LUNG MECHANICS IN ANTHRACITE COAL WORKERS' PNEUMOCONIOSIS

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INTRODUCTION

Anthracite has been traditionally in wide use both at home and in industry in Korea and, therefore, anthracite mining has always been one of the major sources of pneumoconiosis. The prevalence rate of pneumoconiosis in anthracite mines reaches at present 14.5% among coalface workers and even 24.3% among rock drillers. Coal mine dust from anthracite mines may have higher concentrations of silica than that found in bituminous coal mines. Morgan[1] reported the existence of higher prevalence rates for both simple and complicated coal workers' pneumoconiosis (CWP). The essential pathological lesion of CWP is the coal macula with its attendant focal emphysema and a little surrounding fibrosis. CWP in miners from the anthracite region is associated mainly with the presence of coal macula but also with smaller number of silicotic nodule.[2] As these lesions involve only the respiratory bronchiole, they could potentially compress or constrict the lumen of the bronchiole. Studies in coal miners with simple bituminous CWP have demonstrated small airway obstruction and slight changes in lung mechanics. However, these physiologic evidences are not detected in coal miners with simple anthracite CWP. The present study was planned to investigate the physiologic evidence of small airway obstruction and significant abnormalities of lung mechanics in anthracite coal miners with CWP.

SUBJECTS AND METHODS

The subjects of this study comprised 178 anthracite coal miners with CWP and 25 normal subjects as a control group. Miners with significant heart or lung disease were excluded. Miners with CWP were divided into two groups. The first group consisted of 148 miners with suspected or simple CWP. This group was selected on the basis of an absence of significant impairment of ventilatory capacity as defined by a $FEV_{1.0}$ to FVC ratio of not less than 70%. The second group consisted of 30 miners with progressive massive fibrosis (PMF). Many of these subjects had airway obstruction ($FEV_{1.0}$/FVC <70%).

Spirometry was performed using a waterless electronic spirometer attached to Autobox system (model CS-828 FC, Chest Co., Japan). Lung volumes and airway resistance were measured in a constant pressure (flow displacement type) both plethysmograph of Autobox system by the methods of DuBois et al.[3] and Woitowitz and Buchheim.[4]

Compliance was obtained as the ratio of the change in volume to the change in transpulmonary pressure. Transpulmonary pressure was obtained by electronically subtracting mouth pressure from esophageal pressure, which was measured by a 10 cm later balloon attached by polyethylene tube to a pressure transducer. The tip of the balloon was positioned approximately 40–45 cm from the nares. Static compliance was measured from the linear portion, just above FRC, of the expiratory limb of the pressure-volume curve obtained over the full VC range. Pulmonary recoil pressure at TLC (Pst TLC) was also obtained from this curve. The coefficient of retraction was calculated by dividing Pst TLC by TLC. Dynamic compliance was measured at respiratory rates of approximately 30 (0.5 Hz), 42 (0.7 Hz), 54 (0.9 Hz) and 72 (1.2 Hz) breaths/min, and calculated by dividing the change in volume by the corresponding change in transpulmonary pressure at points of zero flow over five respiratory cycles and taking the mean value. Frequency dependence of compliance was defined as a fall in Cdyn/initial Cdyn to less than 80%. All measurements were performed in the sitting position.

RESULTS AND DISCUSSION

The subjects with category 3 and PMF were significantly older than those with control and suspected CWP. The subjects with PMF had significantly worked longer underground than those with suspected CWP. (Table I)

Lung function datums of the subjects are illustrated in Table II. No significant differences were found for all measurements among the groups with control and each category of simple CWP. However, RV tended to be rather higher than predicted in all categories of simple CWP. Mean values of $FEV_{1.0}$ and $FEV_{1.0}$ /FVC were abnormally reduced in all categories of PMF, and those of RV and RV/TLC were significantly lower in PMF than in simple CWP. These findings might be related to the airway obstruction.

Mean results of lung mechanics of the subjects are recorded in Table III. Static compliance (Cst), specific compliance (SCst), pulmonary recoil pressure at TLC (Pst TLC) and coefficient of retraction in individual subjects are illustrated in Figures 1, 2, 3 and 4. In suspected or simple CWP, mean values of airway resistance, Cst, Pst TLC and coefficient of retraction were normal. There were no significant differences in these measurements between control group and CWP group. Static compliance was not related to the category of simple CWP and also, no relationship was observed between specific compliance and increasing

Table I

Characteristics of the Subjects by Radiographic Finding of Coal Workers' Pneumoconiosis

(Mean±SD)

Radiographic finding	No. of subjects	Age (yr)	Height (cm)	Weight (kg)	BSA (m^2)	Cigarettes (pack yr)	Time underground (yr)
Controls	25	41.0 ±11.3	168.4 ±5.5	59.8 ±6.8	1.68 ±0.11	17.9 ±12.3(19)	
Suspected	24	43.9 ±6.6	165.2 ±5.0	60.6 ±6.4	1.66 ±0.09	13.6 ±6.6(19)	14.4 ±6.3
SRO	124	45.5 ±7.2	165.2 ±5.5	59.9 ±6.9	1.66 ±0.10	15.3 ±9.7(105)	16.4 ±6.2
Category 1	66	44.9 ±7.5	164.8 ±5.7	59.9 ±6.4	1.65 ±0.10	15.0 ±7.7(56)	15.9 ±6.3
2	41	45.1 ±7.0	165.1 ±5.2	60.3 ±8.0	1.66 ±0.11	16.5 ±11.2(35)	16.3 ±6.1
3	17	48.9 ±5.5	166.7 ±5.4	59.1 ±6.0	1.66 ±0.09	13.7 ±7.3(12)	19.0 ±5.0
LO	30	51.3 ±5.4	164.4 ±6.0	57.8 ±8.0	1.63 ±0.13	9.3 ±10.7(12)	18.2 ±6.4

BSA: body surface area, SRO: small rounded opacity, LO: large opacity, Pack yr: packs of cigarettes per day × smoking years. Parentheses indicated the number of current smoker.

Table II

Lung Function Data in Controls and Miners with Coal Workers' Pneumoconiosis

Radiographic finding	No. of subjects	VC (% pred.)	$FEV_{1.0}$ (% pred.)	$FEV_{1.0}$/FVC(%)	FRC (% pred.)	RV (% pred.)	TLC (% pred.)	RV/TLC (%)	RV/TLC (% pred.)
Controls	25	107.9 ±9.1	100.8 ±11.1	83.7 ±5.6	104.3 ±9.1	129.2 ±25.8	106.4 ±9.1	30.7 ±6.5	107.0 ±15.8
Suspected	24	109.1 ±11.6	100.0 ±10.5	80.6 ±5.9	110.3 ±18.5	139.2 ±32.4	111.4 ±15.4	32.1 ±6.2	109.3 ±18.9
SRO	124	107.7 ±12.5	99.0 ±12.3	79.6 ±5.7	110.1 ±13.3	137.8 ±27.1	107.9 ±10.2	32.7 ±5.7	109.3 ±18.2
Category 1	66	109.6 ±11.6	100.5 ±12.0	79.9 ±5.9	110.6 ±12.1	138.4 ±27.7	109.2 ±9.3	32.2 ±5.8	108.3 ±18.9
2	41	106.3 ±12.8	96.1 ±11.5	78.3 ±5.3	110.1 ±15.5	136.6 ±27.0	106.5 ±11.6	32.6 ±5.3	109.7 ±17.2
3	17	103.9 ±14.7	100.4 ±14.5	81.8 ±5.4	108.3 ±12.4	138.2 ±25.9	106.3 ±9.8	35.0 ±6.1	112.0 ±18.9
LO	30	91.2 ±19.3	66.7 ±25.2	62.5 ±15.9	109.8 ±18.1	159.6 ±43.1	103.6 ±14.7	41.8 ±9.3	128.9 ±27.2
Category A	12	93.1 ±21.2	73.0 ±23.4	66.2 ±13.6	106.5 ±23.3	157.7 ±52.3	104.1 ±17.4	40.4 ±10.0	126.4 ±31.3
B	12	91.8 ±18.2	70.4 ±28.8	64.4 ±15.5	111.9 ±13.6	159.1 ±38.1	104.1 ±12.7	41.7 ±8.8	130.6 ±25.8
C	6	86.1 ±20.0	47.0 ±8.9	51.8 ±18.5	112.5 ±16.1	164.5 ±39.1	101.6 ±15.1	44.7 ±9.6	130.6 ±25.1

Table III

Lung Mechanics in Controls and Miners with Coal Workers' Pneumoconiosis

Radiographic finding	Raw (cm H_2O/l/sec)	MBC (% pred.)	Cst (l/cm H_2O)	SCst (l/cm H_2O/l)	Cdyn (l/cm H_2O)	Pst TLC (cm H_2O)	Coeff. retract. (cm H_2O/l)
Controls	1.16 ±0.24		0.222 ±0.050	0.062 ±0.020	0.186 ±0.053	29.19 ±7.12	4.850 ±1.210
Suspected	1.32 ±0.46	112.5 ±11.5	0.244 ±0.061	0.067 ±0.011	0.187 ±0.058	26.93 ±7.11	4.517 ±1.419
SRO	1.25 ±0.29	107.3 ±14.5	0.229 ±0.069	0.062 ±0.016	0.179 ±0.054	30.30 ±11.51	5.177 ±2.211
Category 1	1.25 ±0.29	109.6 ±14.9	0.239 ±0.067	0.064 ±0.015	0.182 ±0.049	27.52 ±8.79	4.627 ±1.613
2	1.27 ±0.34	104.0 ±13.3	0.225 ±0.072	0.061 ±0.017	0.180 ±0.058	31.97 ±13.57	5.558 ±2.694
3	1.20 ±0.18	106.1 ±14.7	0.201 ±0.060	0.054 ±0.015	0.161 ±0.062	37.03 ±12.55	6.395 ±2.381
LO	2.96 ±2.35	76.7 ±26.6	0.185 ±0.080	0.046 ±0.020	0.132 ±0.068	34.65 ±13.77	6.510 ±3.447
Category A	2.88 ±2.82	81.2 ±22.5	0.195 ±0.089	0.051 ±0.021	0.136 ±0.056	28.97 ±14.22	5.591 ±3.886
B	2.66 ±2.07	81.3 ±31.5	0.214 ±0.088	0.051 ±0.016	0.160 ±0.078	34.06 ±12.90	6.216 ±3.215
C	3.74 ±2.06	52.9 ±9.5	0.106 ±0.025	0.027 ±0.068	0.071 ±0.016	47.20 ±4.76	8.935 ±1.915

Raw: airway resistance, MBC: maximal breathing capacity, Cst: static compliance, SCst: specific compliance (Cst/FRC), Cdyn: dynamic compliance during quiet breathing (23 breaths/min), Pst TLC: static pulmonary recoil pressure at TLC, Coeff. retract: coefficient of retraction (Pst TLC/TLC)

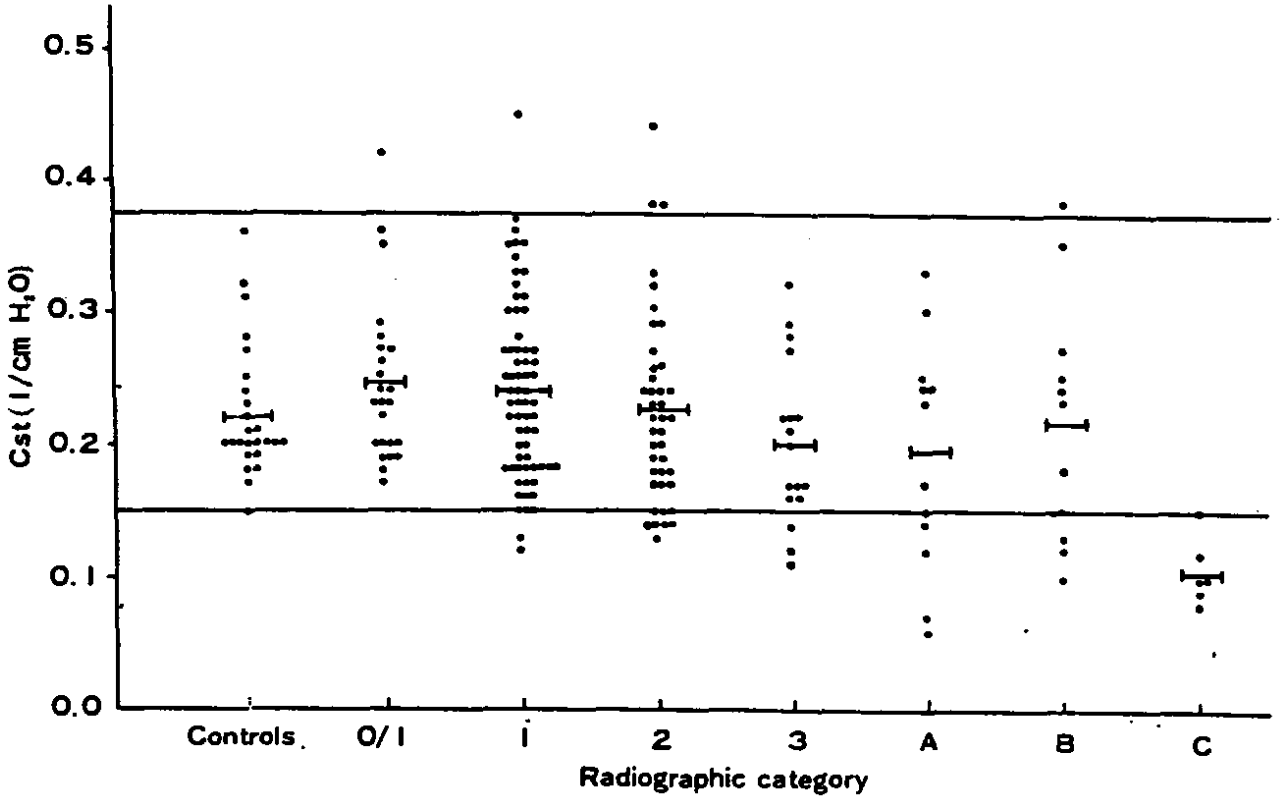

Figure 1. Static compliance in controls and miners with different radiographic categories of coal workers' pneumoconiosis (CWP). Horizontal line represented the normal range and horizontal bar represented the mean value.

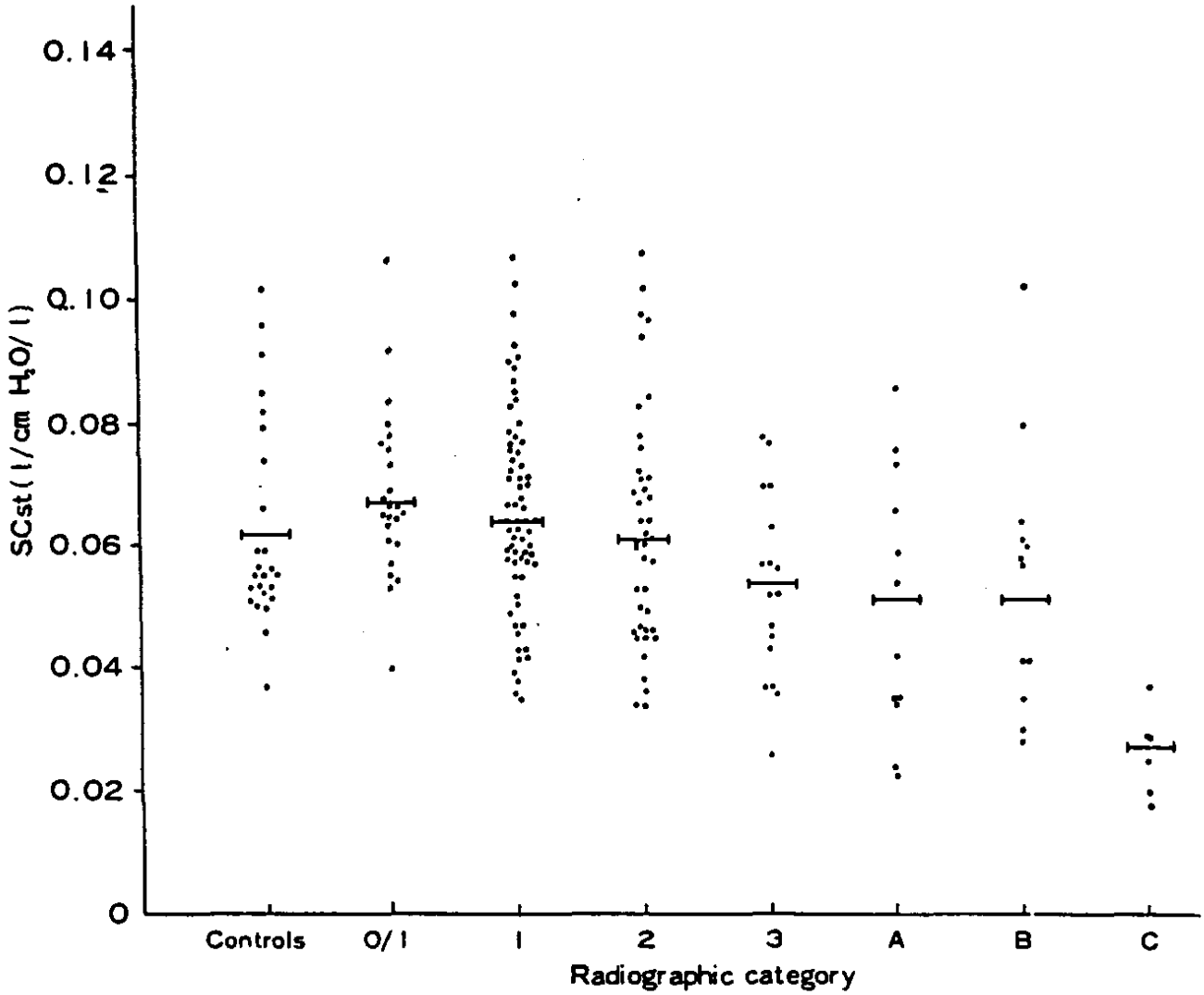

Figure 2. Specific compliance in controls and miners with different radiographic categories of CWP. Horizontal bar represented the mean value.

category of simple CWP. Dynamic compliance at quiet breathing tended to be somewhat lower than static compliance in all categories. Mean coefficient of retraction and number of individuals with higher coefficient tended to increase with increasing category. Subjects with abnormally high coefficient showed 9.1%, 14.6% and 41.2% in category 1, 2 and 3, and those with abnormally low coefficient 22.7%, 14.6% and 0% in category 1, 2 and 3. Pst TLC had the same tendency as coefficient.

In PMF, airway resistance was abnormally increased and mean values of Cst, Pst TLC and coefficient of retraction were normal except category C. A large number of miners fell outside the normal range of Cst and most of these showed values lower than normal, and this was most marked in miners with category C. Dynamic compliance at quiet breathing was lower than static compliance, as in suspected or simple CWP. Similarly, in category C, 5 and 4 of 6 miners showed values of Pst TLC and coefficient higher than normal.

Since the essential pathological lesion of CWP is the coal macula with its attendant focal emphysema and a little surrounding fibrosis, the physiological abnormalities might be detected by the measurements associated with emphysema. These might include an increase in RV and alterations in lung mechanics, such as a high compliance and a low pulmonary recoil pressure and coefficient of retraction. However, if significant interstitial fibrosis were present in the coal macula, these latter changes could be masked and demonstrate a low compliance and a high pulmonary recoil pressure and coefficient.

In a detailed study of lung mechanics in CWP, Ferris and Frank[5] found compliance to be somewhat reduced in subject with complicated CWP. In the subjects with no or simple CWP, there was a wide scatter of compliance value. Seaton et al.[6] studied the lung mechanics in bituminous miners with CWP. In the subject with simple CWP, static compliance was mostly in the normal range, whereas it was

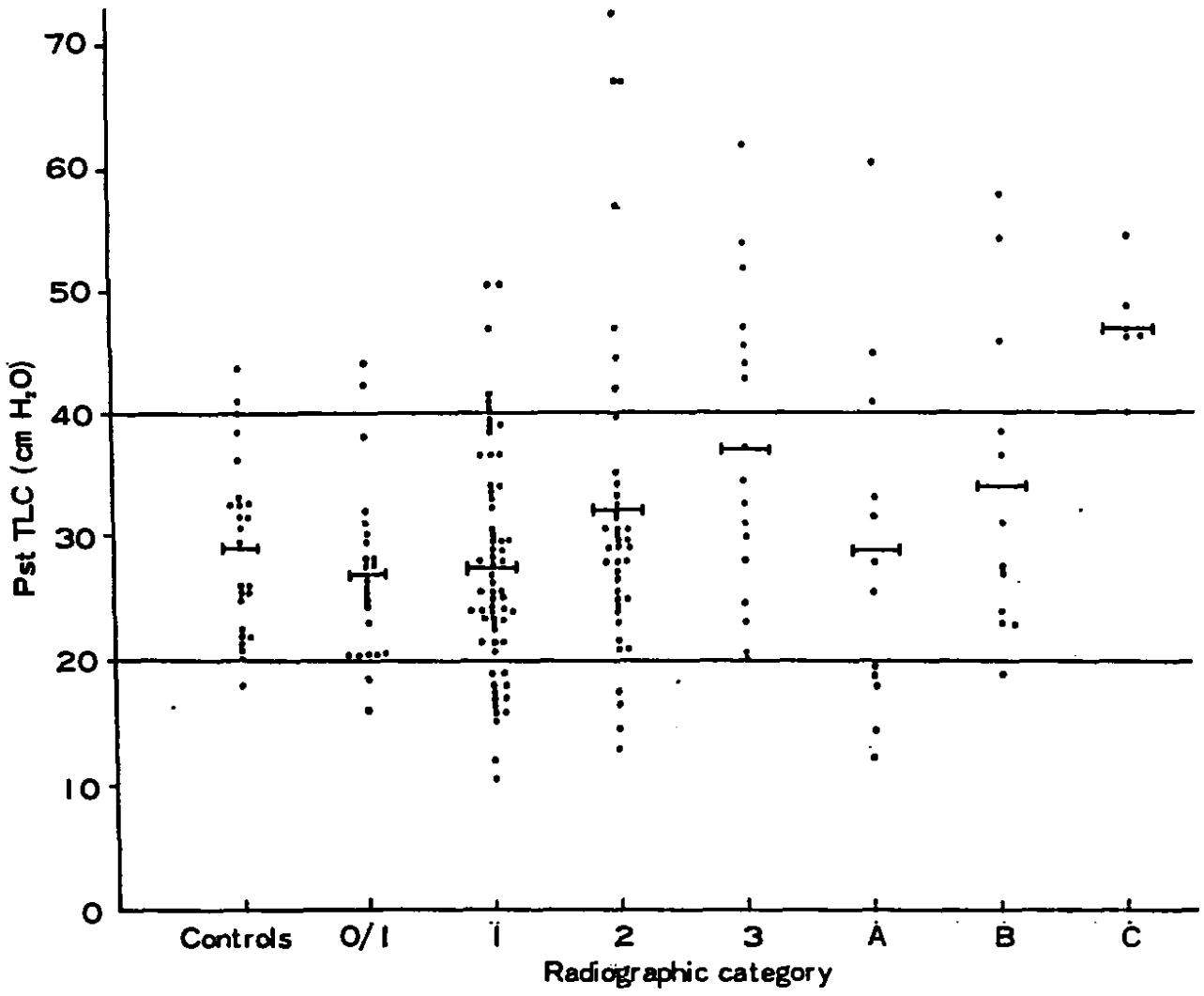

Figure 3. Static pulmonary recoil pressure at total lung capacity in controls and miners with different radiographic categories of CWP. Horizontal line represented the normal range and horizontal bar represented the mean value.

often reduced in complicated CWP. The coefficient of retraction was normal or reduced in most subjects except those with category B and C PMF. They noted that so far as simple CWP was concerned, abnormalities reflected emphysema rather than fibrosis and in severe PMF, changes suggesting fibrosis tended to predominate. Murphy et al.[7] studied a group of 20 miners with simple anthracite CWP and found no significant alterations in lung mechanics. They pointed out that the absence of decreased maximum expiratory flow, a normal coefficient, and a normal specific compliance made significant emphysema most unlikely.

Our findings studied anthracite miners with CWP were similar to the results obtained by the above authors and found a negative correlation between coefficient of retraction and RV, FRC and RV/TLC in miners with suspected or simple CWP. As these measurements correlated with the pathological demonstration of emphysema,[8] a low coefficient may well also be a guide to the presence of emphysema.

If interstitial fibrosis were the predominant change in miners, they should have demonstrated reduced compliance and elevated coefficient and pulmonary recoil pressure. Among the subjects with simple CWP, the number of individuals with abnormally reduced coefficient tended to be more than those with elevated coefficient in category 1 and individuals with elevated coefficient were more than those with reduced coefficient. Among the subjects with PMF, especially category C, most of them had reduced compliance and elevated coefficient. These findings suggested that in simple anthracite CWP, the abnormalities tended to reflect focal emphysema rather than fibrosis in category 1 and fibrosis rather than emphysema in category 3, and in severe PMF, fibrosis tended to predominate.

As the coal macula and the silicotic nodule which are characteristic histological findings of anthracitic CWP are found in relation to the respiratory bronchiole, they could potentially compress or constrict the lumen of the bronchiole.

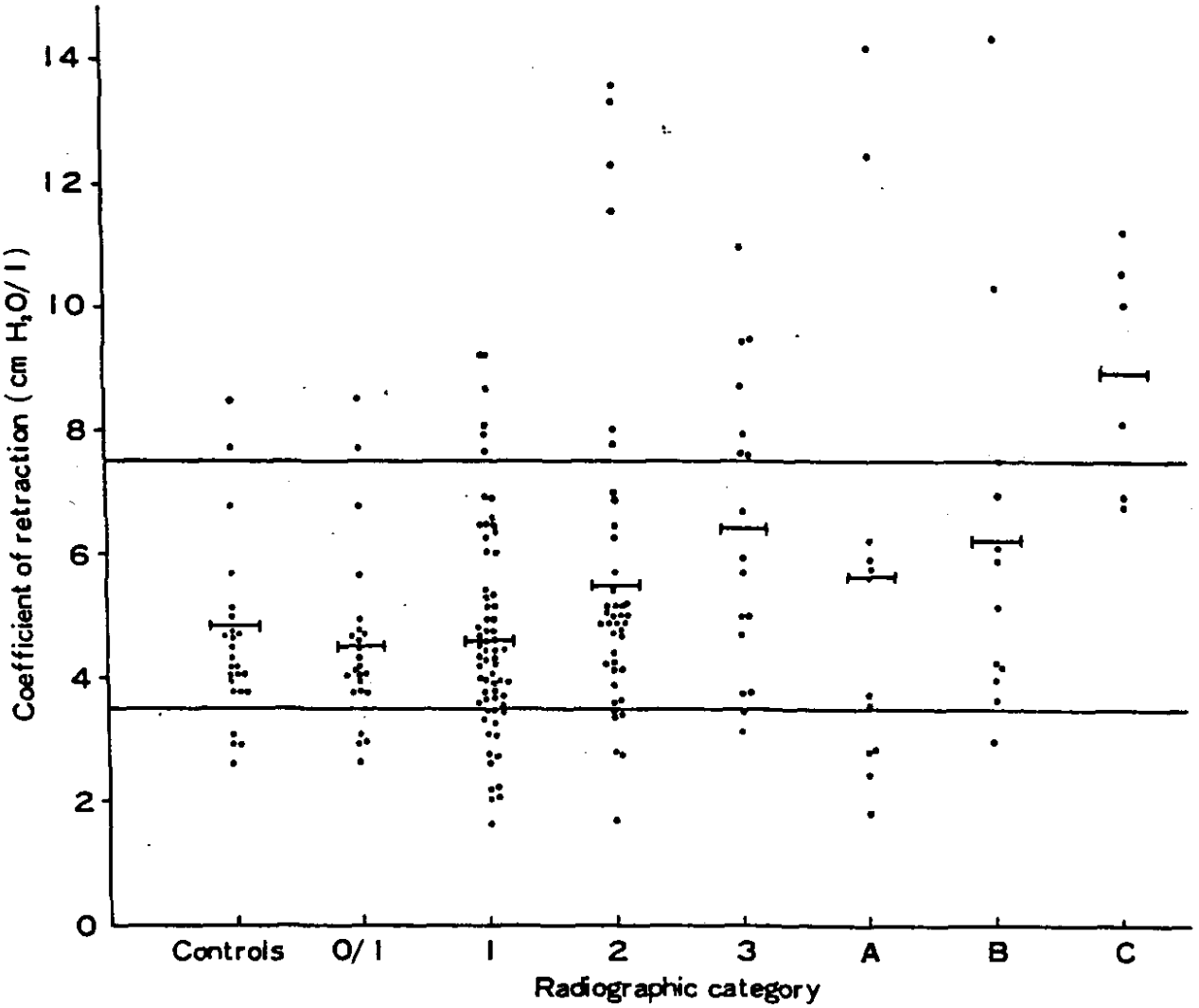

Figure 4. Coefficient of retraction in controls and miners with different radiographic categories of CWP. Horizontal line represented the normal range and horizontal bar represented the mean value.

The technique available to assess the presence of abnormal resistance to airflow through the small airways is the measurement of compliance at increasing respiratory rates.[9] It has been assumed that regional differences in elastic properties sufficient to cause a detectable fall in dynamic compliance at rapid respiratory rates should result in an abnormal static compliance curve. Thus, if a patient has normal pulmonary resistance, spirometry and static pressure-volume curve, a fall in dynamic compliance at faster rates of respiration (frequency dependence of compliance) is most probably due to peripheral airways obstruction. Seaton et al.[6] and Lapp and Seaton[10] noted that 17 of the 25 working bituminous miners with simple CWP demonstrated frequency dependence of compliance, and that this finding did not relate to bronchitis and type of opacity. However, Murphy et al.[7] were unable to detect significant changes in either small airway narrowing and lung mechanics in miners with simple anthracite CWP.

In our study, miners with simple anthracite CWP showed a fall (less than 80%) in dynamic compliance at faster rates of respiration, compared to those with control and suspected CWP. There was no relationship between a change in dynamic compliance at faster rates of respiration and category of simple CWP. (Table IV. Figure 5) In 96 suspected or simple CWP miners with normal spirometry and static pressure-volume curve, the frequency dependence of compliance was observed in 46.9% at 55 breaths/min and in 62.5% at 76 breaths/min. This finding appeared to be the result of increased resistance to airflow in small peripheral airways but was not related to the category of opacity. (Table V)

SUMMARY

The mechanical properties of the lungs were studied on 25 normal subjects, 148 anthracite miners with suspected or simple coal workers' pneumoconiosis (CWP) and 30 miners with progressive massive fibrosis (PMF). The mean values of

Table IV

Dynamic Compliance at Different Respiratory Rates in Controls and Coal Workers' Pneumoconiosis Miners with Normal Pressure-Volume Curve

(l/cm H_2O)

Radiographic category	No. of subjects	Respiratory rate (breaths/min)				
		23	31	43	55	76
Controls	21	0.185±0.054	0.176±0.055 (94.5±8.1)	0.169±0.057 (90.6±9.3)	0.161±0.052 (86.4±8.2)	0.151±0.051 (81.1±9.2)
Suspected	17	0.181±0.040	0.167±0.038 (92.5±8.5)	0.161±0.039 (89.4±15.9)	0.156±0.034 (87.2±15.9)	0.144±0.035 (80.2±16.1)
SRO	79	0.179±0.040	0.163±0.037 (91.4±11.7)	0.157±0.040 (87.8±13.7)	0.145±0.039 (81.2±15.8)	0.124±0.037 (69.4±15.8)
Category 1	46	0.179±0.038	0.165±0.037 (92.2±11.5)	0.159±0.039 (88.4±13.6)	0.142±0.038 (79.5±16.7)	0.120±0.033 (67.6±15.5)
2	26	0.178±0.041	0.159±0.034 (90.7±11.0)	0.154±0.038 (87.9±14.6)	0.147±0.039 (83.4±14.8)	0.126±0.040 (73.4±18.3)
3	7	0.187±0.050	0.166±0.047 (89.4±17.2)	0.157±0.052 (83.5±10.7)	0.156±0.047 (83.5±14.7)	0.137±0.049 (73.4±18.3)

Parentheses indicated the dynamic compliance expressed as a percentage of the initial (23 breaths/min) dynamic compliance.

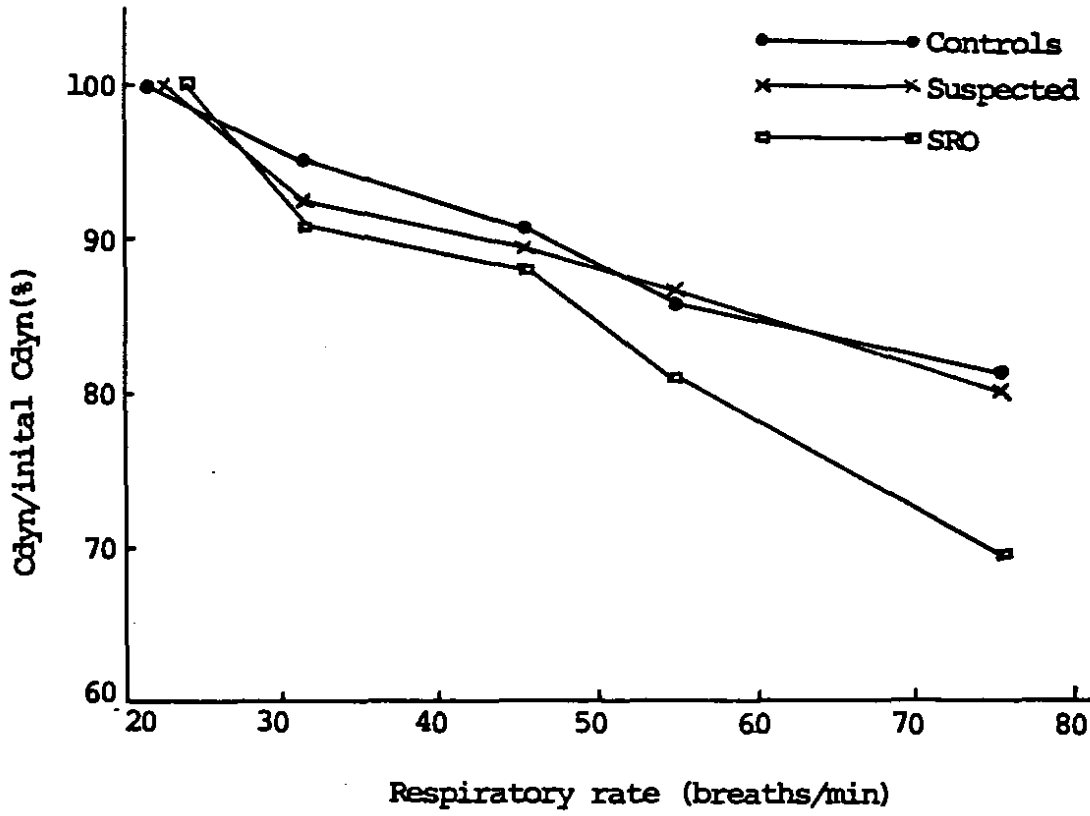

Figure 5. Dynamic compliance with different respiratory rates expressed as a percentage of the dynamic compliance during quiet breathing in controls and suspected or simple CWP miners with normal pressure-volume curve.

Table V

Number of Subjects with Frequency Dependence of Dynamic Compliance in Different Respiratory Rates by the Category of Coal Workers' Pneumoconiosis

Radiographic category	No. of subjects	Respiratory rate (breaths/min)			
		31	43	55	76
Controls	21	—	2 (9.5)	3(14.3)	5(23.8)
Category 0/1	17	1 (5.9)	6(35.3)	7(41.2)	10(58.6)
1	46	6(13.0)	9(19.6)	24(52.2)	32(69.6)
2	26	3(11.5)	8(30.8)	11(42.3)	14(53.8)
3	7	2(28.6)	2(28.6)	3(42.9)	4(57.1)
Subtotal	96	12(12.5)	25(26.0)	45(46.9)	60(62.5)

Frequency dependence of dynamic compliance was defined as a fall in Cdyn/initial Cdyn to less than 80% (Seaton *et al.*, 1972a). Parentheses inidicated the percentage.

static compliance, pulmonary recoil pressure at total lung capacity and coefficient of retraction were normal in all categories of CWP. The static compliance was within normal range in most miners with suspected or simple CWP, whereas it was often reduced in miners with PMF, particularly in category C. The number of miners with higher coefficient of retraction tended to increase in parallel with the progression of pneumoconiosis in terms of the category of opacity. The coefficient of retraction was mostly elevated in miners with category C among PMF. In simple CWP, the abnormalities of lung functions concerned with gas exchange tended to reflect focal emphysema rather than fibrosis in category 1, and fibrosis rather than focal emphysema in category 3. In severe PMF (especially category C), fibrosis tended to predominate. In 96 suspected or simple CWP miners with normal spirometry and static pressure-volume curve, the frequency dependence of compliance was observed in 45 miners (46.9%) at 55 breaths/min and in 60 miners (62.5%) at 76 breaths/min. This finding appeared to be the result of increased resistance to airflow in small peripheral airways.

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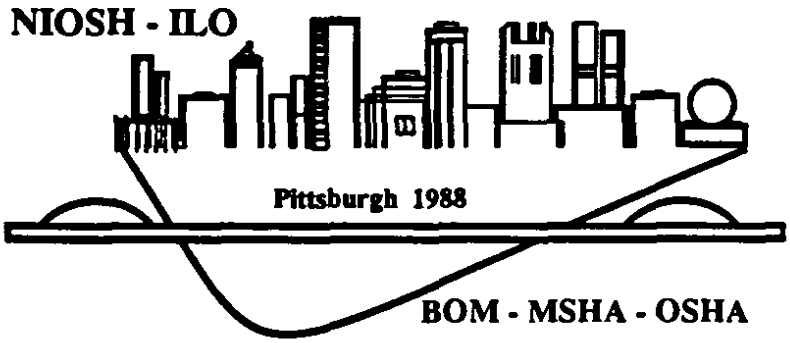

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