Is there an alternative to pre-flight hypoxic challenge testing in scoliotic patients?

Debrata Bandyopadhyay, Nicholas S. Oscroft*, John M. Shneerson, Ian E. Smith

Respiratory Support and Sleep Centre, Papworth Hospital NHS Foundation Trust, Papworth Everard, Cambridge CB23 3RE, UK

Received 14 January 2010; accepted 11 May 2010

KEYWORDS
Flight assessment; Hypoxic challenge testing; Scoliosis; Exercise testing

Summary
Introduction: Hypoxic challenge testing (HCT) is not readily available in all hospitals. It has recently been shown that resting oximetry does not reliably predict the results of HCT in patients with extrapulmonary restrictive lung disease. We assessed other clinical tests to see if they might be used as an alternative screen for HCT.

Methods: People with primary thoracic scoliosis were recruited. Resting SpO₂, arterial blood gases (ABG’s), lung function and shuttle walking test (SWT) were measured. All subjects underwent HCT breathing an inhaled oxygen fraction of 15% for 20 min, or until SpO₂ fell below 85%, when ABG’s were taken.

Results: Fourteen people (5 male) with thoracic scoliosis, Cobb angle 93 (31°), aged 65 (8.5) years, FEV₁ 0.86 (0.4) L, FVC 1.2 (0.4) L were studied. The resting SpO₂ was 96 (2) %, PaO₂ 9.2 (1) kPa and PaCO₂ 6.1 (0.4) kPa. HCT was positive in 11 subjects (PaO₂ < 6.6 kPa). Eight of 11 HCT positive subjects had a resting SpO₂ > 95%. Positive correlation was found between SpO₂ at SWT termination and PaO₂ following HCT (r = 0.56, p = 0.02). Those with saturations of 92% or under at SWT termination had positive HCT.

Conclusions: Despite normal resting SpO₂ subjects with thoracic scoliosis may have positive HCT. Current recommendations for air travel do not accurately identify these people. Desaturation following a SWT may provide a useful screening tool, however a low threshold for performing HCT on people with thoracic scoliosis prior to air travel is warranted.

© 2010 Elsevier Ltd. All rights reserved.

* Corresponding author. Tel.: +44 1480 830541; fax: +44 1480 830620.
E-mail address: nickoscroft@doctors.net.uk (N.S. Oscroft).

0954-6111/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.rmed.2010.05.007
Introduction

People with respiratory disorders are at theoretical risk from hypoxaemia when travelling in commercial passenger planes. These aircraft fly at up to 13,000 m above sea level in order to reduce exposure to turbulent air and improve fuel economy. Regulations stipulate that the cabin is pressurised such that the maximum effective altitude experienced by the passengers is no higher than 2438 m although the level of pressurisation may vary significantly between aircraft. At an effective altitude of 2438 m the partial pressure of oxygen (PO\textsubscript{2}) is equivalent to breathing 15.1% oxygen at sea level, which leads to hypoxaemia in healthy individuals with an estimated arterial partial pressure of oxygen (PaO\textsubscript{2}) of 7–8.5 kPa. This is usually well tolerated. However, people with respiratory disease or pre-existing hypoxaemia at sea level may have precipitous falls in PaO\textsubscript{2} potentially leading to medical emergencies.

Published recommendations regarding air travel advise on methods to identify individuals who will experience a low PaO\textsubscript{2} so they can be provided with supplemental oxygen during flight. Accurate identification of those who require oxygen is important due to the cost, increased risk of fire and travel restrictions supplemental oxygen may impose. The more recently updated and comprehensive British Thoracic Society recommendations state that if oxygen saturations (SpO\textsubscript{2}) in room air at sea level are >95% then no further respiratory assessment is required. Most of the studies cited to support these views report data for people with Chronic Obstructive Pulmonary Disease (COPD) and the guidelines were last reviewed in 2004. Studies published since show that in individuals with COPD, resting SpO\textsubscript{2} may be a poor predictor of desaturation during hypoxic challenge testing (HCT) and that HCT is a good predictor of what will occur in-flight.

Very limited data are available to guide recommendations in individuals with scoliosis. Prevalence estimates performed in the USA suggest 3% of school children have scoliosis, with 0.4% having significant disease with a Cobb angle greater than 40 degrees, implying many thousands of air passengers may have significant scoliosis. One study, in which two out of 17 subjects had scoliosis and the majority interstitial lung disease, has examined the response of those with restrictive lung disease to simulated air travel with hypobaric testing. This showed a mean fall in PaO\textsubscript{2} to a level where supplemental oxygen would be recommended despite the group having a resting mean SpO\textsubscript{2} of 95% on air. A further study has examined the response of a group with neuromuscular disease and idiopathic scoliosis to HCT and demonstrated that 50% of patients with a resting SpO\textsubscript{2} over 95% desaturated to the level where supplemental oxygen is recommended. These studies underline the poor predictive value of resting SpO\textsubscript{2} in identifying those who will desaturate to a level where supplemental oxygen is deemed necessary.

HCT is not available in all institutions and may be difficult to organise at short notice when patients declare an intention to fly. Therefore a clinical evaluation of simpler and more widely available parameters including lung function, Medical Research Council dyspnoea score, arterial blood gases and a shuttle walk test were performed to see if these could predict the response of patients with a primary scoliosis to HCT.

Methods

Setting

The study was performed in a specialist respiratory support centre offering assessments and home mechanical ventilation for people with conditions leading to chronic respiratory insufficiency. It was approved by the Huntingdon Research Ethics Committee. Funding was supplied by charitable donations.

Subjects

A search was made of the respiratory support centre’s diagnostic database for adults (>18 years) with either a congenital or primary acquired scoliosis under follow up or who had been referred for assessment. The coding criterion for scoliosis in the database is a Cobb angle of greater than 20 degrees. Subjects with secondary scoliosis were excluded to avoid compounding effects that might arise with respiratory muscle weakness. Other exclusion criteria were; a second relevant pulmonary pathology such as COPD, previous tuberculosis or pulmonary fibrosis and the use of oxygen therapy. People with cardiac disease not related to scoliosis were also excluded. Individuals were invited to participate in the study in writing prior to routine appointments at the centre. Written consent was obtained.

Assessments

The medical case notes of all subjects were reviewed. Potential subjects were interviewed and examined in the morning of the study day to exclude any acute inter-current illness. Weight, height, arm span and Medical Research Council (MRC) dyspnoea score were recorded. Dynamic lung volumes were measured using spirometry and static lung volumes using whole body plethysmography and the values expressed as percentage of predicted. Using arm span in place of height. If no current films (<1 year old) were available plain radiographs of the spine were obtained. The Cobb angle was calculated for each individual. The patients were rested for 15 min and SpO\textsubscript{2} recorded using a finger probe (3900 Datex-Ohmeda, Hatfield, UK). An arterial sample was collected from the radial artery and analysed for blood gas tensions and pH (GEM Premier 3000, Instrumentation Laboratory, Lexington, USA). Subjects underwent a shuttle walking test (SWT) with continuous monitoring of SpO\textsubscript{2}. A modified Borg score for dyspnoea was recorded just before and immediately after the SWT.

In the afternoon, at least 2 h after the SWT, subjects underwent HCT as previously described. They sat quietly and breathed from a mouth piece while the nose was occluded with a clip. After acclimatisation they were switched to 15.1% oxygen in a nitrogen gas mixture from a Douglas bag. SpO\textsubscript{2} was monitored continuously. The test was discontinued if the SpO\textsubscript{2} fell below 85%, the subject became distressed or after 20 min had elapsed. At the cessation of HCT an arterial blood sample was collected from the radial artery and blood gas tensions measured. If the PaO\textsubscript{2} at the end of the test was less than 6.6 kPa it was
said to be positive, if the PaO$_2$ was 6.6 kPa or over it was deemed to be negative.

Analysis

Data were assessed for normality using the Shapiro–Wilk test. Groups were compared using independent T-tests or the non-parametric Mann–Whitney U test as appropriate. PaO$_2$ measured at the end of HCT was not normally distributed. To establish relationships between PaO$_2$ following HCT and other continuous variables the non-parametric spearman’s correlation coefficient was used. Significance is reported at a level of $p < 0.05$.

Results

Fourteen subjects (five male) were recruited and all completed the protocol. The values recorded during assessments and comparisons of those who had positive and negative HCT are presented in Table 1. There were no current smokers. Seven had a history of ventilatory failure and were using nocturnal, non-invasive ventilation (NIV). Those receiving NIV and those not had similar lung function, arterial blood gases and exercise capacity (Table 2). Although all subjects had abnormal spirometry there was a considerable spread, the FVC for example ranged from 20 to 75% predicted.

The resting SpO$_2$ was 95% or greater in eleven patients. Eleven out of fourteen subjects desaturated during the HCT to a PaO$_2$ below 6.6 kPa. Resting SpO$_2$ did not correlate with PaO$_2$ following HCT (Fig. 1). Eight of the eleven subjects who failed HCT had resting oxygen saturations of 95% or greater. Of the three that did not fail HCT all had saturations over 95% at rest and one was receiving domiciliary NIV. All subjects were able to walk more than 50 m on the SWT and the mean SWT distance was 302 (120) m. There were no significant differences in outcomes measured between those receiving domiciliary NIV and those not.

Relationships were sought between the PaO$_2$ at the termination of HCT and other measured variables. A positive correlation was found between SpO$_2$ at the end of the HCT and other variables:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>All Tested $n = 14$</th>
<th>Positive HCT $n = 11$</th>
<th>Negative HCT $n = 3$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>65.3 (8.5)</td>
<td>65.7 (9.5)</td>
<td>63.7 (2.9)</td>
<td>0.54</td>
</tr>
<tr>
<td>BMI (kg/m$^2$)</td>
<td>24.1 (3.5)</td>
<td>24.1 (2.7)</td>
<td>24.3 (6.5)</td>
<td>0.96</td>
</tr>
<tr>
<td>Cobb Angle (degrees)</td>
<td>93 (31)</td>
<td>97 (27)</td>
<td>78 (47)</td>
<td>0.55</td>
</tr>
<tr>
<td>MRC dyspnoea score</td>
<td>2.6 (0.9)</td>
<td>2.6 (0.9)</td>
<td>2.3 (0.6)</td>
<td>0.52</td>
</tr>
<tr>
<td>Resting SpO$_2$ (%)</td>
<td>96 (2)</td>
<td>95 (2)</td>
<td>96 (1)</td>
<td>0.54</td>
</tr>
<tr>
<td>Resting PaO$_2$ (kPa)</td>
<td>9.2 (1)</td>
<td>9.1 (0.9)</td>
<td>9.7 (1.3)</td>
<td>0.53</td>
</tr>
<tr>
<td>Resting PaCO$_2$ (kPa)</td>
<td>6.1 (0.4)</td>
<td>6.2 (0.4)</td>
<td>5.9 (0.2)</td>
<td>0.19</td>
</tr>
<tr>
<td>FEV$_1$ (L)</td>
<td>0.86 (0.4)</td>
<td>0.76 (0.2)</td>
<td>1.2 (0.8)</td>
<td>0.39</td>
</tr>
<tr>
<td>FVC (L)</td>
<td>1.2 (0.4)</td>
<td>1.1 (0.3)</td>
<td>1.6 (0.8)</td>
<td>0.48</td>
</tr>
<tr>
<td>TLC (L)</td>
<td>2.8 (0.6)</td>
<td>2.7 (0.6)</td>
<td>3.1 (1)</td>
<td>0.53</td>
</tr>
<tr>
<td>SWT distance (m)</td>
<td>302 (120)</td>
<td>314 (122)</td>
<td>260 (122)</td>
<td>0.55</td>
</tr>
<tr>
<td>Post SWT Borg score</td>
<td>3.6 (0.7)</td>
<td>3.9 (0.5)</td>
<td>2.7 (0.6)</td>
<td>0.01</td>
</tr>
<tr>
<td>Post SWT SpO$_2$ (%)</td>
<td>87 (6)</td>
<td>85 (5)</td>
<td>94 (2.3)</td>
<td>0.001</td>
</tr>
<tr>
<td>PaO$_2$ post HCT (kPa)</td>
<td>5.9 (1)</td>
<td>5.5 (0.5)</td>
<td>7.4 (0.9)</td>
<td>0.009</td>
</tr>
</tbody>
</table>

BMI = Body Mass Index, MRC = Medical Research Council, SpO$_2$ = oxygen saturations, PaO$_2$ = arterial partial pressure of oxygen, PaCO$_2$ = arterial partial pressure of carbon dioxide, FEV$_1$ = forced expiratory volume in 1 s, FVC = forced vital capacity, TLC = total lung capacity, SWT = shuttle walk test, HCT = hypoxic challenge testing.

Values reported as mean (standard deviation).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Requiring NIV $n = 7$</th>
<th>Not requiring NIV $n = 7$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>69 (7)</td>
<td>62 (8)</td>
<td>0.1</td>
</tr>
<tr>
<td>BMI (kg/m$^2$)</td>
<td>24 (3)</td>
<td>24 (4)</td>
<td>0.9</td>
</tr>
<tr>
<td>Cobb Angle (degrees)</td>
<td>89 (23)</td>
<td>97 (39)</td>
<td>0.7</td>
</tr>
<tr>
<td>Resting PaO$_2$ (kPa)</td>
<td>8.8 (0.9)</td>
<td>9.6 (0.9)</td>
<td>0.1</td>
</tr>
<tr>
<td>Resting PaCO$_2$ (kPa)</td>
<td>6.3 (0.5)</td>
<td>6 (0.2)</td>
<td>0.1</td>
</tr>
<tr>
<td>FEV$_1$ (L)</td>
<td>0.74 (0.2)</td>
<td>0.97 (0.5)</td>
<td>0.5</td>
</tr>
<tr>
<td>FVC (L)</td>
<td>1.16 (0.3)</td>
<td>1.22 (0.6)</td>
<td>0.5</td>
</tr>
<tr>
<td>TLC (L)</td>
<td>2.9 (0.6)</td>
<td>2.7 (0.7)</td>
<td>0.5</td>
</tr>
<tr>
<td>SWT distance (m)</td>
<td>293 (94)</td>
<td>311 (148)</td>
<td>0.8</td>
</tr>
</tbody>
</table>

BMI = Body Mass Index, PaO$_2$ = arterial partial pressure of oxygen, PaCO$_2$ = arterial partial pressure of carbon dioxide, FEV$_1$ = forced expiratory volume in 1 s, FVC = forced vital capacity, TLC = total lung capacity, SWT = shuttle walk test.

Values reported as mean (standard deviation).
SWT and the PaO₂ following HCT \((r = 0.56, p = 0.02)\) (Fig. 2). Negative correlations were found between the Borg score at the end of the SWT \((r = -0.5, p = 0.04)\) and PaO₂ following HCT and resting daytime PaCO₂ \((r = -0.61, p = 0.01)\) (Fig. 3) and PaO₂ following HCT. When comparing those who had positive HCT with those who did not significant differences in the Borg score following SWT and SpO₂ following SWT were found (Table 1). Subjects with a SpO₂ of 93% or over at the end of the SWT did not desaturate below a PaO₂ of 6.6 kPa on HCT (Fig. 2).

**Discussion**

These results confirm that resting SpO₂ is not able to predict the response to HCT in patients with moderate to severe scoliosis, and that those with a resting SpO₂ of 95% or over, frequently desaturate to a level where supplemental oxygen is considered necessary. Assessments of lung function, MRC dyspnoea score and arterial blood gases at rest did not have discriminatory value but PaCO₂ at rest did correlate with PaO₂ following HCT. SpO₂ following an incremental shuttle walk test correlated with response to HCT and may provide a simpler assessment of the requirement for oxygen during flight than formal HCT.

The current recommendations for air travel are based on the premise that a resting PaO₂ of <6.6 kPa during flight would represent a clinically significant risk that should be prevented by the use of additional oxygen during air travel.³ Although whether such levels of hypoxaemia represent a true clinical risk is a subject of debate.¹⁰ The recommendations suggest that a resting SpO₂ of >95% is reassuring and obviates the need for further assessment. From our results and others¹⁰ this advice cannot be applied to people with a primary thoracic scoliosis. A walking distance of greater than 50 m without distress is suggested as reassuring and can remove the need for HCT.³ The minimum walking distance recorded in our group of subjects with moderate to severe scoliosis was 120 m and SWT distance did not correlate with the response to HCT. The SpO₂ following a SWT did correlate with results following HCT and is likely to provide a simpler method of assessing “fitness to fly”.

Healthy people respond to hypoxaemia by increasing their minute ventilation reducing the impact of the fall in inspired oxygen. The response to hypoxaemia in patients with scoliosis is likely to represent a more complex relationship between changes in VQ matching and the ability to increase ventilation.¹⁰ When exercising, subjects with more severe scoliosis will increase ventilation initially by increasing tidal volume but this soon ‘tops out’ and as respiratory frequency rises dead space ventilation increases.¹⁷ Exercise testing may stress similar limitations to increased ventilation as hypoxaemia in patients with severe scoliosis and potentially predict the response to HCT. Desaturation following a 6 min walk has been demonstrated to predict response to HCT in those with COPD and interstitial lung disease.¹⁸

The generalisability of the current results may be compromised by the population from which the subjects were drawn. All had been referred for a respiratory assessment such that something had marked them out from the generality of people with a scoliosis. Seven previously had ventilatory failure and received domiciliary NIV. Our study group was small but our results agree with a previous report¹⁰ showing no clear relationship between resting SpO₂ and PaO₂ following HCT. The SWT was validated in patients with COPD but is simple to apply, reproducible, incremental and progressive and more likely than non-incremental assessments, such as the 6 min walk, to assess maximal cardiorespiratory capacity.¹⁴ This is likely to be important when using an endpoint of oxygen desaturation post SWT that may be effort dependant.

Spirometry, Cobb angle, MRC dyspnoea score, resting ABGs, resting SpO₂ and exercise capacity are all readily measured but did not have any predictive value in our subjects. The lack of a relationship between resting SpO₂...
and the outcome of HCT again emphasises the need for a circumspect approach when advising people with a thoracic scoliosis about air travel. It would be useful to extend the current study to people who have not been referred for respiratory assessment. The demonstration of arterial desaturation to a SpO$_2$ of 92% or less on a SWT was a good predictor of positive HCT and as such may be a helpful screen where HCT is not available.

**Conflicts of Interest**

None to declare.

**Funding**

RSSC Charitable Funds.

**Acknowledgements**

None.

**References**