Influence of spinal deformity on pulmonary function, arterial blood gas values, and exercise capacity in thoracic kyphoscoliosis

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ABSTRACT

Objective: To evaluate the influence of thoracic spine curvature on lung parameters in kyphoscoliosis.

Methods: Twenty-one patients with kyphoscoliosis were evaluated at the Vallabhbhai Patel Chest Institute, Delhi, India from January to June 2006 using spirometry, arterial blood gas (ABG), and 6-minute walk test. The degree of spinal deformity was measured by Cobb's method for angle of scoliosis and angle of kyphosis.

Results: There were 13 males and 8 females (mean age 47.38±20.10 years). Decreased lung volumes, hypoxemia, arterial oxygen desaturation, and decreased exercise capacity was observed in patients with kyphoscoliosis. The angle of scoliosis ranged from 60-126° (78.1±18.3) and angle of kyphosis ranged from 5-48° (18.05±10.5). The forced vital capacity (FVC) was 1.92±0.8 L (0.66-3.44), and the forced expiratory volume in one second (FEV_1) was 1.51±0.5 L (0.6-2.6). The FEV_1/FVC was 60.9±12.9 (42-86%). The partial arterial oxygen tension was 51.7±6.9 Hg. The partial pressure of carbon dioxide in arterial blood was 49.85±7.9 mm Hg. The functional oxygen saturation was 84±3.7%. No correlation was found between pulmonary function test (PFT) or ABG values with the degree of spinal deformity. Mean oxygen desaturation (87.48-84.43%) and rise in systolic blood pressure (118.48-126.67 mm Hg) during walk test correlated well with degree of spinal deformity.

Conclusions: The severity of pulmonary impairment could not be inferred from the angle of scoliosis alone. The 6-minute walk test gives an early indication of limitations and correlates well with structural deformity. The PFT and ABG parameters do not correlate well with the severity of deformity. Thus, the 6-minute walk test must be included in the thorough evaluation of all patients with kyphoscoliosis.

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Curvature of the spine is said to occur in 10% of the population, with one in 10,000 people having deformities greater than 70°.[1] Kyphoscoliosis shows a female predominance. Respiratory function abnormalities are common in kyphoscoliosis and may lead to cardio respiratory failure and death. Many studies have examined the relationship of pulmonary function to the angle of scoliosis, establishing that pulmonary impairment increases with the angle of scoliosis.[2,3] Patients with Cobb angles of at least 100° may develop cardio respiratory failure, while patients with angles of 70° are at risk of progressing to 100°, and hence, at risk for developing complications.[1] The severity of pulmonary impairment cannot be identified to a clinically useful extent from the angle of scoliosis alone.[4,5] Non skeletal factors also influence the pulmonary function in kyphoscoliosis and these include age at onset, duration of deformity, and concurrent respiratory disorders.[5,6] This study evaluates 22 patients of kyphoscoliosis using chest radiographs, CT scans, pulmonary function tests, blood gas measurements and 6-minute walk tests. Structural deformity, seen in thoracic kyphoscoliosis, results in the scoliotic lung, but this is seldom evaluated by the pulmonologist. To fully assess the severity of the scoliotic lung, besides measuring the impairment in pulmonary functions, the severity of structural distortion, the exercise capacity, and comorbid diseases should also be assessed.

Methods. Thirteen males and 8 females with kyphoscoliosis were studied. Age at onset of the spinal deformity varied from birth to 40 years. The current study was carried out at the Vallabhbhai Patel Chest Institute, Delhi, India from January to June 2006. The study was approved by the ethics committee, and informed consent from the patients was obtained prior to the commencement of the study. Measurements of pulmonary function included forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), FEV_1/FVC, and forced expiratory flow (FEF^{25-75}). Normal values were predicted from age, gender, and non deformed height (arm span).[7] Spirometry was performed on a dry, rolling-seal spirometer of the Transfer Test C model lung function machine (PK Morgan, Kent, UK). Maximal expiratory flow volume (MEFV) curves were obtained as per the American Thoracic Society (ATS) recommendations. Three acceptable and at least 2 reproducible curves were obtained in each subject. The selection of spirometry parameters, FEV_1 and FVC, was carried out as per ATS recommendations. Resting blood gases (on room air, sitting position) were obtained from the radial artery and analyzed immediately on a blood gas analyzer (ORVIM, International laboratories, Milan, Italy). Standard 6-minute walk test were performed. Subjects were instructed to walk as far as possible in 6 minutes, stopping if necessary. However, no active encouragement was given. Oxygen saturation (SaO_2) was monitored using a finger electrode (Medaid, Palco, 305, USA), and minimum desaturation was recorded for each test. Walking distance and recovery time to starting SaO_2 on completion of the walk were also recorded for each test, along with the number of stops and their duration. Breathlessness was assessed at the start and finish of each test. Spinal deformity was assessed from anteroposterior (AP) and lateral spinal radiographs. The following assessments of spinal deformity were made (**Figure 1**). Angle of scoliosis (Cobb method), was assessed from an AP spinal radiograph. Angle of kyphosis (Cobb method) was assessed from a lateral spinal radiograph. Inclusion criteria for the study was angle of scoliosis $\geq$60° and angle of kyphosis $\geq$5°. All patients with associated pulmonary parenchymal disorders that would have altered the spirometry values were excluded.

The data were statistically analyzed using SPSS (version 11.5) computer software package and Graphpad software Prism 4.0 version. Independence of the attributes was compared by use of Chi-square contingency table analysis. Comparisons of the means in the groups were carried out using the student's t-test. A significance level of p<0.05 was accepted for all analysis. Non parametric t-test was also used. Data are expressed as means, standard deviations (SD) and significant (2 tailed) test for non-parametric data.

Results. The patients being evaluated in the present study came to the out patient department with complaints ranging from dyspnea, cough, and exertional shortness of breath. Two had a history of smoking. Their clinical characteristics are described in **Table 1**. The lung volumes were generally decreased in all patients as shown in **Table 2**. On an average, spirometry showed a mild non-obstructive ventilatory defect. The FVC was 1.92±0.8 L (0.66-3.44) and FEV_1 was 1.51±0.5 L (0.6-2.6). The ratio of FEV_1/FVC was 60.9±12.9 (42-86%). The correlation between the angle of deformity and spirometry values is depicted in **Figure 1**. Arterial blood gas measurements were made in all patients at rest, breathing room air. The arterial oxygen saturation was below the normal range of 95-97%. The SPO_2 was 84±3.7% in the 21 evaluated cases. The partial arterial oxygen tension (PaO_2) was 51.7±6.9 Hg (**Figure 2**). The carbon dioxide tension ($PaCO_2$) was 49.85±7.9 mm Hg. Blood pH values varied between 7.333 and 7.441 (**Table 3**). On the 6-minute walk test, all patients showed a fall in oxygen saturation. None of the 21 patients needed to stop during walking tests. The respiratory and heart rate pre and post test values are as in **Table 4**. Mean oxygen desaturation (87.48-84.43%) and rise in systolic blood pressure (118.48 to 126.67 mm Hg) during the 6-minute walk test were observed (**Table 4**). These correlated well with the degree of spinal deformity (p<0.05). Fifteen scoliotic curves were convex

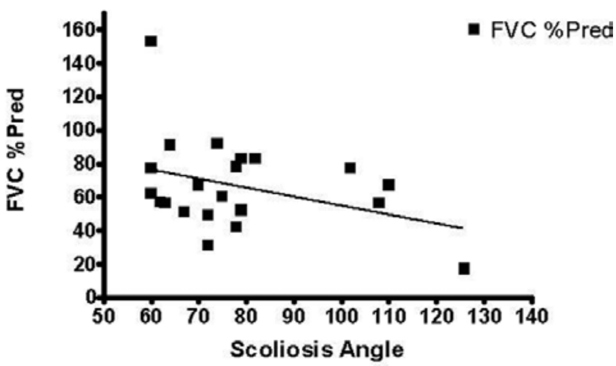

Figure 1 - Scatter plot of forced vital capacity (FVC) % predicted related to angle of scoliosis (p=0.107).

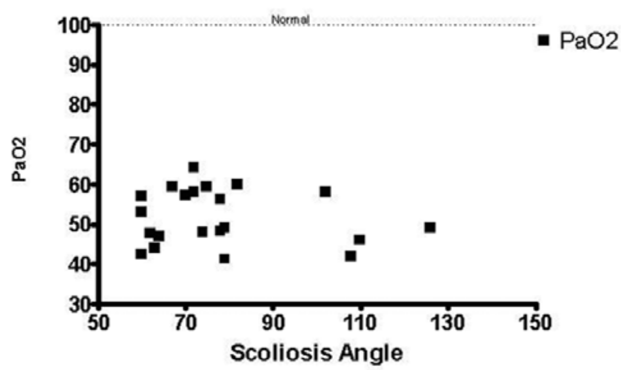

Figure 2 - Partial pressure of oxygen (PaO_2) at room air (mean = 51.73; SD=6.93) related to the angle of scoliosis.

Table 1 - Patient characteristics.

Serial no.	Age	Gender	Heights	Arm span	Age at onset (years)	Scoliosis angle	Kyphosis angle
1	33	F	130	149	5	126	48
2	56	F	136	152	4	72	10
3	31	M	139	141.7	2	70	5
4	38	F	140	147	5	67	9
5	18	M	139	141	7	75	19
6	75	F	132	133	3	78	5
7	62	M	166	166.5	40	60	18
8	22	M	152	163	0	78	21
9	26	M	140	141	0	62	22
10	56	M	162.6	166.5	5	79	18
11	22	M	140	141	4	108	20
12	18	F	139	142.7	3	60	19
13	56	M	147	149	40	102	26
14	80	F	144	148	15	82	10
15	60	F	135	137	20	72	21
16	67	M	155	162	35	64	24
17	55	M	152	157	12	79	17
18	40	M	163	170	10	60	10
19	80	F	130	139	6	110	38
20	45	M	160	164	15	63	12
21	55	F	154	160	7	74	7

Table 2 - Pulmonary function test.

Serial no.	Scoliosis angle	Kyphosis angle	FVC obs	FVC% pred	FEV_1 obs	FEV_1% pred	FEV_1/FVC
1	126	48	2.56	17	2.5	16	60
2	72	10	2.4	49	2.4	47	86
3	70	5	1.47	67	1.47	35	44
4	67	9	0.95	51	0.95	39	67
5	75	19	1.4	60	1.4	33	48
6	78	5	2.16	42	2.16	40	42
7	60	18	1.43	153	1.43	122	65
8	78	21	1.72	78	1.72	65	76
9	62	22	1.16	57	1.16	44	60
10	79	18	0.66	52	0.66	38	60
11	108	20	1.12	56	1.12	42	67
12	60	19	2.42	62	2.42	70	71
13	102	26	3.44	77	1.5	44	44
14	82	10	1.56	83	0.89	61	57
15	72	21	0.77	31	0.55	24	72
16	64	24	2.64	91	1.79	77	68
17	79	17	2.38	83	1.15	49	48
18	60	10	3.44	77	1.5	44	44
19	110	38	1.76	67	1.3	48	52
20	63	12	2.09	56	1.37	44	66
21	74	7	2.85	92	2.32	91	82

FVC - forced vital capacity, FEV_1 - forced expiratory volume in one second, obs - observed values, pred - predicted values

Table 3 - Arterial blood gas analysis (at room air) of the patients with kyphoscoliosis.

Serial no.	Scoliosis angle	Kyphosis angle	FiO_2	SpO_2	PaO_2	pH	$PaCO_2$
1	126	48	21	84	49	7.441	49.8
2	72	10	21	88	58	7.461	51.2
3	70	5	21	87	57.2	7.432	48.2
4	67	9	21	89	59.2	7.392	43.2
5	75	19	21	89	59.4	7.382	40.6
6	78	5	21	86	56.2	7.371	42.6
7	60	18	21	82	42.4	7.352	56.8
8	78	21	21	86	48.2	7.384	41.2
9	62	22	21	85	47.8	7.392	43.2
10	79	18	21	80	41.2	7.333	62.4
11	108	20	21	80	41.8	7.342	60.6
12	60	19	21	86	57	7.352	46
13	102	26	21	86	58	7.352	46
14	82	10	21	90	60	7.342	40
15	72	21	21	92	64	7.362	42
16	64	24	21	82	47	7.343	52.4
17	79	17	21	84	49	7.313	57.8
18	60	10	21	80	53	7.42	60.8
19	110	38	21	80	46	7.386	64
20	63	12	21	80	44	7.332	53.7
21	74	7	21	82	48	7.321	44.5

FiO_2 - fractional concentration of oxygen in inspired gas, SpO_2 - functional oxygen saturation, PaO_2 - partial arterial oxygen tension, $PaCO_2$ - partial pressure of carbon dioxide in arterial blood, pH - hydrogen ion concentration

Table 4 - Six-minute walk test (pre and post test values of the variables measured).

Serial no.	Scoliosis angle	RR pre test	RR post test	HR pre test	HR post test	SBP pre test	DBP pre test	SBP post test	DBP post test	SpO_2 pre test	SpO_2 post test
1	126	38	46	100	126	126	92	136	100	84	74
2	72	26	27	108	106	126	90	136	90	88	88
3	70	28	32	96	102	120	72	130	82	87	87
4	67	32	26	108	110	130	100	140	100	89	89
5	75	26	30	90	100	128	80	126	96	89	89
6	78	30	32	92	106	126	90	136	100	86	86
7	60	32	26	100	110	130	90	140	100	82	82
8	78	26	30	86	89	110	70	130	80	86	86
9	62	28	42	88	100	116	70	120	70	85	80
10	79	36	48	110	140	126	90	130	100	80	71
11	108	38	28	126	140	110	70	120	80	80	56
12	60	24	28	92	94	108	60	110	80	86	85
13	102	24	26	86	90	100	60	110	60	86	86
14	82	24	24	80	90	100	80	110	80	90	91
15	72	26	28	86	92	110	70	124	80	92	92
16	64	26	30	98	98	122	74	122	80	90	88
17	79	30	32	88	90	124	88	130	92	96	94
18	60	38	38	84	84	114	80	120	88	88	84
19	110	26	30	100	122	134	78	140	84	92	84
20	63	36	40	68	72	128	72	130	76	87	87
21	74	34	36	72	80	100	68	120	74	94	94

RR - respiratory rate, HR - heart rate, SBP - systolic blood pressure, DBP - diastolic blood pressure, SpO_2 - functional oxygen saturation to the right, and 6 were convex to the left. Most curves were of moderate to severe degree, Cobb angle 60-126° (78.1±18.3). The angle of kyphosis was an average of 5-48° (18.05±10.5).

Discussion. In the present study, 21 kyphoscoliotic patients were assessed by measurement of lung function, ABG analysis, and 6-minute walk test in relation to the radiological evaluation for the degree of spinal deformity. The results obtained show pulmonary impairment, hypoxemia, hypercapnia, and decreased exercise capacity. The results closely correspond to those reported by other authors in separate studies.[1-5] However, this case study evaluates the correlation of pulmonary impairment, ABG analysis, and the 6-minute walk test to the degree of spinal deformity in patients of kyphoscoliosis simultaneously. Surprisingly, no correlation was found between pulmonary impairment with degree of spinal deformity.

Lung volumes diminish with increasing scoliosis; a Cobb angle of 100˚ correlates with a 29–37% reduction in volumes.[2] In moderate scoliosis, impairment in exercise tolerance may not represent the impending effects of lung restriction and may simply reflect a potentially reversible decrease in physical fitness.[10] Scoliotic angles greater than 110˚, dyspnea, and wheeze are markers of poor prognosis and a vital capacity below 45% predicted an increased risk of developing respiratory failure.[11] It has long been recognized that severe scoliosis of the spine may lead to hypoxemia, hypercapnia, pulmonary hypertension, and cor pulmonale.[9] One-year mortality is estimated to be 50% once cardiorespiratory failure is present and left untreated.[1]

Diminished compliance of the chest wall in kyphoscoliosis leads to an increased work of breathing. Spontaneous breathing is usually rapid and shallow to minimize work of breathing, but this leads to alveolar hypoventilation.[6] Hypoxemia in the patient with kyphoscoliosis may be the result of alveolar hypoventilation, diffusion defect of oxygen across the alveolar membrane, shunting of blood through non-aerated segments of the lungs, and uneven distribution of gas and blood throughout the lungs.[12-14] The alveolar-arterial oxygen difference was inversely related to the vital capacity, percent predicted vital capacity, and the compliance of the respiratory system.[15] In the present study, ABG values demonstrated evidence of hypoxemia with PaO_2 ranging from 41-64 mm Hg, with an average $PaCO_2$ of 49.85 mm Hg. Kafer[15] demonstrated that in scoliosis, 2 primary variables, age and the degree of chest wall deformity, contribute to the abnormalities in gas exchange and ABG. Kearon et al[16] found that mild to moderate scoliosis was associated with a reduced capacity to perform work, but that the severity of this disability was unrelated to the severity and nature of the spinal deformity. Smyth et al[4] reported that reduced vital capacity of mild scoliosis was better correlated with measures of respiratory muscle strength than with degree of spinal curvature, in contrast to studies of severe idiopathic scoliosis. Meecham et al[17] showed that exertional dyspnea in patients with kyphoscoliosis is related to the degree of arterial oxygen desaturation on a baseline 6-minute walk, and can be alleviated by supplemental oxygen, although, correction of desaturation did not improve the walking distance.[17] In the present study, submaximal exercise capacity was assessed with a standardized 6-minute walk test. Oxygen desaturation, increase in respiratory rate, and heart rate and fall in systolic blood pressure during walk test correlated with degree of spinal deformity.

Scoliosis leads to loss of vertical height of the thoracic cage, longer curves involve a greater number of vertebrae and their rib attachments, higher curves involve more functionally important ribs, and relative lordosis may be associated with reduced anteroposterior diameter for the chest.[5] Al-Kattan et al[18] demonstrated evidence of torsion with secondary obstruction of the central airways during bronchoscopic examination of 3 patients. Patients with kyphoscoliosis who present with progressive deterioration in respiratory function with evidence of obstructive airway disease should be considered for bronchoscopic examination. This may demonstrate endobronchial lesion, stenosis at the site of previous tracheostomy, or bronchial torsion.

Buyse et al[19] concluded that survival was better in kyphoscoliotic patients treated with nocturnal nasal intermittent positive pressure ventilation combined with long term oxygen therapy than in kyphoscoliotic patients treated with long term oxygen therapy alone. Ambulatory oxygen therapy should be considered as an important addition to current standard therapy in patients with moderate to severe kyphoscoliosis.[17] By improving dyspnea, ambulatory oxygen therapy may facilitate an improvement in levels of activity and a consequent restoration of physical conditioning with improved exercise tolerance. Bruderman and Stein[20] stressed the life saving role of tracheostomy in the acutely ill kyphoscoliotic patient.

Scoliosis impedes on the movement of the ribs, places the respiratory muscles at a mechanical disadvantage, and displaces the various organs of the thoracic cavity. Scoliosis decreases the chest wall compliance directly and the lung compliance indirectly (due to progressive atelectasis and air-trapping), causing a significant increase in the work of breathing that, because of the associated respiratory muscle weakness, may lead to chronic respiratory failure.[21] The relationship of spinal deformity to pulmonary impairment and of pulmonary impairment to disability is so variable that no direct relationship between deformity and disability can be identified. Evaluation of patients with untreated idiopathic kyphoscoliosis indicates that although the onset of the disease usually occurs during early to mid-adolescence, symptomatic pulmonary insufficiency does not develop until the third or fourth decade of life. Nevertheless, abnormalities of pulmonary function have been found in asymptomatic patients. On the other side of the spectrum, unexpected longevity has been described in patients with kyphoscoliosis. Rom and Miller[22] described 10 patients with severe kyphoscoliosis who had survived into the seventh decade without clinically significant cardiorespiratory embarrassment. Three patients in this study were in their sixth decade, one patient in the seventh decade of life, and one patient in the eighth decade. The survival rate of patients with kyphoscoliosis was significantly higher in patients in whom hypoxia was caused by thoracic spine deformity, than caused by a combination of thoracic deformity and chronic lung or obstructive disease.[19] Jones et al,[23] in a recent study, concluded that patients with moderate to severe kyphoscoliosis have significant oxygen desaturation on exercise, and should thus, routinely receive oximetry on exercise and assessment for ambulatory oxygen therapy.

This multi-factorial analysis reconfirms the influence of spinal deformities on pulmonary impairment in patients with kyphoscoliosis. In order to fully assess severity of the scoliotic lung, it appears appropriate, that besides measuring impairment in pulmonary functions, severity of structural distortion, ABG analysis, and exercise capacity should also be assessed. A complete evaluation is important for severity of pulmonary impairment, hypoxemia, hypercapnia, and decreased work capacity in patients with kyphoscoliosis. Further studies to assess the benefit of ambulatory oxygen therapy on level of activity and exercise tolerance in kyphoscoliotic patients should be pursued. This would have clinically important implications for the management and prognosis of kyphoscoliotic patients.

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