Successful Weaning from Controlled Ventilation Despite High Deadspace-to-Tidal Volume Ratio

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The deadspace-to-tidal-volume ratio (VD/VT) has been used to assess the extent of acute pulmonary disease in patients without chronic airway obstruction.† The VD/VT ratio has also been advocated as a guideline for initiating and weaning patients from controlled ventilation.‡ Weaning from controlled ventilation at VD/VT ratios greater than 0.6 is rare indeed. This report documents the successful weaning of two young patients with prolonged acute respiratory failure secondary to pneumonia whose VD/VT ratios were repeatedly in excess of 0.65.

REPORT OF TWO CASES

Patient 1. A 38-year-old man had been in excellent health until February 1972, when he experienced acute onset of headache, cough, vomiting and diarrhea. The cough became productive and was accompanied by fever, chills, and dyspnea.

On admission he was confused and cyanotic. Rectal temperature was 102°F, heart rate 120 beats/min, and respiratory rate 30/min with labored respiration. The blood pressure was 140/80 mm Hg. Diffuse ronchi and wet rales were heard loudest at the left base and right anterior chest. Roentgenograms of the chest were interpreted as showing diffuse infiltrates in the right upper lobe, right lower lobe, and left upper lobe. Examination of Gram-stained sputum revealed polymorphonuclear cells with gram-positive cocci. Cultures of material from the pharynx, sputum, and blood yielded Group B beta-hemolytic streptococci. Arterial blood-gas values with the patient breathing room air were PO2 62 torr, PCO2 41 torr, and pH 7.31. Serum sodium was 114 mEq. The hematocrit was 43 per cent and the leukocyte count was 7,700, with 37 per cent neutrophils, 58 per cent bands. Central venous pressure was 15 cm H2O.

Aqueous penicillin, 2 million units/day, was administered intravenously. Pharyngeal and sputum cultures taken 24 hours later did not grow streptococci; however, penicillin was continued for the next 12 days. Respiratory distress continued; roentgenograms of the chest were interpreted as showing increase in the size of the infiltrate with consolidation in the right upper lobe. On the tenth hospital day a left lobe pneumonothorax, which was treated promptly by closed thoracotomy, developed. On the tenth hospital day, positive end-expiratory pressure (PEEP: range 5–10 cm H2O) was employed with controlled ventilation to permit a decrease in the inspired oxygen concentration to below 70 per cent. The alveolar-to-arterial oxygen tension difference measured during pure oxygen breathing (A-aDO2) was 360 torr at the start of PEEP and remained elevated for three days (Fig. 1). PEEP, however, did allow the inspired oxygen concentration to be lowered to 55 per cent to maintain the arterial oxygen tension at 80 torr. The A-aDO2 declined to 200 torr during the next six days (Fig. 1). VD/VT ratios remained above normal (range 0.59 to 0.73) even when the patient was weaned from PEEP at the end of the second week.

His nutritional status was as follows. Before his illness the patient was 74 inches tall and weighed 190 pounds. Admission weight in the Respiratory-Surgical Intensive Care Unit (R-SICU) was 180 pounds. After a loss of 20 pounds during the first week, weight was maintained at 182–185 pounds. Caloric intake (from the bedside chart) averaged 1,335, 1,655, and 2,559 cal/day during the second week, third week, and time of transfer, respectively. Corresponding protein intake was 58, 64, and 56 g, respectively. The serum albumin concentration was initially normal (3.7 g/100 ml) and gradually declined to 2 g/100 ml during the second and third hospital weeks.

At the end of three weeks' hospitalization, the patient was able to breathe spontaneously despite a VD/VT ratio of 0.67. Arterial blood-gas values were PO2 79 torr, PCO2 50 torr, and pH 7.31. At the time of transfer from the R-SICU to the twenty-fourth hospital day the patient had persistent fever, attributed to resolving bacterial pneumonia. A chest roentgenogram was interpreted as showing residual pneumatoceles in the right middle lobe. Fever persisted during the next two weeks; the residual

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sterile abscess in the right middle lobe was treated by needle aspiration. After five weeks' hospitalization, arterial blood-gas values measured with the patient breathing room air were \( P_O_2 \) 96 torr, \( P_CO_2 \) 36 torr, \( pH \) 7.37.

After three months' convalescence, the patient returned to full employment, but noted fatigue and dyspnea after moderate exertion. At this time he had a total vital capacity of 4,530 ml (100 per cent of predicted), a first-second vital capacity of 3,690 ml (82 per cent of predicted), a maximum mid-expiratory flow rate of 213 l/min (58 per cent of predicted), and a maximum breathing capacity of 228 l/min (165 per cent of predicted).

Patient 2. A previously healthy 32-year-old woman was transported by airplane to this hospital while receiving controlled ventilation. Two weeks before, she had developed a nonproductive cough, which had also been experienced by eight other people in her house. Three days later she had had an oral temperature of 102 °F, for which ampicillin was prescribed. Cough, fever, and anorexia continued. Roentgenograms of the chest were interpreted as showing alveolar infiltrates in the left upper and lower lobes, and intravenous administration of cephalothin was instituted. The dyspnea increased. Arterial blood-gas values during administration of oxygen by face mask at a flow rate of 10 l/min were \( P_O_2 \) 45 torr, \( P_CO_2 \) 70 torr. Emergency tracheotomy was performed and the patient was transferred to this hospital.

Upon admission the rectal temperature was 102 °F, the heart rate 150 beats/min, and the respiratory rate 30/min. Blood pressure was 120/70 mm Hg. There was marked bilateral enlargement of the parotid glands, and wet rales were heard throughout both lungs. Cardiac and neurologic examinations disclosed no abnormality.

The hemocrit was 37 per cent and the leucocyte count was 15,000, with 59 per cent neutrophils and 32 per cent bands. Cold agglutinins were strongly positive. Roentgenograms of the chest showed bilateral infiltrates with air bronchograms. Arterial \( P_CO_2 \) was in excess of 100 torr, and controlled ventilation was instituted with a volume-
limited ventilator. A succinylcholine infusion at 2–4 mg/min was initially necessary to permit controlled ventilation.

Erythromycin, 500 mg, was administered intravenously every six hours for 14 days. The fever persisted and the antibiotic was changed to tetracycline, which was administered for ten more days. Mycoplasma complement-fixation titers supported the diagnosis of Mycoplasma pneumonia with a rise in titer from 1/16 to more than 1/256.

Numerous attempts at weaning were unsuccessful because of acute alveolar hypoventilation and fatigue. \( V_{DP}/V_T \) ratios ranged from 0.62 to 0.71. By the third week, the patient was able to tolerate progressively longer periods of spontaneous ventilation during those weaning periods she maintained a \( P_{aCO_2} \) between 50 and 60 torr. Repeated measurements of carbon dioxide production and \( V_{DP}/V_T \) ratios showed similar values during periods of spontaneous and controlled ventilation. Mean values were 224 and 225 \( mL/min \) respectively, for \( V_{aCO_2} \) normal basal for her weight; 134 \( mL/min \), R of 0.8 assumed and 0.69 and 0.65, respectively, for \( V_{DP}/V_T \) ratios (fig. 2).

The patient's nutritional status was as follows. Her normal weight previously had been 101 pounds. After transfer from the referring hospital, she weighed 111 pounds; after an induced diuresis, 100 pounds. Weight was maintained between 96 and 98 pounds for the next four weeks. Caloric intakes averaged 2,150, 1,740, 1,685, and 1,140 cal/day for the first, second, third, and final two weeks, respectively. Corresponding protein intakes were 49, 79, 92, and 36 g, respectively. Infusions of salt-poor albumin (given only in the first two weeks) were not included in the calculations. Serum albumin concentrations were 2.2 g/100 ml initially and 4.2 and 3.8 g/100 ml during the second and fourth weeks, respectively.

During the fourth hospital week, the patient was completely weaned from the ventilator despite \( V_{DP}/V_T \) ratios greater than 0.65 (fig. 2). A fenestrated tracheostomy tube was employed for four days and subsequently removed. Two weeks later she was able to walk with only moderate dyspnea. Roentgenograms of the chest were interpreted as revealing only basilar infiltrates. Measured \( V_{DP}/V_T \) ratios had decreased to 0.53. She had a vital capacity of 1,640 ml (38 per cent of predicted), a first-second vital capacity of 1,550 ml (95 per cent of predicted), and a maximal mid-expiratory flow rate of 148 l/min (76 per cent of predicted). At three months follow-up, the \( V_{DP}/V_T \) ratio was 0.37.

**DISCUSSION**

Two patients who had acute respiratory failure requiring controlled ventilation were weaned to spontaneous ventilation despite abnormal increases in physiologic deadspace and \( V_{DP}/V_T \) ratios. In acute respiratory failure resulting from pneumonia, the \( V_{DP}/V_T \) ratio increases and may remain increased even after the \( \Delta aDo_2 \) and roentgenograms of the chest have returned toward normal. Although this pattern has been noted previously, the explanation for the persistent increase in physiologic deadspace or \( V_{DP}/V_T \) ratio remains unclear.

Relative hypovolemia due to hypoalbuminemia may have contributed to the high \( V_{DP}/V_T \) ratio in Patient 1, despite maintenance of normal urinary output and central venous pressure. Serum albumin concentration was kept in the normal range in Patient 2 by infusion of salt-poor albumin. Controlled ventilation itself had minimal effect on \( V_{DP}/V_T \) ratios; similar values were obtained during controlled and spontaneous ventilation in Patient 2 (fig. 2). Furthermore, compression volume within the ventilator system yields minimal error in \( V_{DP}/V_T \) ratios at high values. Added mechanical deadspace, which falsely increases the anatomic deadspace, was not used in either patient. Pulmonary embolism, another cause of elevated \( V_{DP}/V_T \), was not clinically evident in either reported patient.

Of interest were the metabolic rates measured during controlled ventilation and spontaneous breathing in Patient 2. Carbon dioxide production, which was markedly increased, was the same during controlled and spontaneous breathing (fig. 2). Oxygen consumption has been reported as identical during controlled ventilation and weaning. Fever and catabolic illness may contribute more to energy expenditure than does the work of breathing.

Since both patients were able to maintain their weights during their catabolic illnesses, protein synthesis was probably adequate to offset nitrogen losses. Treatment aimed at preventing fatigue, increasing "exercise" tolerance, providing adequate sleep and rest periods, a high protein and adequate caloric intake, may have been critical in the successful weaning from controlled to spontaneous ventilation in our two patients when \( V_{DP}/V_T \) ratios were higher than the currently recommended value for the initiation of weaning.
SUMMARY

Two patients with primary pneumonia and prolonged respiratory failure who were successfully weaned from controlled ventilation at a time when Vd/VT ratios were still markedly abnormal are reported. Both patients were able to maintain spontaneous ventilation at Vd/VT ratios greater than 0.65 although other criteria for weaning had been met. Adequate nutrition may be a critical factor in weaning patients from controlled ventilation.

REFERENCES


Drugs and Their Actions

CORONARY ARTERY RECEPTORS Evidence for the presence of coronary arterial alpha- and beta-adrenergic receptors has been presented for several animal species; in man the issue is unsettled. The opportunity to investigate this question arose fortuitously when a 33-year-old man failed to respond to resuscitative measures, including open-chest massage, following an overdose of sleeping pills and alcohol. A carefully preserved piece of coronary artery was mounted appropriately to permit wall tension measurements during perfusion. When the perfusate contained norepinephrine (1.7 x 10^-7 g/ml), the initially tonic muscular tissue responded with a short contraction, followed by relaxation leading to moderate tone. Pretreatment with sotalol (1.2 x 10^-5 g/ml), a beta-adrenergic blocking agent, suppressed this relaxation. The tonic vessel also contracted when potassium chloride (1.3 x 10^-2 M/l) was added to the perfusate after norepinephrine- and epinephrine-induced relaxation; this reaction was also blocked when preceded by sotalol. However on this occasion wall tension was greater than with KCl alone. This persistent contraction was then reversed by the alpha-adrenergic-blocking drug dibenamine (5 x 10^-6 g/ml). (Andersson, R., and others: Alpha and Beta Adrenergic Receptors in Human Coronary Artery. Acta Med. Scand. 191:3, 1972.)