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Lung volume restriction in patients with chronic respiratory muscle weakness: the role of microatelectasis

M Estenne, P A Gevenois, W Kinnear, P Soudon, A Heilporn, A De Troyer

Abstract

***Background*—It is well established that patients with longstanding weakness of the respiratory muscles have a reduction in lung distensibility. Although this occurs in most patients without any radiographic changes suggesting parenchymal lung disease, it has been attributed to the development of microatelectasis.**

***Methods*—A high resolution computed tomographic (CT) scanner was used in eight patients with traumatic tetraplegia and six patients with generalised neuromuscular disorders to look for areas of atelectasis. With the patient in the supine posture scans of 1 mm thickness were obtained at total lung capacity at intervals of 1 cm from the apex to the base of the lung.**

***Results*—Vital capacity, total lung capacity, and inspiratory muscle strength were reduced to a mean of 59·5%, 73·9%, and 51·1% of predicted values, respectively. Static expiratory lung compliance was decreased in 12 of the 14 patients and averaged 69·1% of the predicted value. The CT scans revealed only small areas of atelectasis in one tetraplegic patient and in one patient with a generalised neuromuscular disorder; no parenchymal abnormality was seen in the other 12 patients.**

***Conclusions*—In many patients with chronic weakness of the respiratory muscles the reduced lung distensibility does not appear to be caused by microatelectasis. It might be related to alterations in elasticity of the lung tissue.**

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Chest Service
M Estenne
W Kinnear
A De Troyer

Department of Radiology
PA Gevenois

Erasme University Hospital

De Bijtjes Institute
P Soudon

Rehabilitation Center, Brugmann Hospital
A Heilporn

Brussels, Belgium

Reprint requests to:
Dr Estenne, Chest Service, Erasme Hospital, Route de Lennik 808, 1070 Brussels, Belgium

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It is now clearly established that the loss of lung volume in patients with longstanding weakness of the respiratory muscles results, in part, from a reduced distensibility of the lung.[1] This reduced lung distensibility has been reported in patients who develop disease in adult life, such as those with traumatic transection of the cervical cord or with poliomyelitis, as well as in patients with muscular dystrophy who usually develop signs and symptoms of the disease in early childhood.[2–8] It is clear, therefore, that failure of development of a normal complement of alveoli is not the primary factor. On the other hand, it is well known that lower lobe atelectasis is a frequent occurrence in patients with severe diaphragmatic weakness.[7 8] Patchy atelectasis has also been found at post mortem examination in many ventilator dependent patients with poliomyelitis.[9 10] Therefore, although in most patients the reduced lung distensibility is present without any radiographic changes suggesting parenchymal lung disease, this alteration has been attributed to dispersed alveolar collapse.[1]

We have used a high resolution computed tomographic (CT) scanner to test this hypothesis directly and have sought to answer the following questions. (1) Do patients with chronic respiratory muscle weakness and normal chest radiographs have areas of atelectasis? (2) If they do, what is the topographical distribution of these areas within the lungs? (3) Are these atelectatic areas large enough to account for the observed reduction in pulmonary compliance?

Methods

Fourteen patients (seven men, seven women) of mean (SE) age 36·1 (4·1) years (range 20–69) were studied. Descriptions of the patients are given in table 1. Eight patients (cases 1–8) had suffered accidental fracture dislocation of the cervical spine between the fourth and seventh vertebrae. They were studied six months to 13 years after injury at a time when they were all tetraplegic and confined to wheelchairs. The other six patients (cases 9–14) had various chronic neuromuscular disorders involving the respiratory muscles. The diagnoses had been made 6–28 years before the study and were based on clinical and appropriate laboratory examinations. None of the 14 patients had a history of respiratory disease although two (cases 1 and 3) were smokers and one (case 14) had previously undergone corrective surgery by the Harrington method for thoracic scoliosis. None of the patients was treated by assisted nocturnal ventilation. At the time of the study all patients were in a clinically stable state and free from respiratory symptoms; none had any evidence of parenchymal disease on anteroposterior chest radiographs.

All pulmonary function tests were carried out with the patient in the sitting position. Total lung capacity (TLC), vital capacity

Table 1 Details of patients with respiratory muscle weakness

Patient no.	*Age (y)*	*Sex*	*Height (cm)*	*Weight (kg)*	*Diagnosis*	*Duration of disease (y)*
1	25	M	187	85	C4–5	11
2	69	F	162	64	C5–6	13
3	47	F	163	44	C4–5	9
4	31	M	176	80	C5–6	6
5	23	M	175	80	C6–7	4
6	22	M	182	60	C6–7	5
7	26	M	187	80	C6–7	0·5
8	33	M	180	70	C6	0·5
9	35	M	184	66	Becker muscular dystrophy	22
10	28	F	150	49	Limb girdle muscular dystrophy	18
11	60	F	154	42	Mitochondrial myopathy	6
12	33	F	152	40	SMA type II	28
13	53	F	160	53	FSH muscular dystrophy	17
14	20	F	156	52	Congenital muscular dystrophy	16

SMA—spinal muscular atrophy; FSH—facioscapulohumeral.

(VC), functional residual capacity (FRC), and residual volume (RV) were determined in duplicate by the closed circuit helium dilution technique (Sensormedics 2400, Sensormedics, Anaheim, California). Pressure-volume (PV) curves of the lung were obtained by a quasi-static method with an oesophageal latex balloon (length 10 cm).[11] The balloon tip was placed in the mid oesophagus and filled with 0·4 ml of air. Recordings of the PV curves were preceded by three full inflations to ensure a constant volume history. Several inspiratory and expiratory curves were performed in each patient and a line of best fit was drawn by eye through at least three sets of PV data that agreed to ±1 cm H_2O. The static recoil pressure of the lung (Pst(L)) was measured at fixed percentages of TLC. Static expiratory lung elastance was calculated above FRC from the linear portion of the PV curve by measuring the change in volume produced by a 5 cm H_2O change in Pst(L). The mean value for lung elastance obtained from at least three PV curves was subsequently converted to its reciprocal to give static lung compliance.[12]

Minimal (inspiratory) pleural pressures (PPLmin) were obtained during maximal static inspiratory efforts at FRC. Pressures sustained for one second were recorded. At least three maximal efforts were obtained in each patient and the lowest value was used as an index of inspiratory muscle strength. Predicted values for lung volumes are from the European Community for Coal and Steel[13] and normal values for the lung PV curves and PPLmin are derived from measurements performed in our laboratory in 120 healthy subjects.[11] Comparisons between predicted and measured values were made with a univariate analysis of variance.

Arterial blood was sampled from the radial artery while the patient was breathing room air in the seated position, and blood gas tensions were measured with an ABL 500 blood gas analyser (Radiometer; Copenhagen). The alveolar-arterial oxygen tension difference ($A\text{-}aDO_2$) was estimated using the alveolar air equation assuming a respiratory exchange ratio of 0·8. Predicted values for PaO_2 and $A\text{-}aDO_2$ are those calculated by Mellemgaard.[14]

CT scans of the lungs were then obtained with a high resolution scanner (Somaton Plus, Siemens AG, Erlangen, Germany). With the patient supine scans of 1 mm thickness were obtained at TLC at intervals of 1 cm from the apex to the base of the lungs; scan time was two seconds, tube current 220 mA, and voltage 137 kV. The images were reconstructed using an ultra high resolution

Table 2 Static lung volumes, lung compliance, and inspiratory muscle strength

Patient no.	*VC (% pred)*	*FRC (% pred)*	*TLC (% pred)*	*RV (% pred)*	*CL (% pred)*	*PPLmin at FRC (% pred)*
1	31	84	59	156	38	50
2	92	65	81	76	72	79
3	51	94	80	138	39	38
4	52	77	67	112	75	48
5	64	94	85	153	104	50
6	54	88	72	134	77	47
7	51	103	81	188	109	57
8	63	79	74	109	65	40
9	85	76	80	67	79	76
10	58	80	75	114	66	51
11	76	88	75	80	76	33
12	50	82	77	137	63	56
13	59	81	70	92	40	47
14	47	57	58	84	64	43
Mean	59·5	82·0	73·9	117·1	69·1	51·1
SE	4·3	3·1	2·2	9·5	5·7	3·5

VC—vital capacity; FRC—functional residual capacity; TLC—total lung capacity; RV—residual volume; CL—static expiratory lung compliance; PPLmin at FRC—minimal pleural pressure measured at FRC.

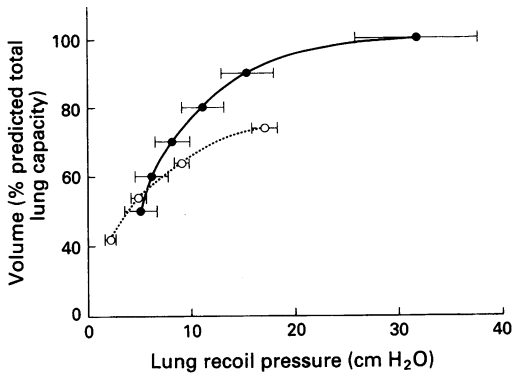

Figure 1 Static expiratory pressure-volume curve of the lung in patients with chronic weakness of the respiratory muscles (open circles); mean data in eight patients with traumatic tetraplegia and six patients with generalised neuromuscular disorders. Closed circles represent mean predicted values. Each bar represents ±1 SE. Volume is expressed as a percentage of the predicted total lung capacity. Note that the curve in the patients is reduced on its volume axis and is substantially flattened.

algorithm with a matrix of 512 × 512 pixels and scored for the presence of atelectasis by a thoracic radiologist (PAG).

Results

All patients had a substantial reduction in inspiratory muscle strength and considerable restrictive ventilatory impairment. As shown in table 2 mean PPLmin was 51·1% of the predicted value ($p < 0·0001$), and VC and TLC were 59·5% and 73·9% of the predicted values, respectively ($p < 0·0001$). The FRC was also reduced in most cases with a mean value of 82·0% of predicted ($p = 0·0001$). In contrast, RV was increased in six of eight patients with traumatic tetraplegia and in two of six patients with generalised neuromuscular disorders. For the patient group as a whole, RV was 117·1% of the predicted value ($p > 0·05$).

The mean expiratory PV curve of the lung obtained in the 14 patients is compared with the predicted curve in fig 1 which clearly shows that the PV curve of the patients was reduced on its volume axis and that Pst(L) was decreased both at full inflation and at FRC. The slope of the PV curve was also reduced. The results in table 2 show that 12 of the 14 patients had a reduced pulmonary compliance giving a mean (SE) value for the group as a whole of 69·1 (5·7)% of the predicted value ($p < 0·001$).

Table 3 Arterial blood gas data and CT studies.

Patient no.	*Pa_{O_2} (kPa)*	*Pa_{CO_2} (kPa)*	*A-aD_{O_2} (kPa)*	*Chest CT*
1	11·55	5·68	1·24	Normal
2	9·79*	5·31	3·48†	Atelectasis
3	12·45	5·57	0·08	Normal
4	10·89	5·43	2·60	Normal
5	11·36	5·28	2·09	Normal
6	12·51	5·27	1·01	Normal
7	13·24	5·01	0·85	Normal
8	13·47	5·01	0·63	Normal
9	9·73*	5·50	3·40†	Normal
10	13·33	4·84	0·47	Normal
11	11·89	5·48	1·69	Normal
12	12·71	5·35	0·27	Normal
13	13·24	4·68	0·43	Atelectasis
14	13·87	4·80	0·09	Normal
Mean	12·15	5·23	1·31	
SE	0·36	0·08	0·31	

Pa_{O_2}—arterial oxygen tension; Pa_{CO_2}—arterial carbon dioxide tension; A-aD_{O_2}—alveolar-arterial oxygen tension difference; CT—computed tomography.
*Values smaller than 2 SD below the predicted ones; †values greater than 2 SD above the predicted ones.[14]

Values of Pa_{O_2}, Pa_{CO_2}, and A-aD_{O_2} obtained during room air breathing are given for each subject in table 3. One tetraplegic patient (case 2) and one patient with a generalised neuromuscular disorder (case 9) had low values of Pa_{O_2} and a slight widening of the A-aD_{O_2}. In the other 12 patients, however, these values were within normal limits with a mean Pa_{O_2} for the group of 12·15 kPa (predicted value 12·60 kPa) and a mean A-aD_{O_2} of 1·31 kPa (predicted value 1·33 kPa).

The CT scans revealed areas of platelike atelectasis in only one tetraplegic patient (case 2) and in one patient with a generalised neuromuscular disorder (case 13). These areas were located in the two lower lobes in case 2 and in the right lower lobe in case 13. As shown in fig 2, however, these areas were small. The other 12 patients studied did not show any parenchymal abnormality. Clinically the two patients with areas of atelectasis did not differ from the others and, in particular, they did not show any clinical sign suggesting diaphragmatic paralysis.

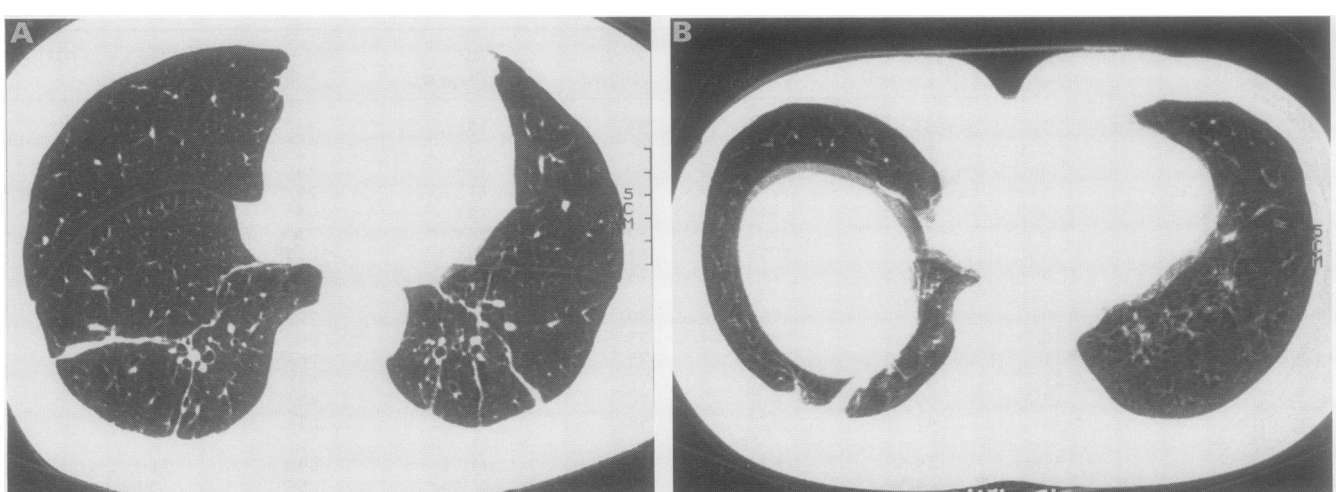

Figure 2 CT scan images of the lungs obtained in (A) case 2 and (B) case 13. Areas of platelike atelectasis are observed in both lower lobes in case 2 and in the right lower lobe in case 13.

Their degree of inspiratory muscle weakness and lung volume restriction was also no greater than in the other patients. Although case 2 had a low Pa_{O_2} and an increased $A\text{-}aD_{O_2}$, these variables were within normal limits in case 13.

Discussion

The alterations in respiratory mechanics found in the patients studied are comparable in all respects to those previously reported in patients with traumatic tetraplegia[3-6] or generalised neuromuscular disorders.[1 2 7 8] All patients had a clear restrictive ventilatory impairment and most had a reduced FRC and a decreased static pulmonary compliance, confirming that the distensibility of the lungs themselves is reduced in such patients.

The reduction in static pulmonary compliance in the patients in this study amounted to a mean of 30%. If this reduction was primarily related to atelectasis about one third of all terminal lung units should be collapsed. Since our patients had no evidence of pulmonary alterations on standard chest radiographs we suspected that this lung collapse was patchy. We therefore used a CT scanner with a particularly high resolution which allows solid structures of 1 mm in diameter to be visualised.[15] No alteration in lung parenchyma was seen in 12 of the 14 patients. Furthermore, the areas of atelectasis seen in the two patients were small and did not account for the measured reduction in pulmonary compliance. It appears, therefore, that dispersed alveolar collapse is not the primary determinant of the reduced lung distensibility in many patients with longstanding weakness of the respiratory muscles.

Two factors would theoretically be capable of reducing lung distensibility in otherwise normal lungs when weakness of the respiratory muscles exists. One mechanism, as suggested by Young *et al*,[16] is a generalised increase in the surface tension of the alveolar lining layer as a result of breathing at a low lung volume. There is ample physiological evidence from acute experiments, beginning with the work in dogs by Mead and Collier,[17] that breathing at a small, constant tidal volume is associated with a decrease in the compliance of the lungs. This disturbance has been well documented both in laboratory animals and in human subjects.[18-20] However, while this alteration is rapidly corrected by a few deep breaths when produced experimentally, it has been shown that the decreased pulmonary compliance of patients with chronic respiratory muscle weakness is not reversed by short periods of positive pressure mechanical hyperinflation of the lungs.[21 22] It is unlikely, therefore, that the reduced lung distensibility in these patients is caused by alterations in surface forces.

The second possible mechanism is an alteration in lung tissue elasticity. Since the elastic properties of a system are partly determined by the stresses to which the system is subjected, the elastic properties of lung tissue might change in patients with respiratory muscle weakness because of their chronically limited range of activity. We are aware of no data which show directly that such patients have abnormal shortening and stiffening of the elastic fibres within their lungs. The lack of improvement after mechanical hyperinflation of the lungs,[21 22] the normal appearance of the lung parenchyma on the CT scanner, and the preservation of normal gas exchange in most subjects (table 3), however, are all consistent with this explanation. The chronically limited range of activity of these patients has also been suggested to explain their reduced rib cage compliance.[5]

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