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Regional lung function in scoliosis

W. A. LITTLER[1], I. K. BROWN, and R. ROAF

Regional Cardiothoracic Centre, Broadgreen Hospital, Liverpool and
Department of Orthopaedic Surgery, University of Liverpool

Radioactive xenon-133 was used to study the pattern of regional lung function in 35 scoliotic patients and 10 normal subjects in the sitting posture. The scoliotic curves were classified into three anatomical sites: high, if the apical vertebra was located between Th1 and Th5; mid, between Th6 and Th10; and low, between Th11 and L4; only the primary curve was considered and in 70% of the patients this measured more than 60°.

The mean pattern of perfusion in patients with low and mid curves was not significantly different from that of the normals, nor was there any significant difference between the convex and concave lungs in these two groups. Patients with high curves showed three distinct patterns:

(*a*) Subgroup 1 (2 patients): Perfusion was greatest at the apex and least at the base in the concave lung, while the reverse was the case in the convex lung.

(*b*) Subgroup 2 (5 patients): Perfusion in both lungs was greater at the apex than at the base or approximately equal throughout the whole lung.

(*c*) Subgroup 3 (5 patients): Perfusion in both lungs was greater at the base than at the apex. Factors relating to these differences are discussed.

The mean pattern of ventilation in the three groups of scoliotic patients was not significantly different from that of the normals although there was wide individual variation. The only patients to show a significantly abnormal ventilation/perfusion ratio were the high group.

Regional lung volumes calculated from the equilibration scan indicated that in a majority of scoliotics the lung on the convex side of the curvature was larger than that on the concave side.

Our results suggest that both the anatomical site and the angle of the scoliotic curvature have an effect on regional lung function but that this effect falls equally on the convex and concave lungs.

Although much is now known about overall lung function in scoliosis (Bergofsky, Turino, and Fishman, 1959; Zorab, 1969), little work has been done on regional function and the findings of different authors are not always in agreement. There is, as yet, no clear indication as to which lung is the more severely affected by the scoliosis nor is there a proven relationship between regional abnormalities and the site or angle of the curve.

In 1883, Paul suggested that the lung on the convex side of the curvature was the more severely disabled since it was more often the site of such diseases as tuberculosis, pneumonia and emphysema. Seventy years later, Steinmann (1951) made bronchospirometric measurements on a small number of scoliotic patients and concluded that the lung within the concavity of the spine contributed very little to overall function. However, bronchospirometry has several disadvantages: considerable skill is needed to position the catheter in the bronchial tree and the use of a general anaesthetic adds to the risk of the procedure. Small stature and distortion of the trachea can add to the technical difficulties.

The use of radioactive gases for the measurement of regional function has overcome many of these problems (Ball, Stewart, Newsham, and Bates, 1962; Dollery, Hugh-Jones, and Matthews, 1962; Dollery and Gillam, 1963). Dollery, Gillam, Hugh-Jones, and Zorab (1965) studied regional lung function in 10 scoliotics using xenon-133 (^{133}Xe); in the main, they found an evening out of perfusion and ventilation throughout the lungs, and, though they do not stress this point, their results revealed no significant difference between the lungs on the convex and

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[1] Present address: The Radcliffe Infirmary, Oxford

concave sides of the curvature. More recently, Westgate (1968), using a gamma camera to study regional function in scoliosis, found that the lung on the convex side was the worst affected.

The purpose of the present study is to describe the regional distribution of ventilation and perfusion, measured by a ^{133}Xe scanning technique, in a group of 35 patients with scoliosis.

PATIENTS AND METHODS

Thirty-five scoliotic patients were included in this study (Tables I–III). These were young people (mean age 18 years) who had not been in either cardiac or respiratory failure, and who had no detectable diaphragmatic paralysis.

Measurement of the angle of the lateral spinal curvature and localization of the vertebrae involved

TABLE I
SCOLIOTIC PATIENTS: LOW CURVES

Case	Age	Sex	Aetiology	Age of Onset	Direction of Curve	Vertebrae in Primary Curve	Angle of Scoliosis
1	16	F	Poliomyelitis	13	Left	Th8 –L2	50
2	19	M	Idiopathic	11	Right	Th9 –L3	106
3	19	M	Idiopathic	11	Right	Th10–L4	80
4	17	M	Idiopathic	16	Left	Th10–L4	54
5	15	M	Idiopathic	13	Right	Th10–L4	46
6	16	M	Hemiparesis	2	Right	Th8 –L4	45
7	17	F	Poliomyelitis	11	Left	Th10–L4	52
8	19	F	Idiopathic	12	Left	Th10–L4	29
9	19	F	Idiopathic	12	Right	Th8 –L2	57
10	17	F	Idiopathic	15	Left	Th8 –L2	70
Mean	17·4			11·6			59

TABLE II
SCOLIOTIC PATIENTS: MID CURVES

Case	Age	Sex	Aetiology	Age of Onset	Direction of Curve	Vertebrae in Primary Curve	Angle of Scoliosis
11	17	F	Idiopathic	13	Right	Th7–L1	90
12	14	F	Idiopathic	11	Right	Th7–Th11	85
13	14	F	Idiopathic	11	Left	Th6–Th11	30
14	16	F	Osteogenesis imperfecta	10	Right	Th7–Li	88
15	16	F	Idiopathic	12	Right	Th4–Th10	96
16	16	F	Idiopathic	12	Right	Th6–Li	55
17	16	F	Idiopathic	14	Right	Th5–Th12	67
18	20	M	Neurofibromatosis	11	Left	Th6–Li	115
19	19	F	Idiopathic	12	Right	Th6–Th12	68
20	16	F	Idiopathic	11	Right	Th5–Th11	69
21	14	M	Congenital	Birth	Left	Th7–L1	75
22	22	F	Neurofibromatosis	13	Right	Th5–Th12	78
23	18	F	Idiopathic	14	Right	Th6–Th12	76
Mean	16·7			10			76

TABLE III
SCOLIOTIC PATIENTS: HIGH CURVES

Case	Age	Sex	Aetiology	Age of Onset	Direction of Curve	Vertebrae in Primary Curve	Angle of Scoliosis
Subgroup 1							
24	16	M	Idiopathic	5	Right	Th1–Th8	138
26	16	M	Poliomyelitis	2	Right	Th1–Th8	78
Subgroup 2							
29	24	M	Poliomyelitis	2	Right	Th1–Th6	90
30	17	M	Poliomyelitis	6	Right	Th1–Th8	103
31	22	F	Brain abcess	4	Right	Th1–Th7	65
32	21	M	Idiopathic	1	Right	Th1–Th5	70
33	24	F	Idiopathic	Childhood	Left	Th1–Th4	80
Subgroup 3							
25	17	M	Idiopathic	1	Right	Th1–Th7	95
27	19	M	Idiopathic	5	Left	Th1–Th7	64
28	26	F	Congenital	Birth	Right	Th1–Th5	60
34	15	M	Poliomyelitis	2	Right	Th1–Th6	65
35	16	F	Neurofibromatosis	6	Right	Th1–Th5	90

were made according to the method of Cobb (1948). Only the primary curve was considered, and in 70% of the patients it measured more than 60° (Table I).

The curves were classified as high if the vertebra at the apex of the curve was located between Th1 and Th5; as mid if located between Th6 and Th10; and low if between Th11 and L4. In this work the lungs are designated as 'convex' or 'concave', the convex lung lying on the side to which the vertebrae at the apex of the primary curve were rotated.

Ten volunteers were studied concurrently as a control group. They were free of respiratory symptoms, were non-smokers, and had a normal chest radiograph. Their ages ranged from 22 to 39 (mean 30) years. The ethical objections to obtaining adolescent volunteers accounted for the difference in the age range between this normal group and the scoliotic patients.

Regional lung function studies were performed using ^{133}Xe according to the method of Dollery and Gillam (1963). The distribution of radioactivity was measured by scintillation counters that were moved vertically over the lungs during a breath-holding period. Patients were studied at rest in the sitting position. Details of the techniques used have been fully described in previous publications from this laboratory (Brown, Kirk, and Seaton, 1969; Gaziano, Seaton, and Ogilvie, 1970).

Indices for the distribution of blood flow and ventilation per unit alveolar volume were calculated at 2-cm intervals up each lung, according to the formula of West (1967).

For the purpose of displaying and comparing the results each lung was divided into three equal zones, subsequently referred to as basal, middle, and apical zones. The distribution indices for each zone were averaged and then expressed as a percentage of the mean distribution index for the whole lung.

In addition to measuring the distribution of a maximal inspiration of gas from functional residual capacity to total lung capacity, regional 'ventilation' was also assessed by determining the count rate of the gas 30 seconds after the injection of xenon-saline solution and comparing this with the count rate immediately following the injection.

Each patient also performed the following routine lung function tests: (1) the subdivisions of lung volume including vital capacity (VC), functional residual capacity (FRC), and residual volume (RV)—FRC and RV were measured by a closed circuit helium technique (Bates and Christie, 1950); (2) forced expiratory volume in one second (FEV_1) and VC were measured with a pulmometer (Godart); (3) transfer factor for carbon monoxide by the single breath method of Ogilvie, Forster, Blakemore, and Morton (1957); (4) arterial Po_2 and Pco_2 were measured with an E.I.L. Bishop electrode and a Severinghaus electrode respectively.

A standard 6-foot postero-anterior chest radiograph was taken.

RESULTS

These are presented in the form of graphs based on tabulated data which are available on request.[1] Tabulated data for tests of overall lung function are also available.

DISTRIBUTION OF REGIONAL BLOOD FLOW

LOW CURVES (10 patients) The distribution patterns in the convex and concave lungs have been plotted separately for each individual (Fig. 1).

In two patients (cases 2 and 9), the apex was better perfused than the base in one lung, the convex in case 2, and the concave in case 9.

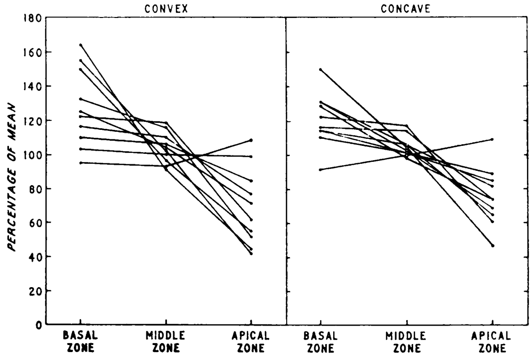

FIG. 1. *Low curves: individual perfusion patterns. Distribution of perfusion between basal, middle, and apical zones in patients with a low curve. Each line represents an individual lung.*

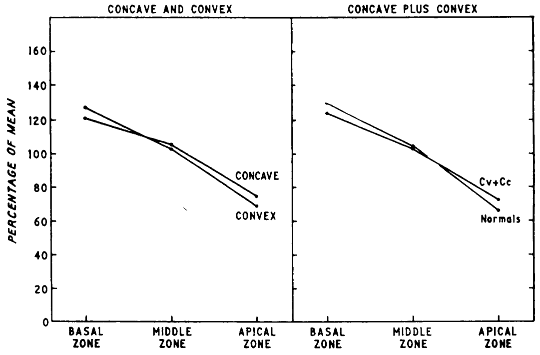

FIG. 2. *Low curves: mean perfusion patterns. Comparison of mean perfusion pattern between convex and concave lungs (left) and between lungs together and normals (right).*

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[1] To: Dr. W. A. Littler, Radcliffe Infirmary, Oxford

In case 4, the perfusion on the convex side was fairly even throughout the lung. The remaining seven cases showed the normal pattern of maximal perfusion at the lung bases. There was no significant difference between the convex and concave lungs in this group ($P>0\cdot05$).

When the mean perfusion gradient of the convex and concave lungs combined was compared with that of the normal subjects (Fig. 2) no significant difference was found between the two groups ($P>0\cdot05$).

MID CURVES (13 patients) The results are shown in Figure 3. In four patients (cases 11, 12, 19, and 23) perfusion was maximal in the middle zone, with the apex perfused as well as or better than the base. This was seen in both lungs in three cases (11, 12 and 23) but only on the concave side in case 19. In the remainder there was a normal distribution of perfusion.

There was no significant difference between the two lungs ($P>0\cdot05$) and the mean pattern of distribution for both lungs combined did not differ significantly from normal (Fig. 4).

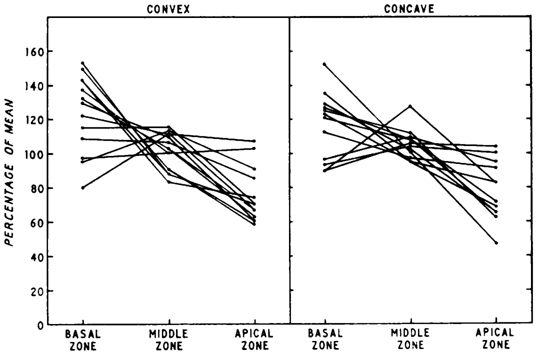

FIG. 3. *Mid curves: individual perfusion patterns (arranged as in Fig. 1).*

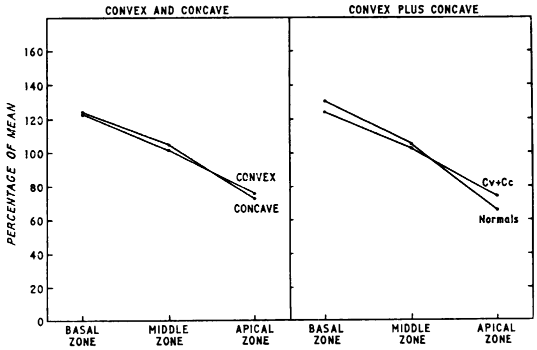

FIG. 4. *Mid curves : mean perfusion patterns (arranged as in Fig. 2).*

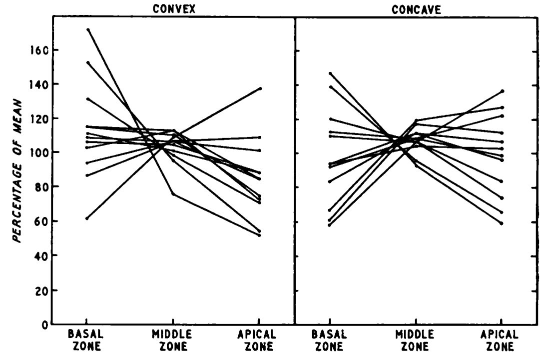

FIG. 5. *High curves: individual perfusion patterns (arranged as in Fig. 1).*

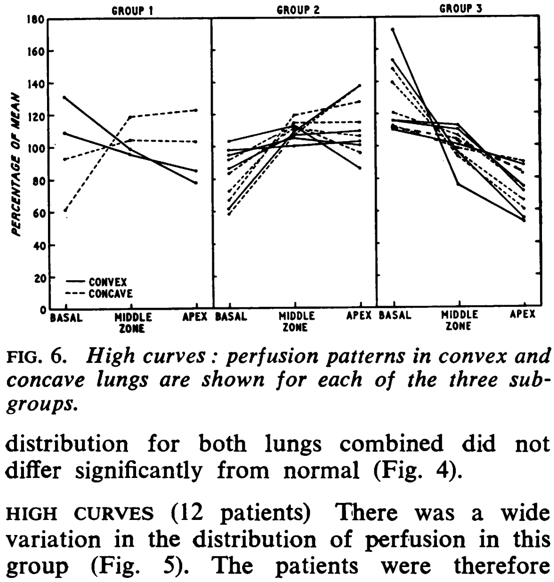

FIG. 6. *High curves : perfusion patterns in convex and concave lungs are shown for each of the three subgroups.*

HIGH CURVES (12 patients) There was a wide variation in the distribution of perfusion in this group (Fig. 5). The patients were therefore divided into three subgroups (Fig. 6).

Subgroup 1 (cases 24 and 26) The perfusion on the concave side was greatest at the apex and decreased down the lung but on the convex side the distribution was normal (i.e., basal perfusion >apical).

Subgroup 2 (cases 29, 30, 31, 32 and 33) The perfusion pattern for both lungs was evened out or reversed, the difference from the normal group being significant ($P<0\cdot005$). There was no significant difference between the two lungs.

Subgroup 3 (cases 25, 27, 28, 34, and 35) The perfusion pattern was similar in the two lungs and did not differ significantly from normal.

Table IV summarizes some of the main phy-

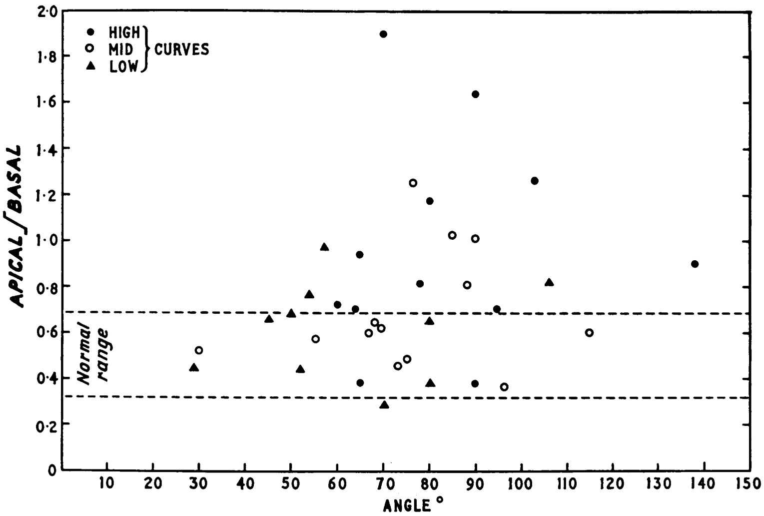

FIG. 7. *Apical/basal perfusion ratio plotted against the angle of curvature for each of the three groups (high, mid, and low).*

TABLE IV

LUNG VOLUMES AND BLOOD GASES IN 3 MAJOR GROUPS: MEAN, STANDARD ERRORS, AND RANGE OF VALUES

	VC (% Predicted)	TLC (% Predicted)	Pao$_2$ (mmHg)	Paco$_2$ (mmHg)
High curves				
Subgroup 1	68·0±18·0	61·5±10·5	80·0±4·0	45·0±0·0
	(50–86)	(51–72)	(76–84)	(45)
Subgroup 2	42·8±16·3	59·4±22·5	72·2±8·7	46·6±3·2
	(25–68)	(53–90)	(66–85)	(42–50)
Subgroup 3	68·8±17·0	75·6±16·7	95·0±6·4	38·4±2·1
	(54–100)	(63–100)	(85–100)	(36–41)
Mid curves	71·8±13·9	83·0±16·4	95·0±6·2	40·4±47·0
	(48–95)	(52–110)	(88–100)	(35–42)
Low curves	90·4±8·3	99·6±15·59	92·0±4·0	37·7±2·9
	(80–100)	(70–116)	(88–98)	(33–41)·0

siological differences between these three subgroups and between the three main groups. Patients in subgroup 2 were more dyspnoeic than those in the other two groups and also had a much greater reduction in their vital capacity with evidence of arterial hypoxia and hypercapnia. On the other hand, patients in subgroup 3 and those in the other two main groups were symptomless and had normal blood gases.

EFFECT OF ANGLE AND SITE OF CURVE

Figure 7 relates the apical: basal perfusion ratio to the angle and anatomical site of the curvature. This ratio was derived by dividing the mean perfusion index for the apical region of both lungs by the corresponding figure for the bases.

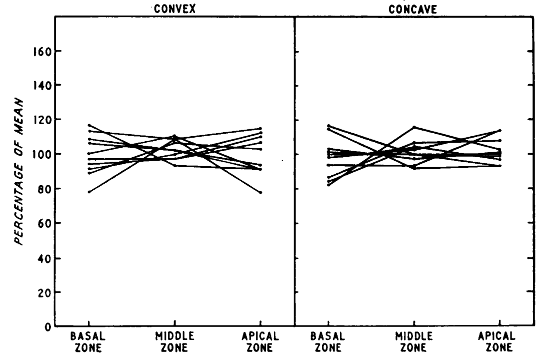

FIG. 8. *Low curves: individual ventilation patterns (arranged as in Fig. 1).*

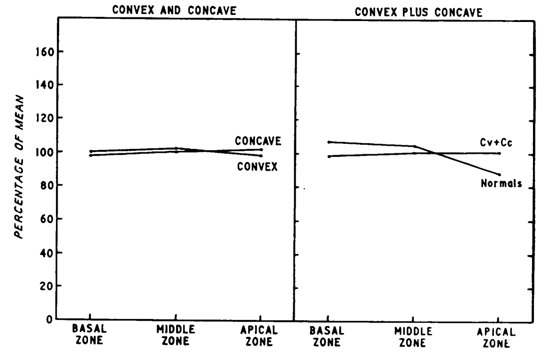

FIG. 9. *Low curves: mean ventilation patterns (arranged as in Fig. 2).*

The ratio tends to increase as the angle increases with all types of curve. It should also be noted that 10 of the 12 high curves showed an abnormally high apical:basal ratio as compared with only 7 of the 23 in the other two groups. This difference was significant ($P<0.05$).

It is concluded that the level of the curve as well as its angle may influence regional perfusion.

DISTRIBUTION OF INHALED ^{133}Xe

LOW CURVES The results are illustrated in Figures 8 and 9. Three subjects (cases 1, 2 and 9) show a peak ventilation in the middle zone in both lungs while two subjects (cases 6 and 7) show a relatively even pattern in both lungs. There was no significant difference between the two lungs. The mean pattern of ventilation does show a deviation from the normal at both apex and base, though this is not statistically significant ($P>0.05$).

MID CURVES Four patients (cases 16, 17, 18 and 19) showed a slight peak of ventilation in the middle zone of both lungs with the basal and apical zones ventilated approximately to the same extent (Fig. 10).

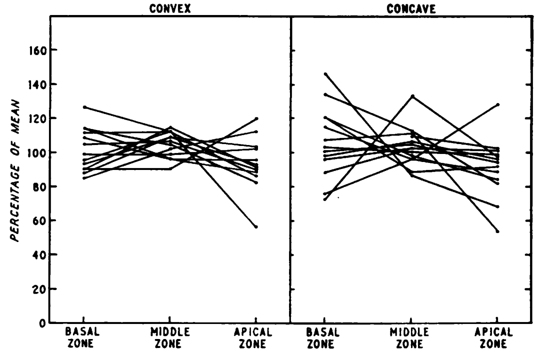

FIG. 10. *Mid curves: individual ventilation patterns (arranged as in Fig. 1).*

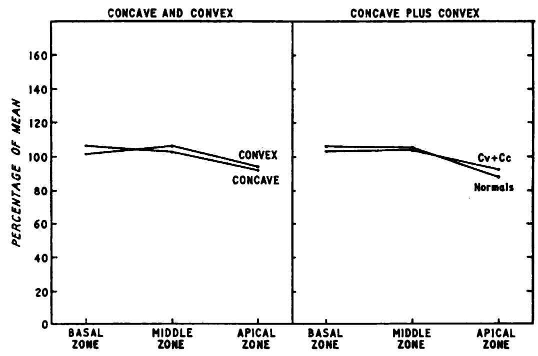

FIG. 11. *Mid curves: mean ventilation patterns (arranged as in Fig. 2).*

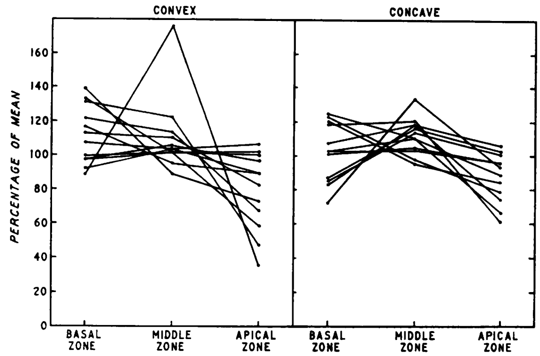

FIG. 12. *High curves: individual ventilation patterns (arranged as in Fig. 1).*

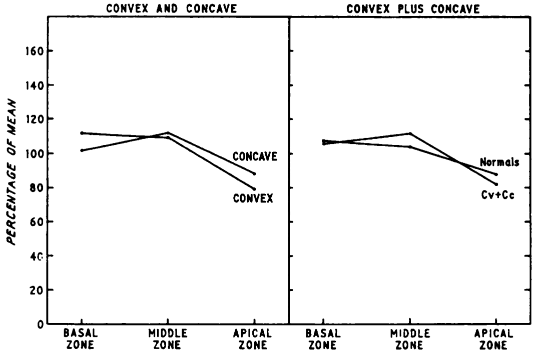

FIG. 13. *High curves: mean ventilation patterns (arranged as in Fig. 2).*

Three patients (cases 13, 15 and 21) showed a greater ventilation at the apex compared with the base in one or both lungs.

However, the mean ventilation patterns for the concave and convex lungs (Fig. 11) did not differ significantly from one another, nor did the group as a whole differ significantly from the normals.

HIGH CURVES The results are shown in Figures 12 and 13 ; it can be seen that there was wide individual variation.

Three patients (cases 26, 31, and 34) showed a peak ventilation in the middle zones of both lungs. A further three patients (cases 25, 29, and 30) showed this middle zone peak in the concave lung only.

One patient (case 27) showed a relatively even pattern throughout the three zones on both sides, while the remaining five showed maximum ventilation at the base, decreasing progressively towards the apex. The mean patterns for the convex and concave lungs showed that on the convex side ventilation was greatest at the base while on the concave side there was a peak in the middle zone. However, these differences were not statistically significant.

This group as a whole showed a tendency towards peak ventilation in the middle zone when compared with normals, although again this was not statistically significant ($P>0·05$).

WASHOUT OF INJECTED XENON

There was no abnormality of xenon washout in any of the three groups; at least 80% of the immediate post-injection activity had disappeared after 30 seconds of normal breathing in every patient.

VENTILATION-PERFUSION (V/Q) RATIOS

The mean distribution of V/Q ratios for each group was determined by dividing the mean ventilation index for each of the three lung zones (basal, middle, and apical) by the corresponding perfusion indices (Fig. 14).

The V/Q ratio is abnormally small at the apex in the high group but all groups have similar V/Q ratios at the base, and only the high group showed a significant overall difference from the normals ($P<0·025$).

LUNG VOLUMES

The count rates obtained during the equilibration scan were used as an index of lung volume, and the mean count rate for each of the two lungs was compared.

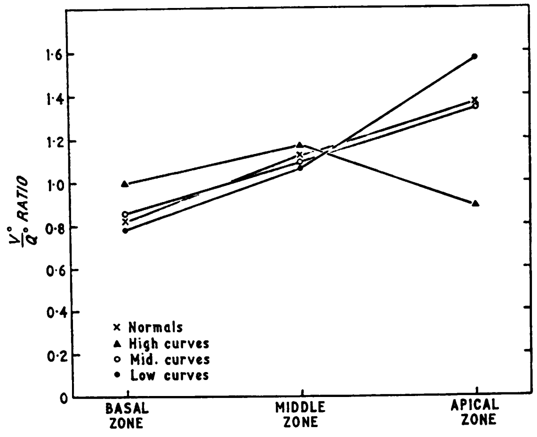

FIG. 14. *Mean V/Q ratios for normals and three scoliotic groups (high, mid, and low).*

In the normal subjects the right lung was found to contribute 53% of the total lung volume. Allowing for this difference, the results for the scoliotic patients were:

(1) Convex lung>Concave 18 patients (52%)
(2) Convex lung=Concave 14 patients (46%)
(3) Convex lung<Concave 3 patients (8%)

There was no significant difference in respect of the volume findings between the high, mid, and low curves.

DISCUSSION

In this study of 35 scoliotic patients, the distribution of blood flow and ventilation was similar in the lungs on either side of the curvature in all but two cases. The two patients who showed a large difference between the two lungs had high curves and similar chest radiographs in which only a thin sliver of lung tissue was visible on the convex side (Fig. 15). It is possible that counters were not always covering lung tissue in their traverse up the convex lung in these two cases and that the results may thus be artefactual. The chest radiograph in scoliosis is deceptive

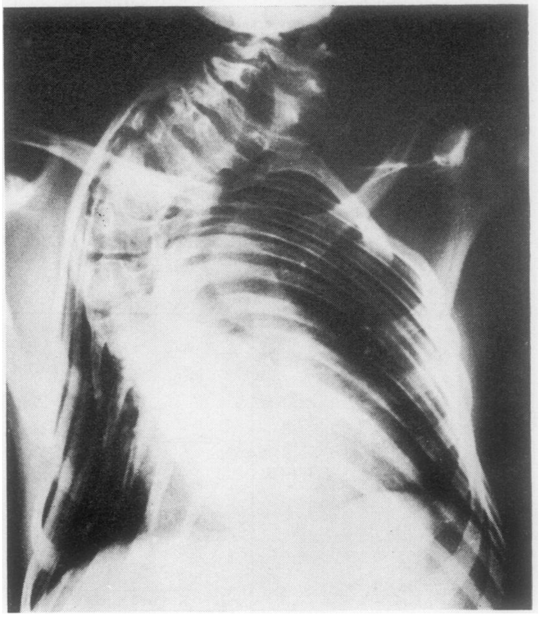

FIG. 15. *Chest radiograph (case 24). Note the apparent lack of lung tissue on the convex side, especially in the upper zone.*

(Simon, 1966). The concave side may appear more transradiant while the convex side seems to be compressed; however, the lung on the concave side often has a reduced anteroposterior diameter while the overlying spine may obscure much of the lung on the convex side. It is therefore not surprising that we found the convex lung had the larger volume in a majority of our patients. Dollery *et al.* (1965) made a similar observation and Reid (1966) found that in six of eight scoliotics coming to necropsy the convex lung was the larger.

Steinmann (1951) suggests that the concave lung contributed little to function on the basis of bronchospirometric measurements in four patients; we have studied one patient by this method with the opposite finding. Bronchospirometry is not an easy investigation in these deformed subjects in whom it may be very difficult to ensure that the Carlens catheter is properly positioned.

Detailed pathological reports (Bergofsky *et al.*, 1959; Naeye, 1961; Reid, 1966) have not supported the view of Paul (1883) that the convex lung was more often diseased, either with respect to the parenchyma or the vasculature. In these more recent studies the two lungs were equally affected.

Patients with low and mid curves, in the main, showed a relatively normal distribution of pulmonary blood flow. Their deformities encroach little upon the thoracic cage and thus do not cause much restriction of ventilation or reduction in lung volume. On the other hand, patients with high curves are more severely deformed; they have a more restrictive pattern of ventilatory capacity, smaller lung volumes, and a tendency towards alveolar hypoventilation. This applies particularly to the members of subgroup 2 who also have the greatest abnormality in the distribution of pulmonary blood flow. The reversed pattern of perfusion (apical greater than basal) may well be a function of the much reduced lung volumes in these cases. At low lung volumes the alveoli at the base are poorly expanded and the contribution of the extra-alveolar vessels to vascular resistance is large. Blood flow is thus relatively reduced at the base and increased at the apex where the lung is more inflated (Hughes, Glazier, Maloney, and West, 1968; West, 1969). A reduction of blood flow at the lung bases has also been observed in patients with a raised pulmonary venous pressure due to mitral stenosis (Dawson, Kaneko, and McGregor, 1965; Seaton, 1970) and left ventricular failure (Ueda, Iio, and Kaihara, 1964). This has been attributed in part to interstitial oedema but it is unlikely that this was a significant factor in producing the abnormal perfusion patterns in our patients. None was in heart failure, and Fishman (1966) did not find a single instance of an abnormally high pulmonary capillary (wedge) pressure in scoliotic patients, even among those in right heart failure.

Pathological studies in scoliotic patients have not demonstrated the type of pulmonary arterial narrowing in the lower lobes that occurs in mitral stenosis, though changes due to pulmonary arterial hypertension certainly do occur (Hasleton, Heath, and Brewer, 1968) and hypoxic pulmonary arterial hypertension has been well documented (Hanley, Platts, Clifton, and Morris, 1958; Bergofsky *et al.*, 1959; Hasleton *et al.*, 1968). Furthermore, Dollery and Hugh-Jones (1963) showed that in all types of pulmonary arterial hypertension, with or without venous hypertension, the flow difference between the apex and the base was abolished. Thus hypoxia could be responsible for redistribution of blood flow; three of our patients were hypoxic at the time of study and all three had abnormal patterns of perfusion.

The only investigation similar to our own was by Dollery and his colleagues (1965). However, three of their 10 patients were older than those in our study (34 to 43 years) and also had chronic bronchitis. An analysis of their results in individual patients reveals examples of each of the patterns that we have observed. These workers did not relate their findings to the anatomical site of the spinal curve, but our results suggest that the site as well as the angle of the curve is important in producing regional abnormalities of blood flow.

No consistent abnormality in the pattern of ventilation was found in the present series. We accept that the distribution of a single breath after inspiration from functional residual capacity (FRC) to total lung capacity (TLC) reflects only one aspect of regional ventilation, but the xenon washout studies were also normal. Dollery *et al.* found that their three bronchitic subjects had the most abnormal ventilation patterns, but patients with bronchitis were excluded from our study.

We are grateful to Mr. Robert Owen for allowing us to study patients under his care and to Dr. Colin Ogilvie for constant encouragement and advice. We should like to thank Dr. C. C. Evans, Dr. J. L. Cunningham, Miss S. Williams, Mrs. M. Deakin, and Mr. M. C. K. Tweedie for their help with various aspects of this work.

The material of this paper forms part of a larger work which has been submitted by one of us (W. A. L.) for the degree of Doctor of Medicine in the University of Liverpool.

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