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.1 The Vd/Vt ratio has also been advocated as a guideline for initiating and weaning patients from controlled ventilation.2,3 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 rhonchi 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 A beta-hemolytic streptococci. Arterial blood-gas values with the patient breathing room air were PaO2 62 torr, PaCO2 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 infiltrates with consolidation in the right upper lobe. Orotracheal intubation was performed on the second hospital day because of progressive hypoxemia, hyperventilation, and acidemia. Controlled ventilation was begun with a volume-limited ventilator. Tracheostomy was performed on the fifth hospital day, since the patient was unable to breathe spontaneously. On the ninth hospital day, a left tension pneumothorax, 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-STICU) was 175 pounds. After a loss of 20 pounds during the first week, weight was maintained at 182-185 pounds. Caloric intakes (from the bedside chart) averaged 1,335, 1,655, and 2,059 cal/day during the second week, third week, and time of transfer, respectively. Corresponding protein intakes were 58, 64, and 98 gm, respectively. The serum albumin concentration was initially normal (3.7 gm/100 ml) and gradually declined to 2 gm/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 PaO2 79 torr, PaCO2 50 torr, and pH 7.31. At the time of transfer from the R-STICU 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 PO₂ 96 torr, PCO₂ 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 4,830 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 1/min (58 per cent of predicted), and a maximum breathing capacity of 228 1/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 right 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 PO₂ 45 torr, PCO₂ 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 hematocrit was 37 per cent and the leukocyte 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 PCO₂ was in excess of 100 torr, and controlled ventilation was instituted with a volume-

Fig. 1. Serial measurements in alveolar-arterial oxygen tension differences (A-aDO₂) and deadspace-to-tidal volume ratios (Vd/VT) in Patient 1. The first values were determined shortly after symptoms developed and before the patient needed controlled ventilation. Vd/VT ratios were already markedly increased. After ten days, positive end-expiratory pressure was instituted and maintained for seven days. During this period roentgenograms of the chest showed improvement in alveolar infiltrates and the A-aDO₂ returned toward normal. The patient was completely weaned from controlled ventilation after 21 days, at a time when the Vd/VT ratio was 0.67.

Fig. 2. Comparison of values determined during controlled ventilation and during weaning periods in Patient 2. Mean values for carbon dioxide production (VCO₂) did not show any difference between controlled and spontaneous ventilation. Alveolar-arterial oxygen tension difference (A-aDO₂), was initially increased, and returned toward normal during the week. Vd/VT ratios were similar during weaning periods compared with values measured on controlled ventilation. At the time of successful weaning, the Vd/VT ratio was still above 0.65. Only after several months' convalescence did the Vd/VT ratio return toward normal.
limited ventilator. A succinylcholine infusion at 2-4 mg/min was initially necessary to permit controlled ventilation.

Erinophyllum, 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 pneumoniae 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. Vp/VT 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 PaCO₂ between 50 and 60 torr. Repeated measurements of carbon dioxide production and Vp/VT ratios showed similar values during periods of spontaneous and controlled ventilation. Mean values were 224 and 225 mIm/m²min, respectively, for PaCO₂ normal basal for her weight: 134 mIm/m²min, R of 0.8 assumed) and 0.69 and 0.65, respectively, for Vp/VT 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, 1,895, and 1,410 cal/day for the first, second, third, and final two weeks, respectively. Corresponding protein intakes were 49, 79, 92, and 56 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 Vp/VT ratios greater than 0.65 (fig. 2). A fenestrated trachostomy 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 Vp/VT ratios had decreased to 0.33. She had a vital capacity of 1,640 ml (38 per cent of predicted), a first-second vital capacity of 1,560 ml (52 per cent of predicted), and a maximum mid-expiratory flow rate of 148 l/min (76 per cent of predicted). At three months follow-up, the Vp/VT ratio was 0.37. Spirometry, arterial blood-gas values and roentgenograms of the chest were normal.

**DISCUSSION**

Two patients who had acute respiratory failure requiring controlled ventilation were weaned to spontaneous ventilation despite abnormal increases in physiologic deadspace and Vp/VT ratios. In acute respiratory failure resulting from pneumonia, the Vp/VT ratio increases and may remain increased even after the Λ-aD₀₂¹,²,³ and roentgenograms of the chest have returned toward normal. Although this pattern has been noted previously,⁴ the explanation for the persistent increase in physiologic deadspace or Vp/VT ratio remains unclear.

Relative hypovolemia⁵ due to hypoalbuminemia may have contributed to the high Vp/VT 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 Vp/VT 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 Vp/VT ratios at high values.⁶ Added mechanical deadspace, which falsely increases the anatomic deadspace, was not used in either patient. Pulmonary embolism, another cause of elevated Vp/VT, 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.⁷ 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 Vp/VT ratios were higher than the currently recommended value for the initiation of weaning.⁸
SUMMARY

Two patients with primary pneumonia and prolonged respiratory failure who were successfully weaned from controlled ventilation at a time when \( \frac{V_D}{V_T} \) ratios were still markedly abnormal are reported. Both patients were able to maintain spontaneous ventilation at \( \frac{V_D}{V_T} \) 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 atomic 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.)