

out that paraplegia is a "neurologic disease state" and therefore a contraindication to regional anesthesia. However, the level of the lesion is well documented in these patients and the physician should not be deprived of this technique to control hypertension.

In summary, the time sequence and reaction of this patient to epidural anesthetic drug injections strongly suggest that epidural anesthesia is an effective method for controlling autonomic dysreflexia during labor and delivery. It allows the patient to be comfortable throughout labor and delivery. Its use is indicated for both patient comfort and prevention of hypertension, which may lead to a cerebrovascular accident. Epidural anesthesia is also indicated in a paraplegic with toxemia as an adjunct to antihypertensive medication to control hypertension.

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Mixed Expired Gas Transients as a Noninvasive Index of the Effects of PEEP

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Acute pulmonary failure is characterized by decreased functional residual capacity^{1,2} and increased venous admixture, primarily due to right-to-left shunting of blood through nonventilated areas.³ Positive end-expiratory pressure (PEEP) may cause a marked improvement in pulmonary oxygen exchange in patients with acute pulmonary failure by recruiting collapsed alveoli.^{2,4,5} Complicating features (of PEEP application) include pulmonary barotrauma⁶ and decreased cardiac output.^{2,5,7-9} The latter decreases oxygen transport^{5,8,9} and increases physiologic dead space.⁵ Invasive measurements of cardiac output and arterial blood gases are usually needed to determine whether a given change in end-expiratory pressure has altered oxygen transport. However, noninvasive on-line respiratory gas analysis for patients in the intensive care unit is increasingly common, and we seek to determine the applicability of the various components of such monitoring. In this report we

examine the feasibility of a method of predicting the effects of PEEP on cardiac output and oxygen transport. The underlying hypothesis is based on the probability that rapid change in ventilation-perfusion relationships or cardiac output will result in a temporary situation in which more (or less) oxygen will be taken up from each breath by the pulmonary blood flow until equilibrium between cellular oxygen consumption and oxygen delivery is re-established. This, in turn, should be reflected in the mixed expired oxygen level of each breath. Similar hypotheses might apply to carbon dioxide exchange.

METHODS

The protocol was approved by the Human Research Committee of the University of California, San Francisco.

We studied 12 patients requiring mechanical ventilation for acute pulmonary failure. The group consisted of nine men and three women, ages ranging 23 to 82 years. Respiratory failure followed massive trauma in seven patients, neurologic injury in two, infection in one, and massive myocardial infarction in one. All patients were ventilated with a volume-limited ventilator in the control mode. The constant

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tidal volume was 15 per cent of predicted normal total lung capacity. The inspired oxygen concentration was held constant throughout each patient study at a level sufficient to maintain arterial oxygen tension at greater than 65 torr. PEEP was applied with an Emerson® PEEP assembly.

The study was initiated in each patient, with the PEEP setting that produced the maximum lung-thorax compliance, as determined from a 1.25-sec inflation hold. Then, once steady state was established, step changes in PEEP of 5 cm H₂O, up or down, were made. Mixed expired oxygen and carbon dioxide tensions were measured breath-by-breath throughout the study. Expired volumes were measured breath-by-breath, after collection, by integration of a pneumotachygraph signal. Expired volumes varied by no more than 5 per cent between PEEP steps. To compare the unsteady-state mixed expired gas with the difference in steady-state before and after the step change in PEEP, values were determined before and 15 min after the change. These values included pH, blood-gas tensions and contents, cardiac output, shunt fraction, alveolar-arterial oxygen difference, systemic oxygen transport, physiologic dead space, and lung-thorax compliance. PEEP levels ranged from 0 to 20 cm H₂O.

Measurements. Mixed expired oxygen ($P\bar{E}_{O_2}$) and carbon dioxide ($P\bar{E}_{CO_2}$) tensions were measured with a Medspect II® mass spectrometer. This instrument has a resolution of ± 1 torr and an accuracy of ± 1.4 torr. The instrument was calibrated with standard gases of oxygen, carbon dioxide, nitrogen, and argon before and after each patient study. Breath-by-breath mixed expired gas was collected using a specially designed valving and expired gas mixing system. Mixed expired gas was monitored and thorough mixing was demonstrated by a change of less than 1 torr through the course of each expired volume. The mixed expired oxygen and carbon dioxide transients were taken as the unsteady-state mixed expired gas tensions at the point of maximum change from the steady state.

Steady-state pH and *blood-gas tensions* from arterial and mixed venous specimens were determined by standard electrode techniques and corrected for the patient's temperature. Hemoglobin and hemoglobin saturation were measured by a colorimeter (Instrumentation Laboratories 282 Cooximeter). Arterial and mixed venous blood oxygen contents (C_{aO_2} , $C_{\bar{v}O_2}$) were then calculated, assuming a hemoglobin oxygen carrying capacity of 1.34 ml/g, and intrapulmonary shunt fraction (\dot{Q}_s/\dot{Q}_t) was determined. End-pulmonary capillary oxygen tension was assumed to be the same as the alveolar oxygen value and was cal-

culated as follows:

$$P_{A_{O_2}} = P_{I_{O_2}} - P_{A_{CO_2}} \left[F_{I_{O_2}} + \frac{1 - F_{I_{O_2}}}{R} \right]$$

Cardiac output (\dot{Q}_t) at each new steady state was determined by the thermodilution technique using the mean of duplicate measurements within 10 per cent agreement.

Systemic oxygen transport was calculated from the product of \dot{Q}_t (l/min) and C_{aO_2} (ml per cent $\times 10$).

Physiologic dead space (V_D/V_T) was determined by the Enghoff modification of the Bohr equation.

Statistical analysis was performed with the non-parametric sign test.¹⁰

RESULTS

Twenty-six step changes in PEEP were performed. The unsteady-state mixed expired oxygen and carbon dioxide changes were correlated with the steady-state alterations in oxygen transport, cardiac output, shunt fraction, and physiologic dead space. The range of mixed expired oxygen changes was -6 torr to +6 torr. The range of mixed expired carbon-dioxide changes was -2 torr to +3 torr. Values for mixed expired oxygen returned to baseline within 15-30 breaths, while changes in mixed expired carbon dioxide returned to baseline after 50-100 breaths. The change in mixed expired oxygen correlated inversely with the change in oxygen transport in 21 of 26 steps ($P < 0.0004$), varied directly once, and did not change in three steps (fig. 1). When the components of oxygen transport were considered separately, the change in mixed expired oxygen correlated inversely with the change in cardiac output ($P < 0.002$) but did not correlate with the change in arterial blood oxygen content ($P < 0.6$). There was no significant correlation between mixed expired oxygen and carbon dioxide transients and shunt fraction or physiologic dead space. In addition, mixed expired oxygen transients did not correlate with changes in lung-thorax compliance.

DISCUSSION

Various approaches have been proposed to monitor the cardiopulmonary effects of PEEP application. Several investigators have assessed the response to PEEP by determining effects on systemic oxygen transport.^{5,8,9} Clinically, repeated invasive measurements of cardiac output and arterial blood gases are necessary to determine the effects of various PEEP levels on oxygen transport. In this study we have evaluated continuous mixed expired gas monitoring

as an indicator of oxygen transport changes following alterations in PEEP levels.

In the steady state, breath-to-breath mixed expired oxygen and carbon dioxide tensions are constant. With alterations in PEEP, transient mixed expired oxygen changes should reflect transient changes in oxygen uptake. These changes should be determined by the net interaction of PEEP-induced effects on cardiac output and ventilation-perfusion relationships. PEEP may affect ventilation-perfusion relationships not only through changes in total pulmonary blood flow but also through redistribution of regional pulmonary blood flow. Additionally, PEEP can be expected to alter regional ventilation-perfusion relationships by alveolar recruitment, derecruitment, and overdistention. PEEP application might produce opposing effects on mixed expired oxygen transients through regional ventilation-perfusion effects. Recruitment of alveoli would tend to increase oxygen uptake while overdistention of alveoli, with a regional decrease in pulmonary blood flow, would decrease oxygen uptake. Thus, unsteady-state changes in mixed expired oxygen, when end-expiratory pressure is changed, will reflect net changes in oxygen transport as affected by all these variables.

The above postulates are consistent with the data and models of Farhi and Rahn.^{11,12} They administered epinephrine to dogs sufficient to produce a doubling of cardiac output while holding ventilation constant.¹¹ They found an approximate 10-torr transient reduction in end-tidal oxygen. The oxygen tension returned to baseline within 5 min. Changes in carbon dioxide tensions were small and occurred over a prolonged period. They also summarized the various factors that would determine the relative magnitudes of oxygen and carbon dioxide transients in the unsteady state. In particular, the gross disparity in volume of the small whole-body oxygen store and the much larger carbon dioxide store result in very different "buffering" capacities.

In our study, the unsteady-state change in mixed expired oxygen reliably predicted the directional change in oxygen transport after step changes in PEEP. The range of mixed expired oxygen changes was ± 6 torr with a return to steady state within 15–30 breaths. When considering the components of oxygen transport, we found that the mixed expired oxygen transients correlated with cardiac output but not with arterial oxygen content. This was expected because all patients had an arterial oxygen tension greater than 65 torr and further increases in arterial oxygen tension would not produce marked changes in content. These results are in basic agreement with

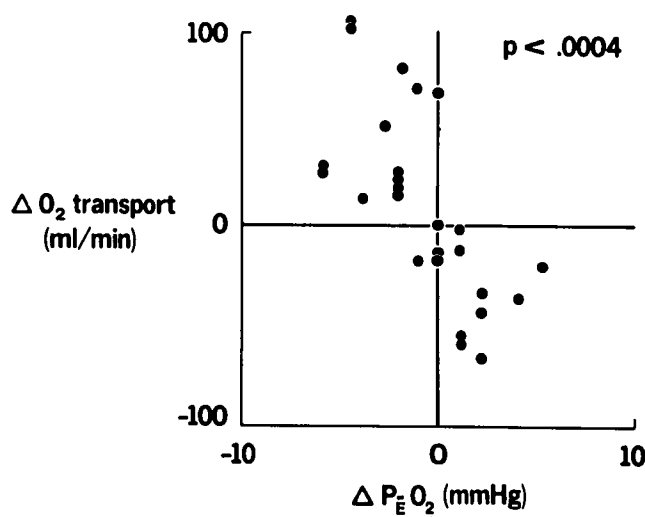


FIG. 1. Relationship of unsteady-state mixed expired oxygen ($\Delta P_{E}O_2$) to steady-state changes in systemic oxygen transport (ΔO_2 transport) after step changes in positive end-expiratory pressure.

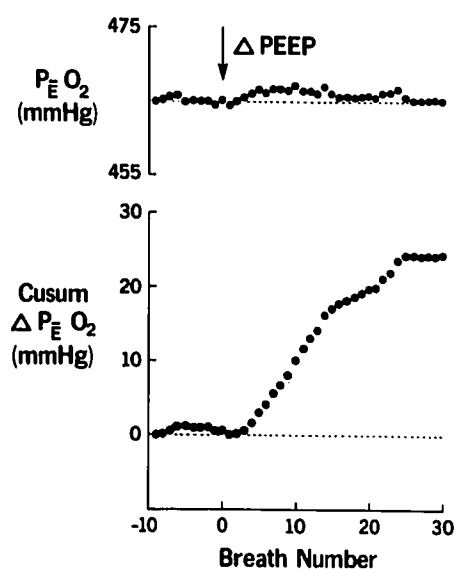


FIG. 2. Breath-by-breath mixed expired oxygen ($P_{E}O_2$) values before and after a step increase in PEEP (top). Cumulative summation analysis of the same mixed expired oxygen values (bottom).

those of Farhi and Rahn. However, there is no linear correlation between either cardiac output or oxygen transport and mixed expired oxygen transients. This may reflect the net interaction of regional ventilation-perfusion alterations after changes in PEEP. Farhi and Rahn held ventilation and airway pressure constant.

Because functional residual capacities were not measured, no direct correlation with alveolar recruitment was made. Suter *et al.*,⁵ however, suggested that changes in lung-thorax compliance followed changes in alveolar recruitment. In our study, there

was no relationship between lung-thorax compliance and mixed expired oxygen transients, which the predominant effect of cardiac output alterations may explain.

We found that the mixed expired carbon dioxide transients were small and did not correlate with cardiac output or physiologic dead space changes.

Although mixed expired oxygen transients predict directional changes in oxygen transport, we cannot make a quantitative correlation from our data. It should be noted that the magnitude of the mixed expired oxygen changes is quite small, requiring very stable steady-state conditions for detection. At present, the very efficient valving required in our collection of mixed expired gas is quite complex. Thus, we are prevented from using it for early clinical application. We are, however, considering mathematical methods of amplifying the directional changes in the mixed expired gases. One such method is cumulative summation analysis,¹³ in which the deviation of the mixed expired gas tension for each breath is calculated from the initial steady-state value. Figure 2 illustrates a cumulative summation analysis of a transient change in mixed expired oxygen after a step increase in PEEP. The analysis shows that a significant directional change has occurred with the application of PEEP. Such analyses may allow the small changes involved to have clinical relevance.

In conclusion, we have shown that the measurement of mixed expired oxygen transients provides a non-invasive guide to the efficacy of imposed changes in end-expiratory pressure; we have also defined the magnitude of the likely changes. These changes are small and, presently, this form of continuous

monitoring by mass spectrometers in the intensive care unit is not readily applicable.

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Anesthesia for Cesarean Section in Achondroplastic Dwarfs

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Achondroplastic dwarfs may encounter problems during both pregnancy and cesarean section delivery. This method of delivery is inevitable, because although birth weights of achondroplastic infants are only slightly less than those of normal infants, the maternal

pelvis is invariably small and contracted. This report describes the management of two achondroplastic dwarfs who underwent cesarean section with epidural and general anesthesia, respectively.

REPORT OF TWO CASES

Patient 1. A healthy, 25-year-old achondroplastic dwarf was admitted to the hospital for an elective cesarean section following an uneventful pregnancy. Physical examination revealed a 122-cm, 57-kg woman with the habitus of achondroplasia (short limbs, relatively normal trunk size, and a large cranium with prominent frontal bossing and flattened nasal bridge). The spine was slightly

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