

Severe pneumonia with pneumatoceles and patent foramen ovale in an infant: optimal ventilation strategy?

Nevin K Chinnan, Ashraf IM Shabaan,
Muhammad Saeed and Wael A Samman

The current lung protective ventilation strategy for acute respiratory distress syndrome (ARDS) advocates low tidal volume (6 mL/kg) and titration of positive end-expiratory pressure (PEEP) and fraction of inspired oxygen (FiO₂) to prevent hypoxaemia.¹ The ventilation strategy of low tidal volume can decrease volutrauma to the lungs, but may cause alveolar collapse if not supplemented by adequate PEEP. This may result in repeated opening and closing of alveoli and has the potential to produce lung injury through shear stress at the interface between aerated and collapsed lung.² To ensure alveolar patency throughout the respiratory cycle, an "open lung strategy" has recently been recommended, with application of PEEP to avoid alveolar collapse and manoeuvres to facilitate alveolar recruitment.² To prevent hypoxia in ARDS, PEEP and FiO₂ are incrementally increased to meet a target PaO₂ greater than 55 mmHg. Based on the ARDS Network protocol, a PEEP above 18 cmH₂O at a FiO₂ of 1 may be needed. However, patients with hypovolaemia, right ventricular dysfunction, congenital heart disease with right-to-left shunts, and bronchopleural fistulas tolerate increments in PEEP poorly. These patients may benefit from individualisation of ventilation strategy rather than adherence to a strict protocol. Here, we describe a 2-month-old infant with severe pneumonia and pneumatoceles in ARDS who could not tolerate a PEEP of 10 cmH₂O because of right-to-left shunting via a patent foramen ovale.

Clinical record

A 2-month-old male infant (4.65 kg) presented with a history of persistent fever and non-productive cough for 2 days, and breathlessness and poor feeding for 1 day. There was no history of vomiting, choking, rash, diarrhoea, cyanosis or abdominal distension. His antenatal, natal and postnatal histories were uneventful.

Vital signs on admission were: temperature, 38.5°C; pulse, normal volume and 150 beats per min; blood pressure, 90/60 mmHg; and respiratory rate, 75 breaths per min. General examination revealed no obvious congenital anomalies. There were bilateral crepitations and rhonchi on chest auscultation. On oxygen supplementation with a nasal cannula (3 L/min), SpO₂ was maintained above 90%. The infant was haemodynamically stable, and cardiovascu-

ABSTRACT

We discuss a case of severe pneumonia with pneumatoceles in a 2-month old infant. Despite peak and plateau airway pressures kept below 30 and 25 cmH₂O, respectively, the infant developed bilateral pneumothorax and pneumomediastinum caused by pneumatocele rupture, necessitating bilateral intercostal drainage. Application of positive end-expiratory pressure (PEEP) of 10 cmH₂O at FiO₂ of 0.7 worsened oxygenation, and transthoracic echocardiography showed right-to-left shunting of blood through the patent foramen ovale. Therefore, PEEP had to be tapered to 6 cmH₂O, and ventilation carried out at FiO₂ of 1 until the lung condition improved. The open lung strategy of higher increments of PEEP and lower FiO₂ for lung protective ventilation actually proved deleterious to our patient. We conclude that a subset of patients with acute respiratory distress syndrome with refractory hypoxaemia may have right-to-left shunting of blood through a patent foramen ovale. This can be detected by echocardiography, and these patients may benefit from a ventilation strategy aimed at lowering pulmonary vascular resistance.

Crit Care Resusc 2006; 8: 209–212

lar examination was unremarkable. The abdomen was soft, with the liver palpable 3 cm below the right costal margin and no splenomegaly. Bowel sounds were normal. There were no focal neurological deficits.

Initial chest x-ray revealed bilateral lung infiltrates and right upper zone opacity. Initial blood, urine and sputum cultures showed no growth. However, empirical antibiotic therapy with ampicillin and ceftriaxone was started. Electrocardiogram on admission showed sinus tachycardia (150 beats per min), and initial echocardiogram did not reveal any abnormality.

On Day 3 of admission, the infant's arterial oxygenation was reduced (SpO₂ < 90%), despite 5 L/min oxygen supplementation with a nasal cannula. Chest x-ray showed spontaneous pneumothorax with underlying lung collapse on the right side and bilateral pneumatoceles.

Oxygenation improved after insertion of a thoracostomy tube. The antibiotic regimen was modified to cover *Staphy-*

CASE REPORTS

Table 1. Capillary blood gas analysis during the infant's intensive care stay

Day of stay	FiO ₂	PaO ₂ (mmHg)	PaCO ₂ (mmHg)	pH	HCO ₃ (mEq/L)	SaO ₂ (%)	PIP (cmH ₂ O)	PAP (cmH ₂ O)	PEEP (cmH ₂ O)
1	0.3	51.0	48.0	7.31	23.6	85.5	–	–	–
3*	0.4	37.9	60.7	7.34	28.3	78.0	–	–	–
6	0.6	48.1	25.8	7.50	22.9	90.3	–	–	–
7†	0.6	39.6	49.3	7.47	35.7	67.1	–	–	–
8	0.7	38.8	43.9	7.47	30.9	76.4	30	23	10
8‡	1.0	49.1	45.6	7.43	29.0	86.0	30	22	6
9	1.0	41.7	56.0	7.45	32.0	81.6	30	23	6
10	1.0	48.8	59.9	7.45	37.1	87.9	30	24	5
11	0.75	46.6	61.2	7.39	32.6	86.3	30	23	5
14	0.7	52.1	49.7	7.55	35.1	91.4	25	20	3
21	0.5	134	37.7	7.50	28.5	98.3	21	–	3

FiO₂ = fraction of inspired oxygen. PIP = peak inspiratory pressure. PAP = plateau airway pressure. PEEP = positive end-expiratory pressure.

* On Day 3, the infant developed severe hypoxaemia and hypercarbia due to spontaneous pneumothorax on the right side, probably due to pneumatocele rupture. † On Day 7, the infant's clinical condition and capillary blood gases worsened, necessitating intubation and mechanical ventilation.

‡ On Day 8, repeat transthoracic echocardiography showed elevated pulmonary artery pressure (50 mm Hg) and right-to-left shunting of blood through a patent foramen ovale with further worsening of oxygenation. A marginal improvement in oxygenation was achieved by increasing FiO₂ to 1.0 and lowering PEEP to 6 cmH₂O.

lococcus aureus (vancomycin) and anaerobes (metronidazole), as these organisms are commonly associated with pneumatocele formation. However, blood and tracheal aspirates did not show growth of these organisms.

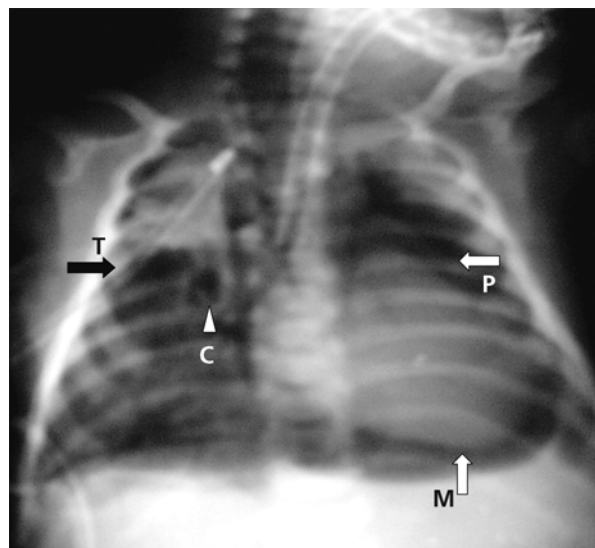
Serum immunoglobulin testing showed low IgA levels (0.485 g/L; reference range, 0.81–3.87 g/L), and normal IgG and IgM levels. On Day 4, culture of tracheal aspirate showed *Comamonas testosteroni* sensitive to ceftazidime and amikacin. These antibiotics were started. Ampicillin and ceftriaxone were discontinued, but vancomycin and metronidazole were continued because of the high clinical suspicion of *S. aureus* or anaerobic infection responsible for the pneumatocele formation.

The infant continued to have intermittent spikes of fever (38.5–39.5°C), although repeated culture of blood and tracheal aspirates failed to show any growth. Considering the increased risk of infections in IgA deficiency by encapsulated organisms, such as *Haemophilus influenzae*, and to cover for atypical pathogens, parenteral azithromycin (10 mg/kg loading dose, and 5 mg/kg subsequently) was also given empirically for the next 7 days.

Serial blood gas analysis during the course of the infant's stay in the intensive care unit is shown in Table 1. Because of his worsening lung condition, the infant was intubated and mechanically ventilated on Day 7. Despite peak and plateau airway pressures kept below 30 cmH₂O and 25 cmH₂O, respectively, he developed bilateral pneumothorax and pneumomediastinum. A thoracostomy tube was inserted in the left side as well as the right.

Chest x-ray on Day 8 before insertion of the second thoracostomy tube is shown in Figure 1. During mechanical ventilation at a FiO₂ of 0.7, with PEEP and peak inspiratory pressure of 10 cmH₂O and 30 cmH₂O, respectively, blood gases continued to deteriorate. Transthoracic echocardi-

Figure 1. Chest x-ray on Day 8 of admission



Chest x-ray on Day 8 showing pneumatocele (C), left-sided pneumothorax (P) and pneumomediastinum (M). The right thoracostomy tube is also evident (T).

gram revealed elevated pulmonary arterial pressure (50 mmHg) and right-to-left shunting of blood through a patent foramen ovale. Subsequently, to lower the pulmonary arterial pressure, PEEP was decreased to 6 cmH₂O, and FiO₂ increased to 1.0.

The infant's condition remained haemodynamically unstable, probably because of the ongoing septic process, requiring vasopressors (noradrenaline, 0.2 µg/kg per min; dopamine, 15 µg/kg per min) to maintain a mean arterial pressure of 50 mmHg. There was a progressive improvement in blood gases and clinical condition over the next couple of days. The infant was extubated after 14 days, and discharged on Day 28.

Discussion

A lung protective strategy of restricting the tidal volume to around 6 mL/kg was reported in the 1990s to decrease mortality in patients with ARDS.^{3,4} Although these claims were disputed in subsequent studies,^{5,6} the landmark ARDS Network trial¹ confirmed a 22% reduction in mortality through adoption of the lung protective strategy. However, this trial has been criticised for flaws in its research design⁷ as it compared the 3rd percentile of tidal volumes used in current practice (6 mL/kg) with the 80th percentile (12 mL/kg), without assessing the most commonly administered level of care (50th percentile, 10 mL/kg).

Lowering the tidal volume has its hazards. It decreases the volume of aerated lung with a consequent increase in shunting, worsening oxygenation, and hypercapnia. Application of PEEP is recommended to prevent this loss of lung volume. The mechanisms proposed to explain the improved pulmonary function and gas exchange with PEEP in ARDS patients are increased functional residual capacity; alveolar recruitment; redistribution of extravascular lung water; and improved ventilation-perfusion matching.⁸

Thus the "open lung ventilation strategy", which is the standard of care in modern intensive care medicine, advocates use of low tidal volumes (6–8 mL/kg), limiting of plateau pressures to 35 cmH₂O, and increments of PEEP titrated with FiO₂ to a target PaO₂ greater than 55 mmHg.¹

However, our patient's oxygenation actually worsened with this protocol (Table 1). Increments of PEEP probably caused further increase in pulmonary vascular resistance and right-to-left shunting of blood. This effect of PEEP on pulmonary haemodynamics was documented by earlier studies,^{9,10} although not supported by a recent trial.¹¹ It is interesting to note that most trials of ventilation strategies in ARDS patients have not analysed data on pulmonary and systemic haemodynamics, but confined themselves to pulmonary mechanics.^{1,3-6} In our patient also, we could not document pulmonary haemodynamics because of the diffi-

culties of pulmonary artery catheterisation in small infants. However, right-to-left shunting of blood across the patent foramen ovale secondary to an elevated pulmonary artery pressure was shown by transthoracic echocardiography.

Another challenge faced in management of our patient was the presence of bilateral pneumothorax and pneumomediastinum. Any pneumothorax in a patient undergoing mechanical ventilation should be decompressed with intercostal drainage to prevent development of tension pneumothorax. In the ICU, localisation and drainage may be difficult because of unusual pneumothorax positions and presence of pleural adhesions. The intercostal drainage may be facilitated by computed tomography guidance of chest catheter placement.¹² Ventilation of patients with air leak syndromes may be carried out with lower tidal volumes (6–8 mL/kg), and lower peak inspiratory pressures and flows, as they help decrease the air leak.¹² Briassoulis et al did not find PEEP to be a major independent risk factor for air leak syndrome.¹³ However, they suggested that increasing PEEP may have a compounding effect on alveolar stretch, especially when tidal volumes are high.¹³ Lowering the peak inspiratory pressures and inspiratory gas flows for a given tidal volume decreases the velocity of lung stretch, and therefore protects the lung from ventilator-induced lung injury.¹³ High frequency oscillatory ventilation is an extreme form of lung protective ventilation strategy that provides very low tidal volumes (1–3 mL/kg), a rapid rate (up to 2400 breaths per minute), and an active expiratory phase to prevent air trapping and maintain near normal carbon dioxide levels. It also provides a continuous distending pressure to prevent cyclical alveolar collapse. This unconventional mode of ventilation has been used successfully in both adults and children with ARDS and air leak syndromes.^{14,15}

The incidence of patent foramen ovale in the general population is about 27.3%, with an occurrence in those aged under 30 years as high as 34.3%.¹⁶ ARDS itself can increase pulmonary vascular resistance,¹⁷ and application of PEEP may further aggravate this.^{9,10} Thus, as in our case, almost one in every three ARDS patients may benefit from a modification of the ventilation strategy aimed at lowering pulmonary vascular resistance, such as low tidal volumes, and application of physiological PEEP (5–6 cmH₂O) and a higher FiO₂, to reverse the hypoxic pulmonary vasoconstriction. Agents directed at lowering pulmonary vascular resistance, such as inhaled nitric oxide, may also prove beneficial in these patients. We suggest echocardiography to rule out patent foramen ovale in all ARDS patients with worsening oxygenation despite an open lung ventilation strategy. Further randomised controlled studies are required to confirm this, and to modify the ventilation strategy accordingly.

Conclusion

Deterioration in oxygenation in a subset of ARDS patients may be caused by shunting of blood through a patent foramen ovale rather than further worsening of gas exchange in the lungs per se. Identification of these patients by non-invasive means, such as echocardiography, and modification of the ventilation strategy to prevent further increase in pulmonary vascular resistance, such as low tidal volumes (6–8 mL/kg), application of physiological PEEP (5–6 cmH₂O) and a higher FIO₂ to reverse the hypoxic pulmonary vasoconstriction, along with other measures to lower pulmonary vascular resistance, may be beneficial. A large prospective trial on this topic is needed.

Author details

Nevin K Chinnan, Resident Intensivist¹

Ashraf IM Shabaan, Resident Intensivist¹

Muhammad Saeed, Paediatrician²

Wael A Samman, Intensivist¹

1 Department of Anaesthesia and Intensive Care Unit, King Khalid Hospital, Najran, Saudi Arabia.

2 Department of Paediatrics, Maternity and Children Hospital, Najran, Saudi Arabia.

Correspondence: nevinkc2001@yahoo.com

References

- 1 The Acute Respiratory Distress Syndrome Network. Ventilation with lower tidal volumes as compared with traditional tidal volumes for acute lung injury and the acute respiratory distress syndrome. *N Engl J Med* 2000; 342: 1301-8.
- 2 Lapinsky SE, Mehta S. Bench-to-bedside review: recruitment and recruiting maneuvers. *Crit Care* 2005; 9: 60-5.
- 3 Hickling KG, Henderson SJ, Jackson R. Low mortality associated with low volume pressure limited ventilation with permissive hypercapnia in severe adult respiratory distress syndrome. *Intensive Care Med* 1990; 16: 372-7.
- 4 Amato MB, Barbas CS, Medeiros DM, et al. Beneficial effects of the "open lung approach" with low distending pressures in acute respiratory distress syndrome: a prospective randomized study on mechanical ventilation. *Am J Respir Crit Care Med* 1995; 152: 1835-46.
- 5 Stewart TE, Meade MO, Cook DJ, et al. Evaluation of a ventilation strategy to prevent barotrauma in patients at high risk for acute respiratory distress syndrome. *N Engl J Med* 1998; 338: 355-61.
- 6 Brower RG, Shanholtz CB, Fessler HE, et al. Prospective, randomized, controlled clinical trial comparing traditional versus reduced tidal volume ventilation in acute respiratory distress syndrome patients. *Crit Care Med* 1999; 27: 1492-8.
- 7 Eichacker PQ, Banks SM, Natanson C. Meta-analysis of tidal volumes in ARDS. *Am J Respir Crit Care Med* 2003; 167: 798-800.
- 8 Villar J. The use of positive end-expiratory pressure in the management of the acute respiratory distress syndrome. *Minerva Anestesiol* 2005; 71: 265-72.
- 9 Koganov Y, Weiss YG, Oppenheim A, et al. Positive end-expiratory pressure increases pulmonary venous vascular resistance in patients after coronary artery surgery. *Crit Care Med* 1997; 25: 767-72.
- 10 Biondi JW, Schulman DS, Soufer R, et al. The effect of incremental positive end-expiratory pressure on right ventricular hemodynamics and ejection fraction. *Anesth Analg* 1988; 67: 144-51.
- 11 Reis Miranda D, Gommers D, Struijs A, et al. The open lung concept: effects on right ventricular afterload after cardiac surgery. *Br J Anaesth* 2004; 93: 327-32.
- 12 Woodside KJ, van Sonnenberg E, Chon KS, et al. Pneumothorax in patients with acute respiratory distress syndrome: pathophysiology, detection, and treatment. *J Intensive Care Med* 2003; 18: 9-20.
- 13 Briassoulis GC, Venkataraman ST, Vasilopoulos AG, et al. Air leaks from the respiratory tract in mechanically ventilated children with severe respiratory disease. *Pediatr Pulmonol* 2000; 29: 127-34.
- 14 Galvin I, Krishnamoorthy R, Saad RSG. Management of advanced ARDS complicated by bilateral pneumothoraces with high-frequency oscillatory ventilation in an adult. *Br J Anaesth* 2004; 93: 454-6.
- 15 Pizov R, Shir Y, Eimerl D, et al. One-lung high frequency ventilation in the management of traumatic bronchial tear in a child. *Crit Care Med* 1987; 15: 1160-1.
- 16 Hagen PT, Scholz DG, Edwards WD. Incidence and size of patent foramen ovale during the first 10 decades of life: an autopsy study of 965 normal hearts. *Mayo Clin Proc* 1984; 59: 17-20.
- 17 Beiderlinden M, Kuehl H, Boes T, Peters J. Prevalence of pulmonary hypertension associated with severe acute respiratory distress syndrome: predictive value of computed tomography. *Intensive Care Med* 2006; 32: 852-7. □