Short reports

Cardiorespiratory responses to dynamic exercise after human heart-lung transplantation

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Although gratifying results have been obtained with heart-lung transplantation,[1] the adaptation of the transplanted denervated lung to exercise has not been reported. We have therefore studied cardiorespiratory responses to dynamic exercise in one patient six months after the transplantation.

Methods

A 26 year old woman underwent heart-lung transplantation for lymphangioleiomyomatosis.[2] Six months after operation she completed a graded, symptom limited bicycle exercise test. At this time vital capacity (VC) was 3·11 litres and total lung capacity 5·15 l, corresponding to 72% and 88% of predicted values based on the recipient's anthropometric characteristics.[3] Functional residual capacity was 3·42 l (115% predicted) and residual volume 2·04 l (128% predicted). The FEV_1 was 2·09 l (67% VC), and airway resistance 1·3 (normal <2·5) cm $H_2O/l/s$.

The work load was increased by 30 w every three minutes, and the patient was asked to continue exercise for as long as possible. Respiratory variables were measured with an open circuit (Ergopneumotest, Jaeger). Arterial blood samples were drawn from an arterial catheter for duplicate measurements of pH, partial pressures of oxygen and carbon dioxide (Pao_2 and $Paco_2$), and lactate concentrations. Physiological deadspace (VD), deadspace–tidal volume ratio (VD/VT), and alveolar-arterial tension difference for oxygen (A-aDo$_2$) were calculated from standard formulae. Predicted exercise values based on the patient's size were calculated according to the method of Jones and Campbell.[4]

Results

The patient continued the exercise test until the work rate reached 90 w, when she stopped because of dyspnoea. The main ventilatory and haemodynamic data are shown in figures 1 and 2. At any given work load, oxygen consumption ($\dot{V}o_2$) was within the normal range, but the maximum $\dot{V}o_2$ achieved was only 1·46 (predicted 2·34 (SD 0·43)) l/min. Minute ventilation ($\dot{V}E$) exceeded the normal range for a given $\dot{V}o_2$ owing to a faster rise in both tidal volume and breathing frequency. As a result, $\dot{V}E/\dot{V}o_2$ was increased throughout exercise, ranging from 38·8 at rest to 34·3 at 90 w. The slope of the line relating $\dot{V}E$ to carbon dioxide prod-
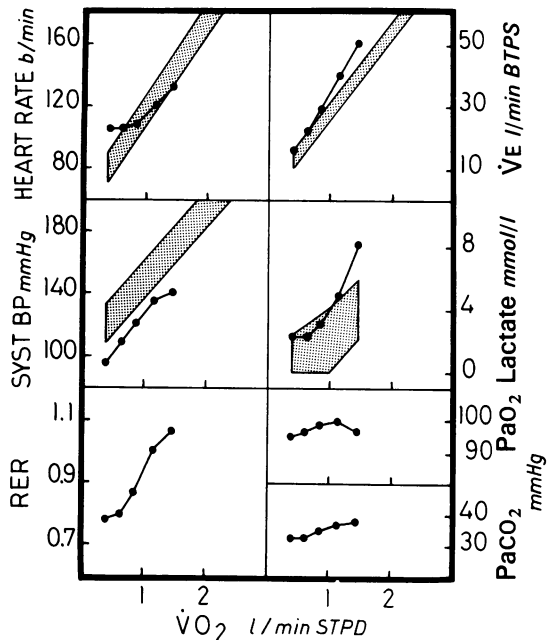
Fig 1 *Changes in heart rate, systolic blood pressure (syst BP), respiratory exchange ratio (RER), minute ventilation ($\dot{V}E$), arterial blood lactate, and arterial partial pressures of oxygen (Pao_2) and carbon dioxide ($Paco_2$) during dynamic bicycle exercise in a patient with a heart-lung transplant. Values obtained in the patient are expressed in relation to oxygen consumption ($\dot{V}o_2$). Shaded areas represent 1 SD of normal values.*[4]

uction ($\dot{V}co_2$) was also increased. Mean inspiratory flow (VT/Ti) increased progressively from 0·64 l/s at rest to 1·86 l/s at 90 w; concomitantly inspiratory time decreased from 1·39 to 0·9 seconds, while the respiratory duty cycle (Ti/Ttot) did not change. At the end of exercise $\dot{V}E$ was 50·1 l/min, close to the maximum value of 51·2 l/min predicted on the basis of the patient's FEV_1.[4] Pao_2 was normal throughout exercise, and $Paco_2$ rose slightly from 32 mm Hg (4·2 kPa) at rest to 37 mm Hg (4·8 kPa) at 90 w. The A-aDo$_2$, which was raised at rest (20·7 mm Hg (2·7 kPa)), decreased to 13·9 mm Hg (1·8 kPa) at 30 w, and then progressively increased to 19·3 mm Hg (2·5 kPa) at 90 w. VD and VD/VT were 0·27 l and 0·31 at rest and 0·33 l and 0·20 at 90 w. At the end
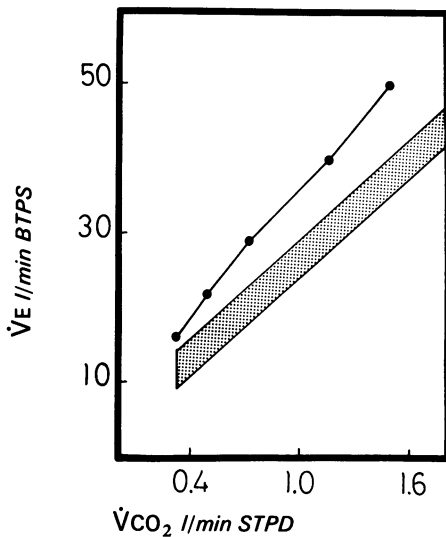
Fig 2 *Relationship between minute ventilation ($\dot{V}E$) and carbon dioxide production ($\dot{V}CO_2$) in a patient with a heart-lung transplant. The shaded area represents 1 SD of normal values.*[4]

of exercise both the respiratory exchange ratio (RER) and the blood lactate concentration were higher than predicted, their respective values being 1·06 and 8·2 mmol/l, with an arterial pH of 7·28.

Sinus tachycardia was present at rest, and the normal increase in heart rate with exercise was delayed. The maximum heart rate was 137 (predicted 195 (SD 10)) beats/min. During recovery the decline in heart rate was much slower than normal. Systolic blood pressure remained low throughout exercise.

Discussion

For obvious ethical reasons, it is difficult to study the effects of vagal blockade on the regulation of breathing in conscious man. Heart-lung transplantation offers a unique opportunity to investigate this question because it results in complete denervation of the lung below the level of the tracheal anastomosis. The pattern of heart rate changes observed in our patient strongly suggests that the heart was denervated at the time of the study.[5] Moreover, it was not possible to elicit a cough reflex at bronchoscopy, indicating that lung reinnervation had not occurred.

The influence of chronic lung denervation on the ventilatory response to exercise has not been reported in man. Studies in the conscious dog have shown that this response is not affected by acute vagal blockade.[6] In animals with chronic lung denervation it has been reported to be either normal[7] or substantially depressed.[8] The present results suggest that in man chronic cardiopulmonary denervation does not impair the ventilatory response to dynamic exercise. Mean inspiratory flow, tidal volume, and breathing frequency all increased regularly with increasing work loads, and the progressive rise in ventilation resulted in maintenance of relatively normal blood gas tensions.

The increase in ventilation in response to exercise therefore still occurs when all vagal afferent information from pulmonary receptors is removed. This supports the conventional theory that the major mechanisms accounting for the hyperpnoea of moderate exercise in normal man depend on proprioceptive influences in the exercising limbs and afferent information from the carotid bodies. Animal studies also suggest[9] that pulmonary chemoreceptors sensitive to mixed venous carbon dioxide might be implicated in the ventilatory adjustments to exercise. The present data provide preliminary evidence that such receptors are not necessary for an appropriate ventilatory response to exercise in man.

Ventilation at any given work load was greater than normal. It has been recently reported in normal man that local airway anaesthesia tends to increase the response of ventilation and tidal volume to exercise,[10] which has been attributed to the removal of inhibitory influences of stretch receptors. This would suggest that the increase in minute ventilation observed here might have been related to lung denervation per se. The increase in ventilatory response induced by airway anaesthesia, however, was of small magnitude[10] and direct comparison of airway anaesthesia and complete denervation may not be appropriate. In addition to any possible role of lung denervation, the increased ventilation observed during exercise in our patient is likely to have been related to the increase in carbon dioxide output, and the metabolic acidosis that developed as a result of the early and exaggerated lactate production. Similar alterations have been reported in recipients of cardiac transplants, who also show an early onset of anaerobiosis during dynamic exercise as a result of a low cardiac output.[5]

Although A-aDo$_2$ was slightly raised at rest, a common finding during the first year after transplantation, the values for Pao$_2$, Paco$_2$, A-aDo$_2$, VD, and VD/VT were within normal limits throughout exercise. These data indicate that gas exchange at rest and during exercise is well preserved after heart-lung transplantation.

References

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