Supplemental Jet Ventilation in a Case of ARDS Complicated by Bronchopleural Fistulae

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ABSTRACT

Objective: To present a case of unusual ventilatory strategy in a 17 year old girl with the acute respiratory distress syndrome (ARDS) complicated by bilateral bronchopleural fistulae.

Methods: The patient was ventilated with a combination of conventional pressure control ventilation (PCV) and high frequency jet ventilation (HFJV) for 110 and 133 days, respectively.

Results: Despite prolonged hypoxia, extensive barotrauma and nosocomial infections, she survived without significant impairment of respiratory function. Two years later she was healthy and independent with only mildly reduced respiratory reserve.

Conclusions: The combination of PCV and HFJV was beneficial in this case of ARDS complicated by bronchopleural fistulae. The case also highlights the utility of HFJV in the desperately hypoxic patient with extensive airway disruption. (Critical Care and Resuscitation 2005; 7: 111-115)

Key words: ARDS, high frequency jet ventilation, bronchopleural fistulae, management

The author presents a case of a 17 year old female with the acute respiratory distress syndrome (ARDS) complicated by bilateral bronchopleural fistulae, who was ventilated with combined high frequency jet ventilation (HFJV) and conventional pressure control ventilation (PCV) for 110 and 133 days respectively. She has made a good recovery and to the author’s knowledge has received the longest period of HFJV in the world and survived.

CASE REPORT

A 17 year old female presented with a five day history of fever, nausea, general malaise, dry cough and sore chest. She was tachypnoeic at 30 breaths per minute (bpm) and febrile (38.4°C). Initially her blood pressure (BP) and heart rate (HR) were stable. Pulmonary infection was suspected, based on the pyrexia, neutrophilia and pulmonary infiltrates. She was hypoxic with an arterial partial pressure of oxygen (PaO₂) of approximately 40 mmHg on high flow inspired oxygen, her arterial partial pressure of carbon dioxide (PaCO₂) was in the range 35 to 45 mmHg.

After a period of non-invasive ventilation (inspiratory pressure 14 cmH₂O, expiratory pressure 7 cmH₂O) she deteriorated rapidly, associated with a tension pneumothorax requiring emergency thoracostomy drainage and intubation of the trachea. Contralateral tension pneumothorax ensued, removing any possibility of independent lung ventilation. Gas exchange was extremely impaired at this time. The patient developed further complications of barotrauma, with air leaks from bronchopleural fistulae requiring up to seven chest drains at a time.

Her condition was desperate, with high airway pressures (> 40 cmH₂O peak, positive end expiratory pressure, PEEP, of 10 - 14 cmH₂O) to achieve tidal volumes of 5 - 7 mL/kg. The respiratory rate was 30 - 40/min. She had sustained hypoxia on 100% inspired oxygen (PaO₂ approximately 30 - 40 mmHg). Inverse ratio ventilation had failed (PaCO₂ rose to more than 120 mmHg) and there was no hope of prone ventilation, with several chest drains in situ. The patient was first heavily sedated, then paralysed with an intravenous atracurium infusion. When those measures failed to achieve the desired improvement in gas exchange, even more desperate therapies outside of our usual practice

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were employed. Aerosolized prostacyclin, inhaled nitric oxide and intravenous N-acetylcysteine (NAC) were used with only temporary improvement in gas exchange. Oxygen free radical protection was initiated with vitamin E and allopurinol. She was too unstable to transfer without the risk of tension pneumothoraces and desaturation, precluding diagnostic imaging.

By day 15 her PaO$_2$ was still in the range 40 - 45 mmHg with the PaCO$_2$ ranging from 50 - 120 mmHg. Single organ failure, namely respiratory, remained the problem, although intravenous noradrenaline was used to combat hypotension due to inflammation, infection, high dose sedation and raised intrathoracic pressure.

Alternative mechanisms of improving oxygenation were examined. Use of partial liquid ventilation with a perfluorocarbon (Perflubron (Liquivent), Alliance Pharmaceutical Corp, San Diego, Ca, USA) was explored. Oxygenation was deemed too impaired to survive the early desaturation associated with the introduction of liquid perfluorocarbons. With bronchopleural fistulae, the fluid was likely to escape through the pleural drains that were under suction, rather than stay within the airways. Almitrine,$^1$ (almitrine bismesylate, Servier Laboratories, France) was considered, but rejected because of insufficient experience in human subjects. Exogenous surfactant was also explored but shunned after consideration of its logistics in the adult in the setting of multiple airway leaks.

Nosocomial infection and extreme hypoxia made her unsuitable for emergency lung transplantation. Extracorporeal membrane oxygenation (ECMO) was proposed. As the duration of treatment was predicted to be prolonged and because of on-going withdrawal vaginal bleeding and the need to anticoagulate on the extracorporeal circuit, it was deferred.

Further enquiries uncovered a Bear Jet Ventilator

![Figure 1](image)

**Figure 1.** This figure shows a different patient connected to the combined conventional-jet circuit, via an endotracheal tube.
Figure 2. This figure shows the eventual extent of additional humidification required for prolonged supplementary jet ventilation: sterile water is being pumped at 15 ml/hour into the circuit just distal to the jet outlet. Further distal in the circuit, immediately prior to the tracheostomy tube, is the Tomtek humidifier booster. Not shown is the Fisher-Paykel heated water bath in series with the conventional ventilator.

(1997, Bear Adult Volume Ventilator, Bear Medical Systems Inc., Bilthoven, Netherlands) at another institution in our city. An anaesthetist (Professor Riley) experienced in its use brought the machine to the bedside where it was configured to provide supplementary gas exchange to the conventional ventilator (Evita-4, Drager Medical, Luebeck, Germany). Peak and mean airway pressures were measured by the jet ventilator via a 15cm hollow catheter placed within the airway lumen, and peak, plateau, mean and expiratory pressures were measured by the Evita conventional ventilator.

The initial settings aimed to improve oxygenation without an increase in airway pressure, and better effect CO₂ removal. The HFJV was initiated at 20 pounds per square inch (psi) and 150 bpm. Jetted peak pressures were 15 cmH2O above the mean airway pressure. Plateau airway pressures as determined by the Evita conventional ventilator became unreliable because of this.

The improvement upon initiation of HFJV was immediate. The patient’s PaCO₂ decreased from 123 mmHg to 75 mmHg over 20 minutes. The PaO₂ remained 54 mmHg on 100 percent inspired oxygen. Reduction of conventional ventilation inspiratory pressure allowed a fall in measured mean airway pressures from 23 cmH₂O to the mid-teens. One hundred and ten days of combined HFJV and PCV followed. Despite sustained improvement in CO₂ removal, bronchopleural fistulae persisted. The patient continued to suffer episodic life-threatening hypoxaemia from “tensioning” of loculated pneumothoraces.

Inadequate humidification of the anhydrous jetted oxygen led to near-complete obstruction of her trachea from inspissated secretions one week after the commencement of combined HFJV and PCV. Standard heated humidification (Fisher-Paykel, Auckland, New Zealand) of the conventional ventilator gases and the addition of a Tomtec HME-Booster (Tomtec Innovating Systems, Augsburg, Germany) to the circuit solved this problem (see figure 2 above). These were in addition to
continuous infusion of water into the side arm of the jetted gases. Aerosolized NAC may have accelerated lysis of secretions and at bronchoscopy on day 12, the tracheal mucosa looked healthy.

Percutaneous tracheostomy allowed removal of sedation and assessment of her sensorium, which was intact, despite the prolonged period of hypoxaemia. The midazolam dosage reached 4,000 mg/day.

Initial and convalescent serology for atypical and typical pneumonia and cultures from lung aspirates, mouth, nares, throat, blood and chest drains were all negative for bacteria, viruses and fungi. She did however develop nosocomial chest, urine and drain infections with gram negative, gram positive and fungal organisms, which were effectively treated.

She transiently became stable enough for transfer to the CT-scanner, giving images of enormous bullae and compacted adjacent lung (figure 3).

Figure 3. A CT scan at 6 weeks into jet ventilation demonstrating bullae that share lung space with infective and inflammatory lung changes.

After 7 weeks of combined HFJV and PCV, ongoing improvement of airway pressures lured us into re-attempting PCV as the sole modality. PCV was gently re-introduced and HFJV reduced, but with disastrous additional barotrauma. Finally, during the third month of combined ventilation, the airway-cutaneous fistulae began to close and weaning could be completed. In the latter stages of weaning, the jet was so well tolerated awake that sedation could be weaned while she was still jet-ventilator-dependent. She was able to deny any distress or discomfort from the 120 - 150 bpm provided by HFJV. The mandatory 5 - 7 mL/kg tidal volume conventional ventilator breaths were weaned to the point that she could breathe spontaneously, super-imposed on the effective gas exchange of the jetted gas. At this point the patient faced additional problems of depression, sedative withdrawal, demineralisation of bone from inactivity, amenorrhoea and hirsutism.

At follow-up four months post discharge from the intensive care unit (ICU), the patient was off home oxygen end enrolled in a tourism course at college. She was mentally intact and had only mild restriction to her physical activity. Two years after her long stay in the ICU she had full physical activity and independence. Her improving spirometry reflected a mixed obstructive (Forced expiratory volume 1.43 litres, predicted 3.21 litres) and restrictive (Forced vital capacity 2.18 litres, predicted 3.57 litres) picture.

DISCUSSION

HFJV has been used infrequently in adults with ARDS, despite having features theoretically ideal for lung protection. The paediatric literature supports the transient use of high frequency oscillatory ventilation (HFOV) to improve outcome in the neonate deficient in surfactant, including in those patients where the alternative is ECMO. However, the results have not been universally positive for HFJV. Neonates differ from the ARDS adult patient by having a reversible deficiency in surfactant, and so seldom need protracted support.

HFOV theoretically minimises gas trapping through "active" expiration or sucking. Sophistication of the equipment has evolved a HFOV ventilator with controllable inspired oxygen concentrations (FiO₂), PEEP, fresh gas flow and humidification independent of the oscillatory rate and tidal volume. Airway recruitment and maintaining the lung open with HFOV relies on a higher mean airway pressure than conventional ventilation. This elevation of mean airway pressure required for effective HFOV could be considered counter-productive to lung protective strategies in ARDS, and even more of a risk where there is already lung disruption from baro- or volu-trauma, as in the case presented. One meta-analysis refers to barotrauma and occasional desiccation of secretions as problems with HFOV. HFOV, however, is more dominant in the adult literature, while HFJV has largely fallen into disuse. There is some evidence for the use of HFOV in rescue of patients with hypoxaemia due to ARDS. Mortality using this modality has been directly correlated to the duration of conventional mechanical ventilation prior to HFOV, suggesting that its demonstrated mortality benefit might be even greater if used earlier.

The combination of HFJV superimposed on mechanical ventilation has anecdotal success in adults and children. HFJV supplementing conventional ventilation is easy to set up at the bedside, reliable and efficient. Weaning is easy, reducing the jet pressure and frequency while augmenting conventional ventilation. It is extremely well tolerated by the awake patient, without the need for sedation. Cyclical airway pressure swings are minimal and airway opening and closure...
almost non-existent. The purchase price and size of the “obsolete” jet ventilator used in this case was less than one fifth that of the cheapest HFOV.

Why HFJV has disappeared from clinical use is unclear to its advocates. It provides a reliable means of gas exchange while keeping lung volumes and pressures within parameters deemed ideal in lung protective strategies in ARDS. This clientele for HFJV is limited (severe ARDS with barotrauma) and regularly perish in the absence of effective alternative therapies.

Extracorporeal CO₂ removal with partial ventilation has been used successfully, but the haemorrhagic risks increase with its duration. Only one clinical group has met with success using this technique. Lung transplantation is not feasible in the potentially infected patient in extremis from hypoxaemic respiratory failure.

CONCLUSION
There does appear to be a role for HFJV and HFOV in patients such as described in the case above. In the absence of a safe alternative, to withhold this form of therapy until the evidence base accumulates for the use of HFJV combined with conventional ventilation may be to confine this sub-group of ARDS patients to the risk of an early and escapable demise.

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