtained when the linear relation was studied.

The linear equation for the relation of TGV at FRC to length is:

$$\text{TGV} = \text{intercept} + \text{slope} \times \text{length} \pm \text{sd of TGV at FRC} \\ \text{TGV, liters} = -0.4646 + 0.0100 \text{ length, cm} \pm 0.0728$$

In an attempt to simplify the calculations relating measurements of TGV at FRC to length and to improve the correlation coefficient of the linear equation, length was cubed as suggested by previous authors. The equation for this relation is:

$$\text{TGV at FRC, liters} = 0.397 + 0.45 \times 10^{-6} (\text{length}^3, \text{cm}^3 - 706,502) \text{ (correlation coefficient} = 0.94)$$

Fig. 2. Individual results are shown for the relation of conductance to TGV on a logarithmic basis for 35 subjects. The solid line represents the line of best fit and the dashed line represents two standard deviations on either side of the line. The cross represents the mean results obtained on 51 newborn infants by the same method [6].

The linear equation for the relation of conductance to TGV is:

$$\text{conductance} = \text{intercept} + \text{slope} \times \text{TGV} \pm \text{sd of conductance} \\ \text{conductance, liters/sec/cm H}_2\text{O} = 0.0297 + 0.1235 \times \text{TGV, liters}$$

The slight differences between these results and those presented in abstract form [5] are a result of reevaluation and a change in the method of analysis.

Discussion

Thoracic gas volume correlated well with the variables of body size and of age. Body length was selected for presentation since studies of older subjects showed the closest correlation was with length. Children with chronic pulmonary disease usually show varying degrees of weight loss making weight an unreliable variable for prediction of lung volume in the evaluation of such patients.

The thoracic gas volume per kilogram body weight of these patients (32 ± 5 ml) was quite similar to that found in newborns by us [6] and others [1, 14]. As can be seen in figure 2, the slope expressing the relation of TGV at FRC, in liters, to length for the 52 children in this study relates very well to the mean TGV obtained on 51 normal newborn infants by the same method. The only comparable study of lung volume in this age group, by KRIEGER [13], resulted in a thoracic gas volume per kilogram body weight of 50 ml, which is higher than our present results and those of others, and of our results for newborns. The reason for the difference is not entirely clear; however, reproducibility and reliability using this technique seemed improved when an oscilloscope was available for immediate visualization of slopes for the lung volume and airway resistance measurements.

Comparison of the results for TGV at FRC obtained in this study, with those obtained in older subjects, is difficult because of the differences in technique. All of the infants and young children in this study were sedated and studied in the supine position, whereas older subjects usually have been studied awake and in the sitting position. In addition, in the young patients, length was related to TGV while for the older patients height was used. In normal subjects length is usually greater than height. BLAIR and HICKMAN [3] and WHITFIELD *et al.* [18] have shown that FRC increased by 25–30% from the supine to the erect position in adults. The relation between the regression line that best fits this data on subjects studied supine and sedated and the data obtained on 88 older subjects studied seated and awake in the total body plethysmograph

[8], is shown in figure 1. The similarity of slope of these two lines indicates a constant relation and the slight displacement was consistent with the alteration due to change in position and degree of sedation. From these results it would appear that there was a logarithmic straight line relation between FRC and length or height, at least through childhood.

We are not aware of any published study of airway resistance in this age group. KRIEGER [12] found a mean total pulmonary resistance (airway resistance plus pulmonary tissue resistance) of 29 ± 20 cm H₂O/liter/sec (range 5–80) in 24 sedated children 1–24 months of age. Her method employed a plethysmograph and air-filled esophageal balloon. Measurements were presumed to be at FRC; however, this volume was not measured at the time total pulmonary resistance was determined. The FRC was estimated by extension of the regression of HELLIESEN *et al.* [11] for FRC versus height by the helium-dilution method in older subjects in the sitting position. Since airway resistance and total pulmonary resistance decrease with increasing lung volume, it is important to measure both resistance and lung volume together in growing subjects. The 14 subjects in our study who were less than 24 months of age had a mean airway resistance of 17.7 cm H₂O/liter/sec (range 8.7–30). BACHOFEN and DUC [2] found the lung tissue resistance to be 29% of the total pulmonary resistance in 10 healthy children, 7–11 years of age. If the same relation is true for infants and small children, our mean results for airway resistance and the calculated mean airway resistance from KRIEGER's data in subjects up to 24 months would be similar.

Comparison of the results for airway resistance obtained on our subjects with those obtained on adults was limited by several factors; sedation and nasal breathing were required in this study to obtain any useful data, whereas the adults were studied while awake and mouth breathing; adults are encouraged to breathe at standardized flow rates, about 0.5 liter/sec, to minimize the effect of airflow rate on airflow resistance, while the expiratory flow rates of the sedated children in this study were uncontrolled and significantly lower, ranging from 0.06 to 0.28 liter/sec.

As seen in figure 2, the infants in this study had airway conductances somewhat lower than the mean value we obtained in 51 normal, nonsedated newborns [6]. The flow rates for these infants were the same as the newborn rates. It is possible that sedation explains the difference observed; however, the possibility that the nasal airway undergoes some change from the newborn period through the first few months of life may also account for some of the difference observed. The difference may also suggest some change in the relation of the size of the airways to lung volume during

this period. The specific conductance (conductance/TGV) in this study (0.221 ± 0.070 liter/sec/cm H₂O/liter TGV) was quite similar to the results we observed in older subjects, age 6–18 years (0.215 ± 0.050 liter/sec/cm H₂O/liter TGV) and slightly less than that observed in adults by PELZER and THOMSON [16] and others (0.21–0.25). It is of interest that our 51 newborns had a specific conductance of 0.659 ± 0.170 liter/sec/cm H₂O/liter TGV. This difference in specific conductance also suggests that a change occurs early in infancy in the relation of the size of the airways to lung volume. Additional longitudinal studies may clarify this relation.

The mean tidal volume per kilogram of 8.8 ± 2.6 ml was similar to what we found in 36 newborn infants (8.4 ± 1.8 ml) using the same method. The mean minute volume per kilogram of 234 ± 77 ml was considerably less than that obtained on the newborns (588 ± 115 ml), which is consistent with the considerably higher respiratory rates observed in the unsedated newborn infants. The ratio of tidal volume to TGV at FRC change in our subjects (0.279) was considerably greater than that found by KRIEGER (0.129) [13]. This difference may be explained by either or both the larger FRC obtained in her study, or the larger tidal volumes observed in our study.

The practical application of this method is illustrated in figure 3 for lung volume (*A*) and for conductance (*B*). The results are shown for three patients with a history of asthmatic bronchitis who were symptomatic at the time of the study and for four patients with cystic fibrosis of the pancreas (CFP). All the patients with CFP were studied initially at the time of diagnosis, and three were studied subsequently one or more times during follow-up. As can be seen, two of the three patients with reversible bronchial obstruction showed an increase in lung volume and all three showed a marked decrease in conductance, especially when the lung volume at which conductance was measured was taken into consideration.

One of the four patients with CFP was diagnosed at 3 months of age, before pulmonary involvement had developed, and had both normal lung volume and conductance (*patient 4*).

Patient 5 was diagnosed at 5 months of age, before significant pulmonary symptoms had developed. The initial TGV and conductance were within normal limits and remained so at follow-up 3 years later while continuing on a comprehensive preventive treatment program [15].

Patients 6 and *7* were both diagnosed after considerable pulmonary involvement had developed. In each case, both TGV and conductance were abnormal initially. *Patient 6* showed considerable improvement clinically and in TGV and conductance (fig. 3*A* and *B*)

Table I. Length, weight and age, and results for TGV at FRC, airway resistance, and other measurements of 52 infants and children

Case no.	Length, cm	Wt, kg	Age, months	TGV at FRC ¹ , liters	Airway resistance, cm H ₂ O/liter/sec	Conduct- ance, liters/sec/ cm H ₂ O	Peak rate inspired, liter/sec	Tidal flow expired, ml	Tidal volume	Respir- atory rate, min
1	54	4.2	2	0.123 (0.119-0.127) ²	29.1 (28.3-30.0) ²	0.034				
2	57	4.1	1	0.145 (0.109-0.164)	22.9 (19.9-28.1)	0.044				
3	58	5.1	2	0.166 (0.132-0.174)	30.0 (28.8-30.1)	0.033	0.16	0.10	35	56
4	59	4.7	1	0.136 (0.118-0.160)			0.11	0.06	46	34
5	61	6.2	2	0.148 (0.136-0.157)	23.6 (18.9-27.7)	0.042	0.10	0.07	32	33
6	61	5.5	4	0.204 (0.194-0.214)			0.12	0.08	58	36
7	61	5.4	3	0.188 (0.166-0.194)			0.12	0.10	42	44
8	63	5.6	4	0.153 (0.144-0.155)			0.16	0.14	55	44
9	67	8.5	7	0.248 (0.238-0.271)	21.2 (20.5-22.1)	0.047	0.14	0.11	73	29
10	69	7.4	5	0.274 (0.269-0.285)	14.3 (11.6-16.7)	0.070				
11	70	8.1	10	0.231 (0.217-0.258)			0.08	0.17	118	14
12	72	8.8	9	0.272 (0.248-0.295)	14.6 (13.5-15.7)	0.068	0.16	0.11	79	23
13	72	9.4	8	0.270 (0.220-0.292)			0.24	0.18	156	25
14	73	9.6	9	0.293 (0.286-0.308)			0.17	0.13	81	25
15	73	11.8	12	0.294 (0.279-0.314)			0.09	0.09	82	44
16	74	9.0	10	0.257 (0.243-0.262)	10.0 (8.9-11.7)	0.100	0.16	0.13	97	29
17	75	9.7	7	0.271 (0.244-0.299)	17.0 (16.6-18.1)	0.059	0.14	0.11	69	33
18	79	9.4	19	0.246 (0.241-0.247)			0.12	0.09	91	26
19	81	10.7	18	0.312 (0.307-0.338)	14.2 (14.1-14.4)	0.070	0.12	0.10	81	26
20	81	9.8	15	0.360 (0.328-0.392)			0.14	0.06	100	19
21	84	14.1	23	0.278 (0.266-0.324)			0.11	0.17	137	18
22	85	10.7	21	0.345 (0.324-0.368)	15.1 (14.2-17.8)	0.066	0.19	0.19	120	20
23	85	11.3	26	0.380 (0.355-0.439)			0.12	0.12	111	22
24	85	13.8	29	0.490 (0.382-0.530)			0.18	0.16	77	25
25	86	10.7	26	0.360 (0.297-0.450)			0.13	0.14	117	23

26	86	11.0	26	0.434 (0.387–0.458)	12.6 (12.1–13.3)	0.079	0.18	0.13	184	19
27	86	12.9	18	0.479 (0.455–0.503)	8.7 (16.2–19.9)	0.115	0.16	0.15	109	40
28	86	13.0	18	0.485 (0.449–0.496)	13.1 (12.5–13.6)	0.076	0.24	0.16	69	26
29	89	13.4	30	0.421 (0.402–0.443)	13.9 (9.1–11.5)	0.072			113	24
30	89	11.7	19	0.415 (0.281–0.438)						
31	90	13.6	27	0.331 (0.318–0.370)	12.4 (11.1–12.9)	0.081				
32	92	13.9	25	0.348 (0.335–0.362)	8.0 (5.2–9.0)	0.125	0.21	0.19	90	38
33	93	12.9	28	0.318 (0.311–0.340)	17.8 (16.5–18.9)	0.056	0.12	0.15	111	21
34	93	14.4	25	0.398 (0.388–0.412)	11.6 (11.0–12.2)	0.086	0.20	0.19	148	25
35	94	13.0	33	0.397 (0.358–0.421)	11.5 (11.1–12.4)	0.087	0.14	0.13	130	20
36	94	14.4	33	0.508 (0.472–0.574)			0.14	0.14	153	22
37	95	12.4	34	0.368 (0.358–0.386)	11.3 (10.9–11.7)	0.088	0.16	0.12	107	24
38	95	14.3	34	0.357 (0.342–0.372)	16.9 (15.6–20.2)	0.059	0.18	0.21	108	40
39	99	13.8	34	0.547 (0.525–0.568)	14.7 (14.3–14.9)	0.068	0.15	0.09	109	19
40	100	10.5	47	0.449 (0.414–0.485)	14.5 (12.9–16.3)	0.069	0.16	0.17	107	25
41	100	14.9	39	0.624 (0.613–0.635)	9.7 (9.6–9.9)	0.103	0.26	0.22	153	29
42	103	15.3	39	0.466 (0.459–0.476)	14.2 (13.7–15.0)	0.070	0.11	0.17	153	20
43	103	14.5	59	0.598 (0.588–0.622)	9.5 (9.3–9.9)	0.105	0.24	0.22	106	20
44	105	16.0	45	0.490 (0.450–0.510)	11.2 (9.5–13.1)	0.089	0.18	0.18	106	27
45	106	17.2	53	0.602 (0.560–0.612)	7.0 (6.1–12.6)	0.139	0.30	0.18	133	28
46	106	16.7	44	0.725 (0.712–0.739)	8.2 (7.3–9.0)	0.122	0.16	0.16	121	25
47	108	15.9	51	0.614 (0.562–0.727)	10.9 (9.5–14.1)	0.092	0.27	0.18	96	29
48	110	18.1	52	0.666 (0.646–0.706)	10.3 (9.1–12.7)	0.097	0.22	0.22	144	26
49	110	18.0	68	0.634 (0.620–0.643)	8.1 (7.9–8.8)	0.123	0.18	0.12	172	19
50	114	25.2	59	0.836 (0.796–0.886)			0.36	0.28	128	24
51	116	24.2	66	0.786 (0.686–0.890)	10.0 (8.1–13.9)	0.096	0.28	0.18	109	25
52	118	23.3	58	0.906 (0.786–0.923)	6.2 (5.3–6.8)	0.161	0.18	0.07	145	23

¹ TGV indicates thoracic gas volume; FRC indicates functional residual capacity.

² Values within parentheses indicate range.

Table II. Analysis of the relation of TGV at FRC and conductance to length, age, weight, surface area, and to each other

*A*¹

Log TGV at FRC versus	Log length	Log age	Log wt	Log surface area
Mean, 52 subjects	4.4323	0.3389	2.4080	-0.7017
Coefficient	1.57×10^{-5}	0.3096	0.0271	0.9739
Exponent	2.238	0.4032	1.0678	1.4385
sd of log TGV at FRC	± 0.1538	± 0.1932	± 0.1680	± 0.1502
Correlation coefficient	0.948	0.917	0.938	0.951

All logarithms are to base $e = 2.71828$. TGV indicates thoracic gas volume, FRC indicates functional residual capacity. Log mean TGV at FRC = -1.0358.

*B*²

TGV at FRC versus	Length, cm	Age, yr	Wt, kg	Surface area, m ²
Mean, 52 subjects	85.8654	2.1425	12.0788	0.5206
Intercept	-0.4646	0.1668	-0.0418	-0.1736
Slope	0.0100	0.1074	0.0363	1.0957
sd of TGV at FRC	± 0.0728	± 0.0793	± 0.0685	± 0.0658
Correlation coefficient	0.919	0.903	0.929	0.934

Mean TGV at FRC = 0.3968 (liters).

*C*¹

Log conductance versus	Log TGV	Log length	Log age	Log wt	Log surface area
Mean, 35 subjects	-0.9544	4.4761	0.4995	2.4746	-0.6411
Coefficient	0.1431	0.120×10^{-3}	0.0679	0.0126	0.1435
Exponent	0.6441	1.4290	0.2606	0.7339	0.9636
sd of log conductance	± 0.2042	± 0.2243	± 0.2349	± 0.2131	± 0.2206
Correlation coefficient	0.835	0.797	0.774	0.819	0.804

All logarithms are to base $e = 2.71828$. Log mean conductance = -2.5592.

*D*²

Conductance versus	TGV, liter	Length, cm	Age, yr	Wt, kg	Surface area, m ²
Mean, 35 subjects	0.4279	89.6857	2.4520	12.8086	0.5506
Intercept	0.0297	-0.0296	0.0522	0.0199	0.0041
Slope	0.1235	0.125×10^{-2}	0.0124	0.489×10^{-2}	0.1425
sd of conductance	± 0.0179	± 0.0198	± 0.0212	± 0.0188	± 0.0193
Correlation coefficient	0.789	0.733	0.687	0.765	0.750

Mean conductance = 0.0826 (liters/sec/cm H₂O).

¹ *A* and *C* indicate the logarithmic relation.

² *B* and *D* indicate the linear relation.

Fig. 3. Measurements of lung volume (A) and conductance (B) on three young patients with asthmatic bronchitis and four patients with cystic fibrosis of the pancreas. Asthmatic bronchitis patients: 1, 2, and 3, ○; cystic fibrosis patients: 4, ■; 5, ◇; 6, ▲; and 7, ●.

after a period of intensive treatment in the hospital. On subsequent home therapy, TGV increased at a predicted normal rate but remained larger than normal, while conductance remained within the normal range. Patient 7 showed no significant improvement in TGV while on intensive hospital and home therapy. Conductance did improve but never returned to normal.

Summary

Using the total-body plethysmograph, a method was developed to measure the thoracic gas volume (TGV) at functional residual capacity (FRC) and the airway resistance at this volume. Fifty-two normal subjects, 1 month-5 years of age, were studied. Body length and weight, age, inspiratory and expiratory flow rates, tidal volume, and respiratory rate were recorded. Body surface area, TGV at FRC, TGV per kilogram, airway conductance (conductance/TGV), tidal volume per kilogram, and minute volume per kilogram were calculated. The TGV at FRC and airway resistance were related to body length, weight and surface area, to age, and to each other in linear and logarithmic fashion.

Using the logarithmic relation, the equation for the fitted line TGV at FRC versus length, cm was:

$$\text{TGV, liters} = 1.57 \times 10^{-5} \times \text{length, cm}^{2.238}$$

Using the logarithmic relation, the equation for the fitted line conductance versus TGV was:

$$\text{conductance, liters/sec/cm H}_2\text{O} = 0.1431 \times \text{TGV, liters}^{0.6441}$$

Application of the total-body plethysmograph method to the study of infants and young children with obstructive pulmonary disease is illustrated.

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26. These patients were obtained with the assistance of Dr. ROBERT IZANT and Dr. RICHARD C. MILLER of the Department of Pediatric Surgery, Children's Clinical Research Unit, Babies and Children's Hospital, University Hospitals of Cleveland.
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