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Forced oscillation technique for determination of resistance to breathing in children

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Cogswell, J. J. (1973). *Archives of Disease in Childhood*, **48**, 259. **Forced oscillation technique for determination of resistance to breathing in children.** A method for measuring total respiratory resistance (R_T) using a forced oscillation technique was applied to children between 3 and 12 years of age. R_T at midinspiration was higher than airway resistance (Raw) measured on the same children by total body plethysmography. Normal R_T values were compared with results in children with asthma and cystic fibrosis. It is suggested that the technique could have a wider application in the assessment of airway obstruction in children.

Many of the techniques for the measurement of airway obstruction which have been developed for investigation of adults have been successfully applied to children. Indirect methods of measuring flow resistance, i.e. peak expiratory flow rate and timed forced expiratory volume, are perhaps the simplest and most convenient way of assessing obstructive airways disease. However, these simple tests do require the co-operation of the patient and they are in part effort dependent, which limits their application to children under 5 years.

Direct measurements of airflow resistance have been done in children with a pneumotachograph at the mouth and a balloon in the oesophagus to record transpleural pressure changes (Helliesen *et al.*, 1958; Engstrom, Karlberg, and Swarts, 1962). These techniques required sedation and the passage of an oesophageal balloon. Airway resistance measurements have also been made by total body plethysmography in co-operative children (Briscoe and DuBois, 1958; Zapletal *et al.*, 1969; Weng and Levison, 1969). Total body plethysmography is not easy to carry out in children under 6 years, or in very sick children. The need to develop a method for the direct measurement of airflow resistance in unsedated young children without requiring oesophageal balloons or body plethysmography prompted the adaptation of the forced oscillation technique. The method was first described by DuBois *et al.* (1956b), and has been successfully applied to measure total respiratory resistance in animals (Brody *et al.*, 1956), human adults (Fisher, DuBois, and Hyde, 1968; Goldman *et al.*, 1970), and babies (Wohl, Stigol, and Mead, 1969).

The purpose of this paper is to describe the use of the forced oscillation technique in children. The results are compared in the same child with airway resistance measurements (Raw) obtained by body plethysmography. Normal data for total respiratory resistance (R_T) are presented, and use of the technique in the assessment of children with obstructive airways disease is described.

Method

Theory. Total respiratory resistance (R_T) was derived from flow and pressure relations recorded at the mouth of the subject during the application of a sine wave of airflow superimposed at a frequency approximating to the natural frequency of the respiratory system.

When a sine wave of airflow is applied to the tracheobronchial tree the transthoracic pressure changes induced are related to the total impedance of the system. Impedance comprises the vector sum of effective resistance and effective reactance. Reactance is the sum of elastic and mass inertial properties which, for a sine wave superimposed on a linear system, is 180° out of phase. At low frequencies elastic impedance dominates, while at high frequencies inertial impedance dominates. At a certain intermediate frequency, the resonant frequency, elastic and inertial impedance are of equal magnitude, and opposite in sign. The resonant frequency is found where the pressure and flow are in phase, and their relation describes the flow resistance of the respiratory system. In our experiments, the sine wave frequency selected was 5 to 7Hz. This was found to be the natural frequency of the bronchial tree

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in healthy children, and is similar to the natural frequency in adults (Fisher *et al.*, 1968). Because it was found difficult to find resonance in children with obstructive airway disease, the same frequency was selected for all measurements, and no attempt was made to 'tune' to each patient.

Precise tuning was not necessary if measurements were made between certain points of the cycle—namely, the points of zero volume acceleration at the extremes of flow. Between such points elastic and inertial properties do not contribute to the pressure differences, which relate only to flow resistance (Goldman *et al.*, 1970).

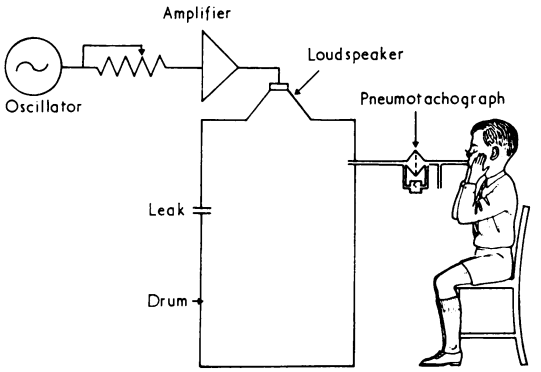

FIG. 1.—*Schematic representation of apparatus.*

Apparatus. Fig. 1 shows a block diagram of the apparatus. The child sits by the equipment and breathes quietly through a pneumotachograph via a soft rubber mouthpiece. The pneumotachograph was mounted in a cone-shaped assembly with a side opening to record airway pressure close to the mouth.

Mouth pressure was sensed with respect to atmosphere by an ether strain gauge transducer. Airflow was measured by a Fleisch (no. 3) pneumotachograph connected to an isovolume differential transducer of high sensitivity.* After amplification, the flow and pressure signals were recorded simultaneously on a direct writing recorder.†

The oscillations were provided by a loudspeaker mounted on a rigid drum connected to the mouthpiece assembly by a wide bore tube. The loudspeaker was driven by a low frequency sine wave oscillator and power amplifier, which was linear down to 2Hz. The system acted in the same way as a sine wave pump, and allowed the frequency and amplitude of the oscillations to be varied.

Other tests of ventilatory function. Normal children, and those with asthma and cystic fibrosis, had other tests of ventilatory function performed on the same laboratory visit.

The peak expiratory flow rate (PFR) was determined by the Wright peak flow meter (Wright and McKerrow, 1959). After explanation and practice, the best of 3 consistent blows was recorded.

The vital capacity (VC) and forced expiratory volume in 0·75 second (FEV 0·75) was determined on a reverse plethysmograph system (Milner, 1971).

Thoracic gas volume (TGV) and airway resistance were measured by total body plethysmography. A constant volume total body plethysmograph was used, designed on the principles described by DuBois, Botelho, and Comroe (1956a). The modifications for paediatric usage incorporated a total volume of 600 l. and walls constructed of transparent acrylic plastic. The instrument was used to measure thoracic gas volume and airway resistance. Measurements were made with the child panting at 90 breaths per minute while the cheeks were supported. Airways resistance was measured on inspiration at flow rates from zero to 0·25 l./sec.

Technique of R_T measurement. Calibration was carried out before each experiment. Mouth pressure was calibrated by a water manometer connected to the ether strain gauge transducer. Calibration of airflow through the pneumotachograph was performed with a rotameter using moist room air at 22 °C.

In practice, the measurement of R_T could be carried out in less than 3 minutes, but attention to detail was essential. The child sat by the equipment and a leak-free seal at the mouth was achieved with a soft rubber mouthpiece. The child was asked to breathe quietly while supporting the cheeks with both hands. The nose was held, or clipped off. When the child was breathing in a relaxed way the oscillator was turned on at 5Hz, and the gain on the amplifier was adjusted so that flow wave deflections of 0·25 l./sec were obtained. 4 to 5 tidal breaths were adequate for analysis.

Analysis of the record. A typical trace is shown in Fig. 2. The volume trace is obtained by electronic integration of flow, and it allows each phase of the respiratory cycle to be identified. In children, the most satisfactory point at which to measure R_T was at midinspiration. R_T results presented in this paper were all made at the midinspiratory point (R_{TI}), and each result is the mean of 3 readings made on different breaths. Only satisfactory sinusoidal pressure and flow waves were selected for analysis. Artefacts, due to leaks at the mouth or complete closure of the glottis, could be identified and were discarded. Very rapid (over 60/min) respiratory rates prohibited accurate analysis.

Subjects

Normal children. 204 normal children took part in the study. Consent from parents and school authorities was obtained. Normal children under 5 years were studied at an adjacent nursery school using portable apparatus. The majority of normal children over 5 years came from schools in the London area. Others were relatives of medical staff, and some were children who had been admitted to hospital before

*Elema Schonander Type EMT 32.

†Devices equipment.

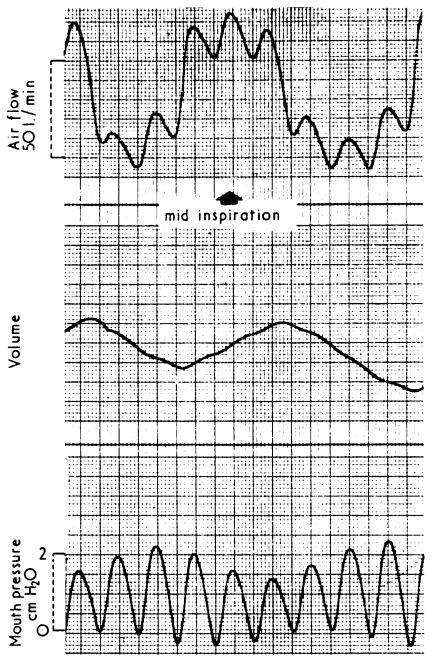

FIG. 2.—*Record obtained during measurement of total respiratory resistance in a normal boy of 12 years. The trace shows the flow and mouth pressure to be 'in phase' at 5 Hz. Total respiratory resistance was derived from the pressure/flow relation at the midinspiratory point.*

minor operations. No child with a history of asthma or lung disease was included.

At each study a record was made of the child's name, age, sex, height, weight (without shoes and outdoor clothes), and arm span. The mean values of the physical measurements are shown in Table I in which the children are divided into 10 cm height groups. The average height and weight of each group was appropriate for age (Tanner, Whitehouse, and Takaishi, 1966), except that an excess of tall 12-year-old children was included.

Children with asthma. 42 children with asthma were studied by the forced oscillation technique. The ages ranged from 2 years 10 months to 12 years 1 month. All had chronic asthma of sufficient severity to require outpatient hospital management. No child was receiving steroid drugs. The clinical severity of their disease varied widely; some were symptom free at the time of study and others had a definite wheeze. The asthmatic children were selected for lung function studies, which included the forced oscillation technique, by the outpatient clinician.

Children with cystic fibrosis. 44 children with cystic fibrosis were studied by the forced oscillation technique. All had had the diagnosis confirmed by sweat electrolyte analysis. The youngest child examined was aged 3 years 1 month. All the children were referred from the outpatient department of the hospital which they attended on a regular basis. The degree of lung involvement was variable.

Results

Reproducibility. Duplicate measurements of total respiratory resistance (R_T) were made in normal 8-year-old children with 1 hour's interval between the 2 determinations. The data are presented in Table II. The mean SD of duplicate measurements was 0·56. The mean % SD of repeated measurements was 12%.

It was not possible to sustain interest in very young children to obtain repeated measurements. In 2 co-operative children, aged 8 and 5 years, studies of R_T were determined repeatedly over a period of 1 hour. Results indicating the change in R_T obtained are shown in Fig. 3.

Normal children. 204 normal children aged 3 to 12 years were studied to establish the accepta-

TABLE I

Physical characteristics of 204 normal children

Height group	Height range (cm)	No.	Mean age (yr)	Mean height (cm)	Mean weight (kg)	Mean span (cm)
I	90–99	11	3·10	97	15·0	95
II	100–109	40	4·6	105	18·0	103
III	110–119	33	5·11	115	21·2	112
IV	120–129	44	7·9	125	25·9	125
V	130–139	38	9·8	135	30·1	135
VI	140–149	24	11·3	143	38·0	145
VII	150–159	14	11·9	154	47·8	153

TABLE II

Reproducibility. Duplicate observations of total respiratory resistance made in 8 healthy 8-year-old boys

Subject	A	B	C	D	E	F	G	H
First measurement R_T	4·4	4·4	4·4	5·8	6·8	3·0	3·6	5·0
Second measurement R_T	6·5	4·8	4·7	4·5	6·3	3·8	2·9	4·7
Mean	5·5	4·6	4·5	5·1	6·5	3·4	3·2	4·8
SD	1·5	0·3	0·2	0·9	0·3	0·6	0·5	0·2
% SD	28·0	6·0	4·7	18·0	5·4	16·7	15·3	4·3

Note: The second measurement was made 1 hour after the first. Each measurement is the mean R_T of 3 readings at the midinspiratory point.

R_T, total respiratory resistance (cmH_2O/l per sec).

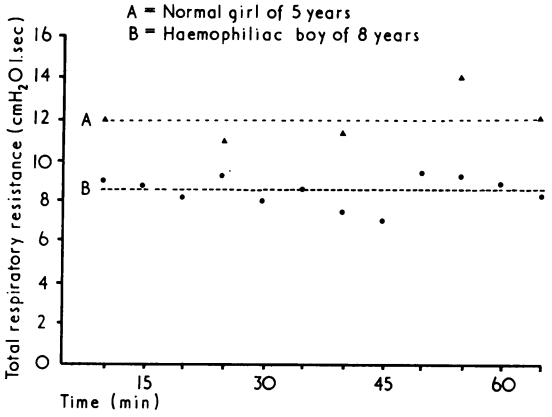

FIG. 3.—*Repeated total respiratory resistance* (R_T) *determinations in 2 children over a 60-minute period.*

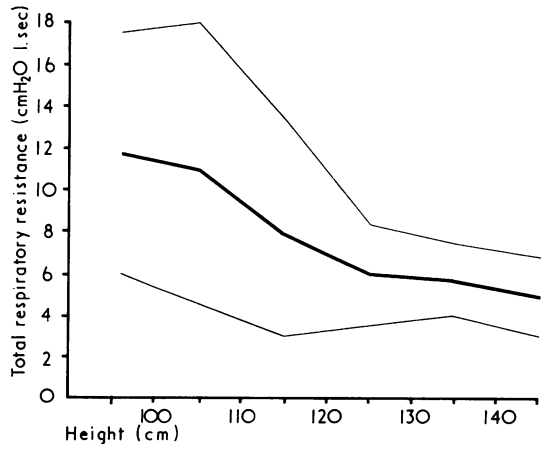

FIG. 4.—*Total respiratory resistance* (R_T) *plotted against height in 204 normal children. The thick line indicates the mean* R_T *of each 10 cm height group. The thin lines represent 2 SDs of the mean.*

bility of the technique and to provide normal data for R_T in this age group.

Results are expressed graphically as a function of height in Fig. 4. The graph indicates the mean R_T of each 10 cm height group together with 2 SDs. 106 of these normal children were old enough to co-operate in plethysmographic determination of airway resistance at the same visit. The mean data determined by both methods are expressed as a function of height in Fig. 5.

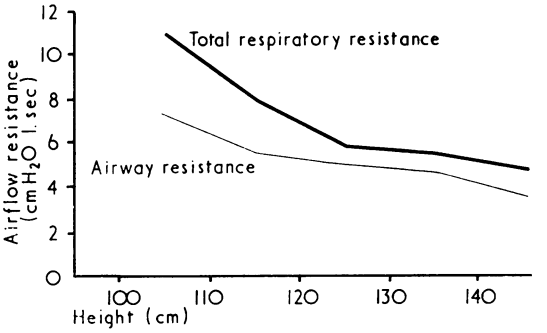

FIG. 5.—*Total respiratory resistance* (R_T) *measured by the forced oscillation technique and airway resistance (Raw) measured plethysmographically plotted against height in 106 normal children. The thick line indicates the mean* R_T *of each 10 cm height group, and the thin line indicates the mean Raw of each 10 cm height group.*

Children with asthma. 42 children with asthma were examined by the forced oscillation technique. Superimposed oscillation frequency of 5 to 6 Hz used for the normal subjects was unchanged, but precise resonance was not present in all cases. R_T measurements were made at mid-inspiration. At the same laboratory visit other tests of ventilatory function were carried out, and results are presented in Table III.

Results of R_T/height are expressed graphically

TABLE III

Children with asthma

Patient	Sex	Age (yr)	Height (cm)	Weight (kg)	Span (cm)	PFR	VC	FEV 0·75	MMEF	MVV	TGV	Raw	R_T
F.H.	M	2·10	90	—	—	110	—	—	—	—	—	—	25·6
J.A.	F	3·3	97	14·9	—	85	—	—	—	—	—	—	15·1
L.M.	M	4·0	97	14·5	95	95	—	—	—	—	—	—	9·8
T.O.	M	4·11	104	18·5	—	160	1260	960	—	—	—	—	7·5
J.P.	M	6·4	119	20·5	114	150	800	620	0·88	20	2050	9·4	10·1
Q.H.	M	6·7	106	17·2	106	40	240	150	—	—	—	—	12·5
G.E.	M	7·4	113	20·2	113	185	1480	1180	1·50	29	1080	8·0	9·1
T.T.	M	7·5	116	20·0	113	200	1000	800	1·00	21	1180	10·2	17·0
D.S.	M	7·6	118	22·5	116	180	1650	960	1·10	46	1680	4·9	5·5
A.D.	M	7·6	119	23·5	121	140	1160	540	0·45	16	1350	10·9	15·7
D.L.	M	7·7	117	20·5	115	170	1280	760	0·95	16	1840	9·5	6·4
J.C.	F	7·10	122	21·2	117	190	1390	1050	1·20	29	1490	9·9	8·8
I.H.	M	7·11	122	22·3	118	215	1850	1400	1·90	21	1310	6·9	10·1
M.M.	F	8·1	124	23·5	123	165	1120	740	0·96	23	1620	5·0	5·0
J.Y.	F	8·6	129	28·2	130	185	1800	1100	1·30	27	1500	4·3	5·8
N.P.	M	8·7	130	25·1	132	45	680	320	0·36	9	2150	12·2	12·8
S.H.	F	8·8	135	28·5	131	180	2000	1300	1·70	10	1310	9·2	10·0
D.M.	M	8·8	127	24·5	—	175	2000	1020	—	—	1820	6·3	8·0
H.W.	F	8·9	120	19·6	119	52	600	260	—	—	2450	25·7	23·8
M.B.	M	8·9	121	24·5	—	210	2090	1130		—	1730	5·3	7·5
C.J.	F	8·10	126	24·8	127	185	1620	920	1·00	24	1810	9·4	12·1
M.N.	M	9·0	123	23·9	123	205	1620	1250	1·60	29	1170	6·4	6·2
D.M.	M	9·0	125	24·0	124	175	1740	1000	0·80	34	2210	8·9	8·3
T.M.	M	9·2	118	23·0	116	245	1800	1300	1·70	26	1820	3·7	3·5
H.W.	F	9·2	122	20·5	121	170	1400	900	1·00	30	1320	9·8	10·2
D.B.	M	9·3	120	22·0	118	145	1800	800	0·70	17	1790	19·9	16·1
C.T.	F	9·6	133	25·5	128	210	1700	1200	1·50	37	1530	9·4	10·1
M.S.	M	9·8	125	23·0	120	130	1680	760	0·80	13	2250	7·3	12·1
C.A.	M	9·8	123	24·5	119	180	1500	1000	1·00	33	1600	6·5	11·2
C.E.	M	9·10	141	34·5	138	210	2600	1050	1·40	32	1500	8·8	9·4
N.B.	M	9·11	121	18·9	123	110	1440	580	0·60	12	2130	14·0	15·6
M.N.	M	10·2	128	26·2	—	180	1750	1250	—	—	2100	5·8	7·9
H.W.	F	10·4	125	24·0	—	105	1100	520	—	—	2170	10·8	18·7
J.M.	M	10·6	140	28·0	140	170	1640	910	1·50	17	2250	7·0	8·3
J.C.	M	10·7	140	34·0	140	310	2430	1700	2·10	25	1230	6·0	7·5
J.M.	M	10·7	140	30·0	139	205	2350	1200	1·20	18	2370	7·0	8·5
E.N.	M	10·8	148	36·0	142	190	1900	950	0·80	24	2660	7·7	8·9
J.M.	M	11·6	145	30·5	—	105	1850	1050	—	—	2270	7·0	7·9
C.W.	M	11·8	138	28·0	142	150	2500	1240	1·20	34	2000	4·7	5·7
W.J.	F	11·9	148	38·5	145	225	2050	1200	1·20	17	3060	5·8	9·5
H.Y.	M	11·10	132	29·0	130	150	1980	940	1·20	32	2700	6·9	6·5
S.K.	M	12·1	134	28·0	136	160	1650	900	0·90	21	2090	15·2	15·0

PFR, peak flow rate (l./min); VC, vital capacity (ml); FEV 0·75, forced expiratory volume at 0·75 second (ml); MMEF, maximum mid-expiratory flow rate (l./sec); MVV, maximum voluntary ventilation (l./min); TGV, thoracic gas volume (ml); Raw, airway resistance (cmH_2O/l. per sec); R_T, total respiratory resistance (cmH_2O/l. per sec).

in Fig. 6, which also shows the mean and ±2 SD for the normal schoolchildren. 23 asthmatic children had R_T values above +2 SD of the mean for healthy school children.

Children with cystic fibrosis. 44 studies by oscillation technique were carried out in patients with cystic fibrosis. 24 studies were carried out on 18 children under 6 years. These children were too young to co-operate in spirometry or plethysmography.

Results of R_T measurements in the children with CF are presented in Tables IV and V. Results of R_T/height for all the children with CF are plotted in Fig. 7. The mean and 2 SDs for the healthy schoolchildren is indicated. 6 children with CF had R_T values in excess of 2 SDs above the mean.

Results of serial observations in 5 patients with CF over a 16-month period are shown in Fig. 8.

Clinical details of these children are summarized here:

M.P. A 4-year-old boy (height 103 cm at first study). CF diagnosed at 4 months. Symptom free, and chest clinically normal. Minimal change on chest *x*-ray. The final R_T determination was made at the time of an exacerbation with radiological evidence of a chest infection.

S.F. A 4-year-old girl (height 102 cm at first study). CF diagnosed at 3 months. Asymptomatic, and chest

TABLE IV

Children with cystic fibrosis under 6 years of age

Patient	Sex	Age (yr)	Height (cm)	Weight (kg)	PFR	R_T
M.C.	M	3·1	89	10·9	80	13·8
T.C.	M	3·3	93	15	40	8·2
H.G.	F	3·3	92	13·3	105	9·0
R.L.	F	3·5	101	19·5	175	12·5
T.B.	M	3·6	95	11·5	90	21·1
A.C.	F	3·6	89	10·9	110	6·8
		4·6	97	15	155	17·0
V.T.	M	4·0	97	15·7	105	11·0
T.W.	M	4·0	111	19·5	190	8·2
S.F.	F	4·0	102	15·6	150	12·7
		4·9	103	15·5	150	8·5
		5·5	108	17	155	10·0
M.P.	M	4·0	103	18	140	11·6
		4·9	105	18	130	9·5
		4·11	109	19	150	15·0
M.W.	M	4·2	93	17	150	13·5
J.B.	F	4·6	98	14·5	160	11·0
R.B.	M	4·7	103	18	170	11·0
I.M.	F	4·9	108	19	160	8·8
M.O.	M	4·11	106	16	180	9·5
A.T.	M	5·0	109	19	170	9·2
		5·6	111	20	170	15·0
A.D.	F	5·2	111	18·5	145	7·0
R.B.	M	5·6	116	19·7	200	6·3

PFR, peak flow rate (l./min); R_T, total respiratory resistance (cmH_2O/l. per sec).

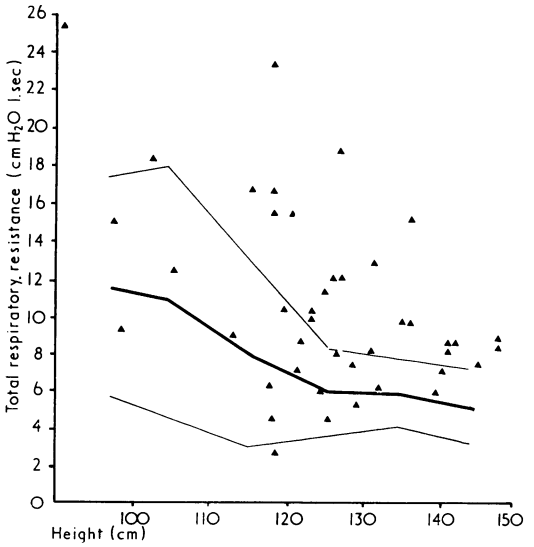

FIG. 6.—*Total respiratory resistance* (R_T) *in 42 children with asthma plotted as a function of height. The mean* $R_T \pm 2$ *SDs for normal children is indicated.*

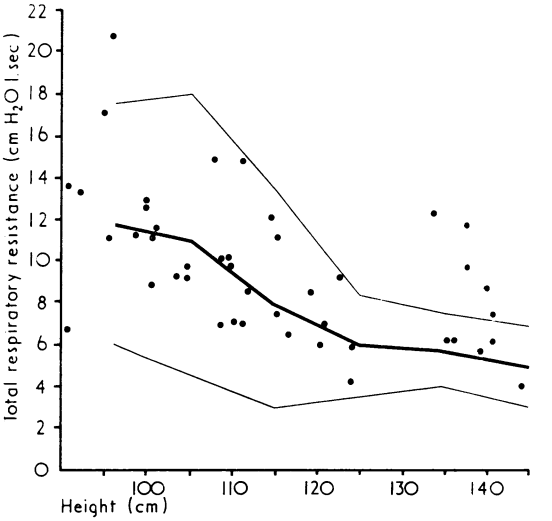

FIG. 7.—*Total respiratory resistance* (R_T) *in 44 children with cystic fibrosis plotted as a function of height. The mean* $R_T \pm 2$ *SDs for normal children is indicated.*

clinically normal. Minimal chest *x*-ray changes. R_T results remained within the normal range.

J.D. An 11-year-old girl (height 123 cm at first study). Productive cough and râles in all chest areas. Fingers clubbed. Chest *x*-ray showed advanced disease. Clinical course fluctuates. There were 2 exacerbations of chest infection in April 1971 and May 1972, both associated with abnormal R_T values.

P.B. A 13-year-old boy (height 160 cm at first study).

TABLE V

Children with cystic fibrosis over 6 years of age

Patient	Sex	Age (yr)	Height (cm)	Weight (kg)	Span (cm)	PFR	VC	FEV 0·75	MMEF	MVV	TGV	Raw	R_T
A.T.	M	6·0	116	21·6		170	1090	840	—	—	1280	11·3	12·5
E.D.	F	6·6	116	21·5	114	165	1200	720	0·80	23	1100	7·0	7·9
P.B.	M	6·6	109	19·5	—	170	1110	850	—	—	—	—	7·0
M.L.	M	7·1	118	21·0	119	170	1600	850	0·90	18	1540	8·8	8·5
C.D.	F	7·3	110	19·0	110	180	1160	920	1·30	21	1000	6·7	7·4
E.D.	F	7·4	121	22·0	—	175	1250	590	—	—	1510	7·7	7·0
P.B.	M	7·6	120	25·0	118	170	1500	840	0·76	26	1970	7·3	6·2
J.R.	M	7·6	116	21·5	110	200	1580	980	1·10	25	1250	10·5	11·6
M.L.	M	7·6	124	22·5	122	175	1600	670	0·85	20	1570	3·3	5·3
J.D.	F	7·7	123	21·0	120	205	1720	1180	1·50	26	1260	6·2	4·0
T.P.	F	8·4	116	18·7	118	210	1520	1080	1·40	23	1110	7·2	9·8
S.B.	M	8·5	123	22·7	123	190	1080	480	0·50	21	1250	6·2	9·0
H.W.	M	9·0	138	25·5	140	140	1280	640	0·50	20	2130	11·4	10·0
J.D.	F	9·2	132	28·0	—	210	1750	1100	—	—	1730	6·7	12·7
C.H.	M	10·4	141	31·5	144	190	1900	1400	2·00	35	1650	4·5	6·5
K.G.	F	10·4	136	35·5	—	185	1170	800	—	—	1730	7·5	6·2
J.K.	F	10·4	138	34·4	—	300	2100	1580	2·00	28	1990	4·0	6·0
S.G.	M	10·11	140	29·0	140	265	2400	1300	1·40	24	2500	6·0	7·8
C.H.	M	12·9	140	30·0	143	220	1500	1200	1·70	24	1360	6·3	8·7
J.B.	M	12·10	136	31·5	137	310	1740	1230	1·40	53	2280	5·9	6·2
C.H.	M	13·9	144	31·8	—	195	1770	1000	—	—	2380	3·7	4·5
P.N.	F	16·6	145	35·5	—	325	2500	2160	—	—	1600	3·3	4·5

PFR, peak flow rate (l./min); VC, vital capacity (ml); FEV 0·75, forced expiratory volume at 0·75 second (ml); MMEF, maximum mid-expiratory flow rate (l./sec); MVV, maximum voluntary ventilation (l./min); TGV, thoracic gas volume (ml); Raw, airway resistance (cmH_2O/l. per sec); R_T, total respiratory resistance (cmH_2O/l. per sec).

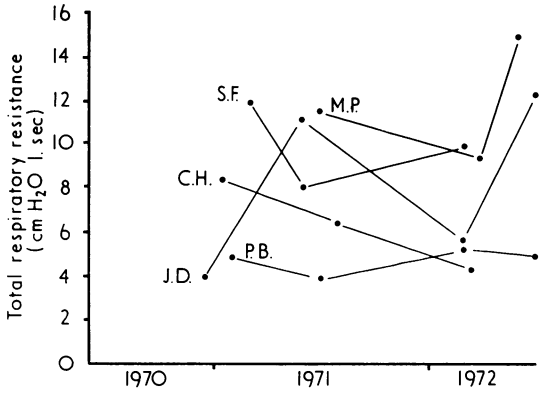

FIG. 8.—*Serial studies of total respiratory resistance (R_T) in 5 children with cystic fibrosis over a 16-month period.*

Little clinical disability, except productive cough. Finger clubbing. Chest *x*-ray showed hyperinflation.

C.H. A 13-year-old boy (height 144 cm at first study). Chest infection was present at time of first study in January 1971, but no recurrence. He has a productive cough and râles in all chest areas. Chest *x*-ray showed moderately advanced disease.

Normal children, and children with asthma and cystic fibrosis, who were old enough to co-operate had whole body plethysmography performed

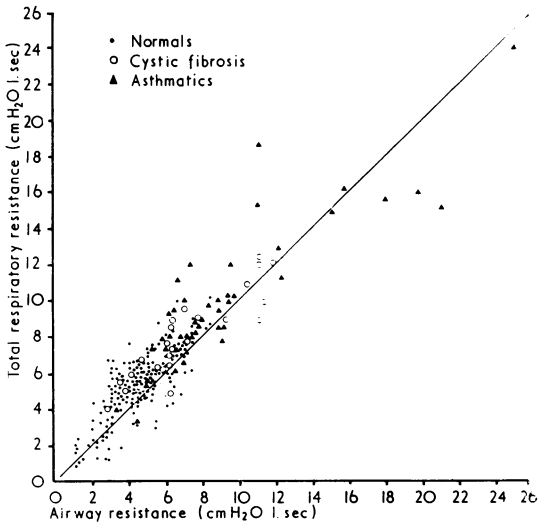

FIG. 9.—*Total respiratory resistance plotted against airway resistance measured in the same child on the same visit. Normal children and children with obstructive airway disease are included. The straight line represents the line of identity.*

at the same visit. The results of airway resistance (Raw) measured by this method, and R_T measured by the forced oscillation technique are expressed in Fig. 9. R_T measured by forced oscillation was

on average 30% higher than airway resistance measured plethysmographically in the same subject at comparable flow rates.

Discussion

The forced oscillation technique has been used to measure total respiratory resistance in adults (Fisher *et al.*, 1968; Goldman *et al.*, 1970) and babies (Wohl *et al.*, 1969). Experience reported here indicates that the method is applicable to children between 3 and 12 years of age. The test is quick to carry out and satisfactory results can be obtained in children under 5 years, an age when other respiratory function tests are not well tolerated. A normal range of R_T values is reported in healthy children. R_T falls with increasing growth of the child. The scatter of normal values is high in the young children.

The technique is applicable to ill children, and causes no discomfort in a dyspnoeic child. Asthmatic children may have values of R_T which are several times greater than the expected mean for healthy children of the same height. Many of the young patients with cystic fibrosis have R_T values within the normal range. There is a tendency for R_T to rise above normal with increasing age, or during exacerbations of chest infection.

Total respiratory resistance by the oscillation technique tends to be higher than airway resistance measured plethysmographically in the same child. There could be more than one reason for this. Airway resistance measured by body box does not include those components of resistance due to lung tissue and chest wall. Though measurements by both methods in each child were made at the same visit, they could not be performed on simultaneous breaths, nor at identical flow rates and lung volumes. The panting manoeuvre could not be used during forced oscillations, and it is possible that there was a contribution of resistance from the partially closed glottis during quiet inspiration. Finally, though the impedance of a healthy lung at resonant frequency does approximate to respiratory resistance (DuBois *et al.*, 1956b), this may not be the case in diseased lungs where physical characteristics are unevenly distributed. It is not possible to exclude the possibility that reactance may be making a contribution to the observed measurements by the oscillation technique in sick children.

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