Ventilatory Studies in Healthy Infants

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Extract

Thoracic gas volume (TGV), specific compliance (SC), and mean pulmonary resistance were measured in 38 healthy infants between 4 and 46 weeks of age. TGV had a mean value of 30 ± 3.3 ml/kg of body weight or $0.768 \pm 0.089 \times 10^{-3}$ ml/cm body length³. The mean value for SC was 0.056 ± 0.01 cm H₂O/l TGV; that for specific pulmonary conductance was 0.298 ± 0.075 l/sec/cm H₂O/TGV. Pulmonary conductance related to body length³ had a mean value of $0.221 \pm 0.066 \times 10^{-6}$ l/sec/cm H₂O/cm³. The value for the change in intraesophageal pressure between the minimum and maximum values in each respiratory cycle was 8.0 ± 1.47 cm H₂O.

The results of this study indicate that TGV, SC, and pulmonary resistance, when related to body size, show little difference when comparing newborn infants and adults.

Speculation

Measurements of respiratory function in infants are known to be practical. The availability of such measurements in healthy infants should make possible the determination of abnormalities in the respiration of infants with acute viral bronchiolitis and cystic fibrosis of the pancreas, or other respiratory diseases.

Introduction

Ventilatory function has been measured rarely in infants and children between the ages of 1 month and 6 years, probably because of the technical difficulties in studying a subject who is unable to cooperate or who actively resists any examination he finds uncomfortable. In studies of respiratory function in newborn infants, lung volume [1, 2, 5, 7] and the mechanics of ventilation [5, 9, 20, 29] have been reported. Only one worker, however, has investigated these parameters in normal infants beyond the neonatal age [22, 23].

This study provides further information on the measurement of TGV, dynamic compliance, and pulmonary resistance in healthy infants.

Materials

Thirty-eight healthy infants between the ages of 4 and 46 weeks were studied, eight of them on more than one occasion. The infants were awaiting adoption in a babies' home. All had been free of respiratory distress during the neonatal period. Clinically they were nor-

mal and had no evidence of disease of the upper or lower respiratory tracts. Radiological examination was not undertaken.

Methods

Thoracic gas volume (TGV), the volume of air in the respiratory passages at end expiration, was measured with a 49-liter body plethysmograph [12]. The method used was similar to that adapted to measure TGV in premature infants [5].

Tidal volume was measured while the infant, partially enclosed in the plethysmograph, breathed room air. A small piece of perspex, in which a hole 4.5 cm in diameter provided an opening for the mouth and nose, was placed over the oval aperture in the lid of the plethysmograph. The perspex was sealed around the nose and mouth and to the lid of the plethysmograph with putty (fig. 1). This method gave a more reliable seal and caused less disturbance to the infant than did that of Cross [11], who used an inflatable rubber cuff. Tidal volume was measured by recording the pressure change in the plethysmograph with a strain gauge.

Dynamic compliance was calculated as the ratio between tidal volume of the infant at rest, measured in the plethysmograph, and change in intrapleural pressure. Intrapleural pressure was estimated from measurement of intraesophageal pressure with a thin latex balloon, 3.5–5.0 cm in length and 2.6 cm in perimeter, which contained 0.2 ml of air [27]. Pressure was measured with a strain gauge. The infant was in the supine position when measurements were made.

Mean pulmonary resistance was calculated as the ratio of total transpulmonary pressure change to the corresponding total change in flow rate between points of equal volume midway in inspiration and expiration [9]. The transpulmonary pressure was measured with an intraesophageal balloon, and the flow rate with a

heated Fleisch pneumotachygraph of resistance 4.0 cm H₂O/l/sec.

Statham strain gauges were used to measure all pressures, and output of the gauges was amplified and recorded using an Electronics-for-Medicine 8 Channel recorder equipped with pressure preamplifiers.

Values for TGV were obtained by analysis of 5 breaths; there was a constant variation of about 10 % in the measurements. No further statistical analysis was undertaken. Ten breaths were analyzed to obtain values for dynamic compliance and pulmonary resistance, and the mean and standard error of the mean of the 10 measurements were calculated.

All patients were mildly sedated with Quinalbarbitone® given orally in a dose 7–8 mg/kg of body weight. Studies were carried out soon after feeding. With gentle handling, the infants remained lightly asleep during the tests, but quickly awoke if disturbed.

Results

The results of the measurements of respiratory function are given in table I.

The relation of TGV to body weight, to body length³, and to body surface area was calculated. Results of these calculations, together with results of the regression analysis, are given in table II. In fig. 2, TGV is plotted in relation to body weight and body length³; the line of closest fit, calculated by the sum of least squares, is drawn, and the equation of the line is given.

The relation of dynamic compliance and mean pulmonary conductance (defined as the reciprocal of mean pulmonary resistance) to TGV and that of mean pulmonary conductance to body length³ were calculated, and regression analysis was performed. The results are given in table III. In fig. 3, mean pulmonary conductance is plotted in relation to TGV and body length³.

The value for the change in intraesophageal pressure between the minimum and maximum values in each respiratory cycle was calculated (table I). The value for each study was obtained by analysis of 10 respirations. The mean and standard deviation for the 36 measurements of intraesophageal pressure change was 8.0 ± 1.47 cm H₂O.

Discussion

The results of the study showed considerable variation in normal values of respiratory function in infants.

TGV correlated well with the three parameters of body measurement selected. The correlation with body length³ was the closest. This function of length

Fig. 1. The 49 liter body plethysmograph as used to measure tidal volume. The subject's mouth and nose were exposed to the atmosphere and the plethysmograph was sealed using a piece of perspex and putty.

Fig. 2a and b. Thoracic gas volume is plotted against body weight in a) and against the cube of body length in b). Dots represent individual values. The line of closest fit was determined by the sum of least squares.

Fig. 3a and b. Mean pulmonary conductance is plotted against thoracic gas volume in a) and against body length cubed in b). Dots represent individual values. The line of closest fit was determined by the sum of least squares.

Table I. Respiratory function data on 24 healthy infants

Patient	Age (weeks)	Length (cm)	Weight (kg)	Respi- ration rate	Tidal volume (ml)	T.G.V. (ml)	Compliance		Mean resistance		Intra- eso- phageal differ- ence (cm H ₂ O)
							Mean	Standard error	Mean	Standard error	
M.P.	4	53	3.8	45	43	110	6.8	0.19	30	0.64	8.3
M.M.	5	53.5	3.6	52	28	140	5.9	0.09	30	0.82	6.8
E.Z.	5	57	4.3	35	43.5	110	8.1	0.20	25	1.13	6.7
T.Z.	5	58	4.8	36	35.5	140	8.6	0.18	16.5	0.83	7.0
D.T.	5	58	4.6			145					
	13	61.5	6.5	32	60	180	8.9	0.10	23	0.39	8.9
C.T.	5	55.5	4.5	27	58	160	7.3	0.13	33	0.65	10.7
	9	56	5.4	46	46	170	10.0	0.25	17	0.59	5.7
M.B.	5	54	4.6	84	29	140	7.1	0.03	22	0.21	6.1
C. McD.	6	55	4.4	53	39	135	8.3	0.31	21	0.73	7.6
	10	59	5.0	45	47	145	8.6	0.12	19.5	0.37	7.0
	14	64	6.4	36	56.5	195	11.1	0.19	18	0.64	6.7
P.I.	6	52	3.6	58	26	120	6.0	0.03	21	1.20	6.2
J.G.	6	58	4.5	57	48.5	120	8.3	0.15	28	0.94	10.4
	10	61	5.5	37	61	145	11.3	0.38	29	0.81	8.6
	14	63	6.4	34	54	160	10.0	0.21	24	0.67	7.7
	18	66.5	7.1			215					
B.P.	7	59.5	4.5	40	50.5	155	7.4	0.12	15.5	0.13	7.8
	12	62	5.1	34	57	165	8.5	0.34	19	0.58	7.7
A.C.	8	56	4.3	48	40.5	155	8.8	0.20	25	1.35	6.8
C.S.	8	58.5	5.5	53	53.5	160	6.1	0.16	23	0.92	10.9
	12	61.5	6.4	30	78	175	13.0	0.41	17	0.85	7.4
J.B.	12	54.5	4.9	32	49	120	7.5	0.15	32	0.86	9.6
L.P.	12	59.5	5.0	44	42	160	6.5	0.15	26	0.69	8.0
	17	62	5.8	46	59	200	9.7	0.24	18	0.66	7.1
L.T.A.	13	58	4.9	28	58	145	9.1	0.12	16	0.59	7.5
K.B.	21	63	5.7	40	46	180	11.2	0.32	30	0.38	7.8
M.C.	22	63	6.0	32	63	170	11.6	0.32	16.5	0.78	7.4
I.C.	22	69	8.9	36	74	205	10.4	0.35	22	0.65	10.8
K.C.	26	63	6.5	34	76	195	12.5	0.13	15	0.63	7.4
	31	66	6.9	36	55	210	11.8	0.17	21	0.71	7.0
	35	68	7.3	34	65	250	12.1	0.26	14	0.60	6.9
	40	71.5	7.9	34	66.5	260	11.7	0.25	22	0.82	8.2
D.W.	33	67	7.3	30	66	175	9.7	0.19	19	0.83	9.1
P.D.	36	70	8.2	32	77	255	9.9	0.27	20	0.71	9.9
K.D.	36	70	9.0	44	61	245	13.1	0.16	15.5	0.45	7.8
G.Q.	40	74	8.7	31	80		10.8	0.19	19	0.61	11.5
E.W.	46	70	7.6	37	85	255	13.2	0.36	15.5	0.73	7.9

Compliance = ml/cm H₂O; resistance = cm H₂O/liter/sec.

Table II. Relation of thoracic gas volume to certain body measurements

Body measurement	Mean	S.D.	p	Correlation coefficient
Body weight, kg	30 ml/kg	± 3.3	< 0.001	0.874
Body length, cm ³	0.768×10^{-3} ml/cm ³	$\pm 0.089 \times 10^{-3}$	< 0.001	0.926
Body surface area, m ²	580 ml/m ²	± 63	< 0.001	0.917

Table III. Relation of dynamic compliance to thoracic gas volume, and mean pulmonary conductance to thoracic gas volume and body length³

Relationship	Mean L/cm H ₂ O/l TGV	S.D.	p	Correlation coefficient
'Specific compliance'	0.056 l/cm H ₂ O/l	± 0.01	< 0.001	0.720
Dynamic compliance to TGV	TGV			
'Specific conductance'	0.298 l/cm H ₂ O/l	± 0.075	< 0.001	0.474
Conductance to TGV	TGV			
Conductance to length ³	0.221×10^{-6} l/sec/cm H ₂ O/cm ³	$\pm 0.066 \times 10^{-6}$	< 0.01	0.460

Table IV. Previous reports of measurements of respiratory function in healthy newborn babies

Author	TGV, ml/kg	Compliance, ml/cm H ₂ O	Specific compliance, ml/cm H ₂ O/ml TGV	Resistance		
				Mean, cm H ₂ O/l/sec	Inspiratory, cm H ₂ O/l/sec	Expiratory, cm H ₂ O/l/sec
BERGLUND and KARLBERG [2]	27					
KLAUS <i>et al.</i> [21]	27					
AULD <i>et al.</i> [1]	36					
CHU <i>et al.</i> [7]	38.5		0.040 $\pm$ 0.010			
BURNARD <i>et al.</i> [5]	27	5.2 $\pm$ 1.3	0.063		25 $\pm$ 7.7	36 $\pm$ 7.8
COOK <i>et al.</i> [10]		4.9		29 $\pm$ 12.9		
SWYER <i>et al.</i> [29]		4.9		26 $\pm$ 6.5		
KARLBERG and KOCH [20]				38.5 $\pm$ 25.2		
Present study	30 $\pm$ 3.3		0.056 $\pm$ 0.010			

was selected, because studies in older children, in whom the regression curve of closest fit had been determined, had suggested that functional residual capacity (FRC) correlated with a factor close to the cube of height. ENGSTROM *et al.* [14] demonstrated that a factor of height^{2.68} gave the largest correlation coefficient; HELLIESEN *et al.* [17] had found a factor of 2.91, and ENGSTROM *et al.* [15] a factor of 3.103. In the present study, the regression curve of closest fit was not determined when the high correlation coefficient between

TGV and body length³ was demonstrated. The purpose of this study was to determine a practical measurement that would allow comparison of infants with respiratory disease with normal infants.

There was a significant relation between pulmonary conductance and TGV. A significant relation between airway conductance and FRC has been reported previously in older children and adults [5]. The term specific conductance is applied to this relation. There was also a significant, but not so close, correlation between pul-

monary conductance and body length³. ENGSTROM *et al.* [15] also demonstrated this relation. They found that the regression with the closest fit in older children was related to height^{2.672}. Body length³ seemed to be a more practical measure. Recently, MEAD and WOHL [30] have confirmed the significant relation between pulmonary resistance and body length³ in a group of healthy infants between 6 and 60 weeks of age.

The relation between compliance and FRC has been found to be significant in healthy adults [24]. The results of the present study demonstrated a significant relation between compliance and TGV in healthy infants ($p < 0.001$). The value for TGV/kg of body weight found in these healthy infants was similar to that reported by other investigators who studied newborn infants (table IV).

KRIEGER [23] reported that in 20 infants between 1 to 33 months of age, the mean value for lung volume was 50 ml/kg of body weight or alternatively, 1,000 ml/M² or 1.17×10^{-3} ml cm (length)³. These values were substantially higher than those found in the present study. KRIEGER is the only author who has reported such studies of normal infants, other than neonates.

In older children, values for FRC, measured by use of a helium dilution technique, have been reported to be 50 ml/kg and $0.88 \times \text{ht}^{2.91} \times 10^{-3}$ for 85 children 5 to 17 years of age [17] and $0.98 \text{ ml} \times \text{ht}^{2.86} \times 10^{-3}$ for 93 children 6 to 14 years of age [15]. Because of the different powers of the height to which FRC was related, these values could not be easily compared with the values in the present study, but nevertheless were of a similar order of magnitude. Since studies of the older children were carried out while they were in a sitting position, it was difficult to compare those values with values found in the present study. It has been shown that FRC increases by about 25 % when a subject moves from the supine to the sitting position [3].

KALTREIDER *et al.* [19] measured FRC in 50 young men who were in the recumbent position; the mean value was found to be 30 ml/kg and 0.41×10^{-3} ml/cm³. Thus, the results of the present study showed that there is little change in TGV in relation to body size from the neonatal period until at least toward the end of the first year of life. FRC in older children appeared to be somewhat higher than that found in this study, but the effect of the different body positions makes comparison unreliable. Values for FRC in the young adults were similar to those in the present study in relation to body weight, but show a considerably smaller FRC in relation to body length³. KRIEGER's values [23], which were also obtained with supine subjects, were substantially higher than those found in newborn infants, in older children, in young adults, and in the present study. There is no explanation for this discrepancy.

The value for SC was similar to that reported in newborn babies (table IV), in older children who had a value of 0.057 ml/cm H₂O/ml FRC [10], and in young adults who had a value of 0.050 ml/cm H₂O/ml FRC [24]. These values, however, could not be directly compared, since the studies in the older subjects were carried out while they were in the upright position. In this position, measurements of intrapleural pressure by an intraesophageal balloon are more accurate [26] and FRC is greater.

In the present study, pulmonary resistance was similar to that reported for newborn infants by other investigators (table IV). KRIEGER [22] studied 24 infants 1 to 24 months of age and found the following mean values: pulmonary resistance, 29 ± 20 cm H₂O/l/sec; inspiratory resistance, 22 ± 17 cm H₂O/l/sec; and expiratory resistance, 37 ± 29 cm H₂O/l/sec. The variation in these values, however, was much greater than that found in the present studies. TGV was not measured in the same group of infants, and KRIEGER did not relate her measurement to any somatic measurement.

MEAD and WOHL [30] measured resistance in a group of healthy infants using the forced oscillation method of DUBOIS *et al.* [13]. This method is advantageous because an esophageal balloon is not required and the study can be performed without sedation. Resistance of the chest wall can also be measured. Values for both inspiratory and expiratory resistance were found to be 46 ± 17 cm H₂O/l/sec.

It was difficult to compare values for resistance in the present study with values found in older children and adults, since most of the latter studies had been carried out while the subjects were breathing through the mouth. In adults, the nasal passage has been shown to contribute between 50 and 70 % of the pulmonary resistance when the subject breathes through his nose [6, 16, 18], and in newborn infants who breathe through the nose, about 25 % of the pulmonary resistance has been due to the nasal passage [28].

With these reservations, there did seem to be a similarity between our results and those of ENGSTROM *et al.* [15], who found that, in older children, conductance was equal to height^{2.67} $\times 0.256 \times 10^{-6}$. Using a body plethysmograph, BRISCOE *et al.* [4] measured airway resistance in subjects between 4 and 80 years of age and suggested a mean value of 0.24 with a range of 0.13 to 0.35 for the ratio of conductance to FRC. The results for pulmonary conductance related to TGV found in the present study were of a similar order of magnitude.

In newborn infants, COOK *et al.* [8] found a mean intraesophageal pressure difference of 5 cm H₂O, a value substantially less than that found in the present study. In adults, MEAD [25] found a range of 3 to 8 cm

H₂O, which was also lower than that in the present series. KRIEGER [22], however, found a mean value of 7.4 cm H₂O, with range of 4.6 to 11.0 cm H₂O.

Thus, the measurements of pulmonary function in the 38 healthy infants studied were generally similar to those reported in newborn babies and in older children and adults when allowance was made for the difference in the sizes of the subjects. As the majority of infants studied were less than 24 weeks of age, it was impossible to determine whether there were any significant changes in the measurements of pulmonary function related to body size during infancy.

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