Impaired Exercise Capacity in Adults with Moderate Scoliosis*

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We measured lung function and exercise tolerance in 15 adults with moderate kyphoscoliosis (thoracic curvatures between 25° and 70°, mean ± SD = 46.93° ± 14.02°). Forced vital capacity showed a slight reduction from values predicted from age and sex matched control subjects (3.39 ± 1.06 vs 4.06 ± 0.82 L, p < 0.05). However, exercise tolerance was significantly lower than previously reported in healthy adults (V̇O₂max = 31.60 ± 9.12 vs 37.07 ± 4.91 ml/kg/min, p < 0.05). Despite the reduced exercise tolerance, the ratio of maximum tidal volume to vital capacity (V̇Tmax/VC) was similar to that observed in healthy adults. The mean dyspnea index (V̇E/V̇E/MVV) was also normal at 19.4 ± 19.0. Hypoxic and hypercapnic ventilatory responses were within predicted normal limits at 0.67 ± 0.37 L/min⁻¹ fall in SaO₂⁻¹ and 1.67 ± 0.92 L/min⁻¹ mm Hg Pco₂⁻¹. We conclude that the impairment of exercise performance found in adults with moderate scoliosis cannot be attributed to any important ventilatory limitation, abnormality in lung volume, or impaired chemoreceptor sensitivity. We suggest that the reduced V̇O₂max likely arises from deconditioning and lack of regular aerobic exercise.

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### Methods

Fifteen adults (12 women, 3 men) with kyphoscoliosis were studied. Their ages ranged from 21 to 50 years. Subjects with a history or evidence of cardiac disease, neuromuscular disease, or respiratory abnormalities not directly related to their spinal deformity (i.e., obstructive lung disease) were excluded. The degree of spinal curvature was assessed by the method of Cobb6 on a three-foot standing roentgenogram. Those subjects with Cobb angles less than 25° or greater than 70° were excluded from the study.

All procedures were performed on the same day in fixed sequence with a suitable rest period between studies. All subjects underwent the following pulmonary assessments: spirometry, lung volume measurement, incremental treadmill exercise testing, and measurement of ventilatory responses to hypoxia and hypercapnia.

#### Spirometry and Lung Volumes

Flow-volume curves were obtained by maximal forced expirations using a 12 L dry rolling seal spirometer. The best of three expiratory maneuvers was used to obtain a value for FEV₁ and FVC. Functional residual capacity was determined by the helium dilution method.7 All volumes were corrected to BTPS. Arm span was used in place of body height in determining predicted values for flows and lung volumes.

#### Incremental Exercise Testing

Incremental exercise testing was performed on a treadmill using the protocol described by Clark et al and Jones.8 The workload began at a very low level (1.7 mph, 0 percent grade) and was gradually increased each minute according to a modified Bruce protocol until a symptom-limited maximum was reached. The total duration of each test was approximately 8 to 12 min.

Heart rate was monitored continuously using a cardiac monitor. The subjects breathed through a mouthpiece attached to a Hans Rudolph low deadspace plastic body two-way nonrebreathing valve. Ventilation, breathing frequency, and tidal volume were monitored continuously by a ventilometer system. This system consists of a turbine transducer placed at the inspiratory port of the breathing valve, as well as an instrument control and readout unit. Expired gas was collected in a mixing chamber, and continuous samples were analyzed for O₂ and CO₂ concentrations using gas analyzers.

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This information was compiled by means of the exercise test autolink configuration system, and the data were analyzed by means of a physiologic exercise testing system (version 2.0). The program generated a printout of the variables throughout the test, with a 10-s sample rate, and calculated oxygen consumption and carbon dioxide production at each sample. Predicted maximum voluntary ventilation was estimated as $35 \times$ measured $\text{FEV}^1$, and this value was used to calculate the dyspnea index. Anaerobic threshold was determined for each subject using the V-slope method.

The following criteria were used to verify that the exercise tests were maximal: symptom limitation and either respiratory exchange ratio $\geq 1.1$, heart rate reserve $\leq 15$ beats/min or $\dot{V}e/MVV \leq 0.8$.

**Ventilatory Response to Hypercapnia**

The ventilatory response to hypercapnia was determined according to the method described by Read. A rebreathing circuit was used in which the rebreathing bag contained 7 percent CO$_2$ and 93 percent O$_2$ to a volume equivalent to the subject's vital capacity plus 1 L. Gas was sampled continuously by an infrared CO$_2$ analyzer calibrated before each test against gravimetrically analyzed gases. All gas was returned to the circuit to eliminate changes in bag volume. The circuit was connected to a wedge spirometer for the measurement of expired volume. Tidal volume and expired CO$_2$ concentration were recorded throughout the test on a multichannel recorder. The ventilatory response was calculated using least squares linear regression.

**Ventilatory Response to Hypoxia**

Progressive isocapnic hypoxia was induced using the method described by Rebuck and Campbell. A rebreathing circuit was used in which the rebreathing bag contained an initial mixture of 30 percent O$_2$ and 70 percent nitrogen. End-tidal CO$_2$ was kept constant ($\pm 1$ mm Hg) by drawing gas from the bag through a CO$_2$-absorbing bypass using a variable-speed pump. The study was terminated when arterial oxygen saturation decreased to approximately 75 percent as measured by an ear oximeter. The ventilatory response was calculated using least squares linear regression.

**Data Analysis**

All values reported are means $\pm$ standard deviation. Measured values were compared to predicted normal values using Student's paired $t$-tests (with Bonferroni correction factor for multiple comparisons). The value 0.05 was used as the significance level in all hypothesis tests.

**Results**

**Physical Characteristics**

The physical characteristics of the 15 subjects ($M = 3; F = 12$) are summarized in Table 1. The mean $\pm$ SD spinal curvature (Cobb angle) was 46.93 $\pm$ 14.02 and ranged from 25° to 70°.

**Spirometry and Lung Volumes**

The mean values obtained from spirometry and lung volume measurement are summarized in Table 1.

<table>
<thead>
<tr>
<th>Table 2—Spirometry and Lung Volumes</th>
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<tr>
<td>Measured Values</td>
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<td>Mean $\pm$ SD</td>
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* $p<0.05$.
† $p<0.01$.

2. Lung volumes were mildly but significantly reduced in the scoliosis patients when compared to predicted normal values. The mean FVC and $\text{FEV}_1$ were 81.4 $\pm$ 22.99 and 82.20 $\pm$ 24.77 percent of predicted normal values. Similarly, RV, FRC, and TLC were 77.87 $\pm$ 21.60, 78.2 $\pm$ 21.91, and 82.47 $\pm$ 19.64 percent of predicted values, respectively.

**Exercise Test**

The ventilatory responses obtained during maximal exercise testing are summarized in Table 3. The $\dot{V}o_2\text{max}$ was significantly lower in the scoliosis patients as compared with predicted normal values (31.60 $\pm$ 9.12 vs 37.07 $\pm$ 4.91, $p<0.05$). Tidal volume at maximal exercise was also reduced significantly (1.55 $\pm$ 0.47 vs 2.07 $\pm$ 0.56, $p<0.05$), but $Vr\text{max}/VC$ was not significantly different from predicted normal values (0.48 $\pm$ 0.08 vs 0.51 $\pm$ 0.07, $p>0.05$). The mean $\dot{V}e\text{max}/MVV$ (0.70 $\pm$ 0.19) was within the accepted normal range ($<0.8$), indicating that there was no ventilatory limitation to exercise. The subject with the largest spinal curvature (70°) was the only subject who had a ventilatory limitation ($\dot{V}e/MVV$ $>0.8$) with a high HRR (>15 beats/min). However, $\dot{V}o_2\text{max}$ was still reduced as compared to predicted normal values even when this subject was excluded from the analysis (32.79 $\pm$ 8.17 vs 37.22 $\pm$ 5.06 ml/kg/min, $p<0.05$).

The mean anaerobic threshold was 1.33 $\pm$ 0.37 L/min. This value represents 70.34 $\pm$ 9.17 percent of $\dot{V}o_2\text{max}$ and 57.05 $\pm$ 14.72 percent of predicted

<table>
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<th>Table 3—Ventilatory Responses During Maximal Exercise Testing</th>
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<td>Mean $\pm$ SD</td>
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<td>$\dot{V}o_2\text{max}$, ml/kg/min</td>
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<td>HRR, beats/min</td>
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<td>O$_2$ pulse, ml/beat</td>
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<td>Anaerobic threshold, L/min</td>
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<td>Anaerobic threshold, %$\dot{V}o_2\text{max}$</td>
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<td>Anaerobic threshold, % predicted $\dot{V}o_2\text{max}$</td>
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<td>$\dot{V}co_2\text{max}$, L/min</td>
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VO₂max (normal > 40 percent VO₂max). Mean O₂ pulse at maximal exercise was not significantly different from predicted normal values (10.99 ± 3.31 ml/beat vs 12.45 ± 2.41 ml/beat, p > 0.05), suggesting that there was no arterial hypoxemia during exercise in our subjects.¹²

**Ventilatory Responses to Hypoxia and Hypercapnia**

The mean slope of the ventilatory response to hypoxia was 0.67 ± 0.37 L.min⁻¹.lfall in SaO₂⁻¹. The mean slope of the ventilatory response to hypercapnia was 1.67 ± 0.92 L.min⁻¹.mm Hg⁻¹. These responses fell within the lower end of the normal range as 80 percent of normal subjects will have a ventilatory response between 0.6 and 2.75 L.min⁻¹.lfall in SaO₂⁻¹ and between 1.00 and 3.99 L.min⁻¹.mm Hg CO₂⁻¹.¹³

**DISCUSSION**

To the best of our knowledge, there have been no previous reports that have dissected the components of exercise capacity in adult patients with only moderate scoliosis. Exercise performance in our subjects was less than the predicted values, based on age, sex, and arm span. The decrease in VO₂max occurred despite a normal pattern of ventilation. Resting lung volumes were only mildly diminished, and the ventilatory responses to challenges such as hypercapnia and hypoxia fell within the normal range.

It has long been recognized that severe scoliosis of the spine may lead to hypoxemia, hypercapnia, pulmonary hypertension, and cor pulmonale. One-year mortality is estimated to be 50 percent once cardiorespiratory failure is present and left untreated.¹ Patients with Cobb angles of at least 100° may develop cardiorespiratory failure while patients with angles of 70° are at risk of progressing to 100°, and hence, at risk for complications.¹ Lung volumes diminish with increasing scoliosis; a Cobb angle of 100° correlates with a 29 to 37 percent reduction in volumes.¹⁶ Ventilatory responses to hypercapnia in such patients are impaired.¹⁶ It was, therefore, of considerable interest to us to study a group of patients whose curvature had not reached these levels of severity.

In contrast to patients with severe scoliosis, adolescents with mild scoliosis have no abnormalities either in exercise tolerance or lung function. Smyth et al² studied 44 adolescents with curves less than 35°, finding normal vital capacities and levels of exercise tolerance that were entirely within the normal range. Although patterns of breathing tended toward showing increased respiratory rate and decreased tidal volumes, overall ventilatory responses to hypercapnia and hypoxia were normal. DiRocco and Vaccaro³ performed incremental exercise testing on 19 adolescents with Cobb angles between 12° and 40°; the 11 with angles less than 25° reached a normal VO₂max with no evidence of ventilatory impairment. Clearly, mild scoliosis is not associated with any significant impairment of resting pulmonary function or the ability to achieve satisfactory levels of aerobic fitness.

It is difficult to establish from the literature the pulmonary function finding in patients that fall between these two well documented groups. Weber et al⁴ reported a reduction in lung volumes, diffusion capacity, and ventilatory response to carbon dioxide in a group of adolescents with a mean thoracic scoliotic curve of 72°. Shneerson⁵ documented a decrease in lung volumes and VO₂max in a group of adolescents with a mean Cobb angle of 62°. DiRocco and Vaccaro³ reported a decrease in VO₂max in eight adolescents with angles between 25° and 40°. Conclusions from these studies cannot be drawn with certainty as few patients were adults and the wide range of reported Cobb angles among the studies mitigated against appropriate statistical analysis. We have therefore defined and examined a group of 15 adult patients with Cobb angles between 25° and 70°.

Although one subject appeared to have a clear ventilatory limitation, the mean VO₂max in our subjects was below the predicted normal value and was seen in the presence of a normal V̇E/MVV, indicating a normal breathing reserve. This finding is consistent with other’s results.³,⁵ Therefore, moderate scoliosis does not seem to diminish exercise tolerance on the basis of ventilatory limitations secondary to chest wall restriction.

Why then, was VO₂max diminished? Perhaps predicted values based on arm span rather than height are somewhat inaccurate. There is some basis for this hypothesis in children,¹⁷ but arm span does correlate very well with height in adults,¹⁸ and unlike Shneerson and DiRocco and Vaccaro,³ all subjects in the present study were adults. It might also be argued that the impaired exercise tolerance was related to poor motivation and effort during the laboratory study. However, as all subjects were symptom-limited and reached either a HRR≤15 beats/min, an RER=1.1 or a ventilatory limitation, it is apparent that the incremental exercise tests were indeed performed up to the level of physiologic limitation. It could be suggested that subjects may have discontinued exercise because of a heightened perception of dyspnea secondary to abnormalities of the chest wall altering stretch receptors. Specifically addressing this issue is beyond the scope of this study. If there was a heightened perception of dyspnea, one might expect the subject to stop exercising prior to attaining an objective measure of a maximal test; this was not the case in our subjects. A maximum heart rate at a lower than expected VO₂max is consistent with cardiac disease, but none of our subjects had a history of cardiac disease and had normal continuous electrocardio-
grams during exercise. In summary, as a group, there was no ventilatory limitation to exercise, no apparent cardiac disease, and yet, \( \dot{V}O_2 \)max was low in these well motivated subjects under laboratory conditions.

It appears that impairment of exercise tolerance in patients with moderate scoliosis simply represents diminished physical fitness due to decreased participation in aerobic activities. Our findings raise the possibility that patients with moderate spinal curvatures suffer embarrassment about their physical appearance and are unwilling to participate in aerobic physical activities. Furthermore, they may fear injury because of their deformity or have received instructions to avoid strenuous exertion because of possible repercussions if spinal injury should occur. We conclude that in moderate scoliosis, an impairment in exercise tolerance may not represent the impending effects of lung restriction and may simply reflect a potentially reversible decrease in physical fitness. A low \( \dot{V}O_2 \)max should be interpreted carefully and is not necessarily evidence to hasten surgical intervention.

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REFERENCES