

# High frequency oscillatory ventilation in infants with increased intra-abdominal pressure

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## Abstract

**Aims**—To describe the short term effect of high frequency oscillatory ventilation on infants with severe abdominal distension who could not be conventionally ventilated.

**Methods**—Eight infants (25 to 38 gestational weeks, birthweight 600-3200 g, postnatal age 1 to 190 days) with a variety of intra-abdominal pathologies, resulting in severe abdominal distension and failure of conventional ventilation, were studied.

**Results**—The oxygenation status of all infants significantly improved within an hour of changing from conventional to high frequency oscillatory ventilation. Infants who were hypercapneic on conventional ventilation also showed a reduction in PaCO<sub>2</sub>. As a group, the mean (SD) PaO<sub>2</sub>/FIO<sub>2</sub> improved from 4.99 (0.98) kpa to 11.55 (3.8) kpa (P = 0.002), and the PaCO<sub>2</sub> from 6.48 (2.12) kpa to 4.89 (1.22) kpa (P = 0.028). These improvements were sustained throughout the next 48 hours.

**Conclusion**—High frequency oscillatory ventilation seems to be an effective rescue measure for infants with respiratory failure secondary to increased intra-abdominal pressure.

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Keywords: abdominal distension; high frequency oscillatory ventilation; respiratory failure.

Infants with severe abdominal distension often have reduced lung volume and impaired diaphragmatic movement. In extreme cases conventional mechanical ventilation may be unable to maintain satisfactory oxygenation or ventilation, resulting in respiratory failure. This is often the immediate cause of death in infants with severe intra-abdominal pathologies, such as necrotising enterocolitis. High frequency oscillatory ventilation is effective in allowing collapsed alveoli to function and maintaining lung volume, but its role in the management of infants with increased intra-abdominal pressure has not been determined. We describe eight infants with severe abdominal distension who failed conventional mechanical ventilation but were successfully ventilated with high frequency oscillatory ventilation.

## Case reports

From June 1994 to February 1996, eight preterm infants with a variety of intra-abdominal complications were treated with

high frequency oscillatory ventilation (Sensor-Medics 3100A, SensorMedics Inc., Yorba Linda, California, USA) when conventional mechanical ventilation (Infant Star neonatal ventilator, Infrasonics Inc., San Diego, USA) failed to provide satisfactory oxygenation and/or ventilation. Their details and clinical course are summarised in table 1.

Immediately before the start of high-frequency oscillatory ventilation, the ventilator settings of these infants were: peak inspiratory pressure (PIP) 30-42 cm H<sub>2</sub>O; positive end-expiratory pressure (PEEP) 4-6 cm H<sub>2</sub>O, rate 30-60 breaths per minute; inspiratory time 0.4-0.8 seconds; and FIO<sub>2</sub> 1.0. These settings achieved optimal blood gases after multiple adjustments of the ventilator parameters, including increasing the PIP, PEEP, and inspiratory time. High frequency oscillatory ventilation was started at the following settings: frequency 10 Hz (600 breaths per minute); fractional inspiratory time 0.33 (inspiratory:expiratory ratio of 1:2); FIO<sub>2</sub> 1.0; mean airway pressure 1-2 cm H<sub>2</sub>O higher than the mean airway pressure on conventional ventilation; and pressure amplitude sufficient to produce visible chest vibration. Subsequently, mean airway pressure and FIO<sub>2</sub> were adjusted to maintain an arterial oxygen tension of 8-12 kpa. Priority was given to reducing mean airway pressure once FIO<sub>2</sub> was decreased to 0.4.

The outcome of the infants is summarised in table 1. The oxygenation status of all infants significantly improved, expressed as an oxygenation efficiency index [PaO<sub>2</sub> (kpa)/FiO<sub>2</sub>], almost immediately after the start of high frequency oscillatory ventilation (fig 1). A decline in PaCO<sub>2</sub> was also observed in infants who were hypercapneic (cases 2, 3, and 5) during conventional ventilation (fig 1). As a group, the differences in PaO<sub>2</sub>/FIO<sub>2</sub> and PaCO<sub>2</sub> before and one hour after high frequency oscillatory ventilation were significant (mean SD): PaO<sub>2</sub>/FIO<sub>2</sub> 4.99 (0.98) kpa vs 11.55 (3.8) kpa, P = 0.002; PaCO<sub>2</sub> 6.48 (2.12) kpa vs 4.89 (1.22) kpa, P = 0.028; paired *t* test). These improvements were sustained throughout the next 48 hours (fig 2).

Once stabilised on high frequency oscillatory ventilation, mean airway pressure could be gradually decreased in all infants, and none had radiological or clinical evidence of hyperinflation of the lungs. However, all infants required multiple boluses of plasma expander to maintain satisfactory blood pressure, peripheral perfusion, and urine output. Three infants had either grade II or III intraventricular haemorrhage before high frequency oscillatory

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Table 1 Demographic characteristics and clinical course of infants studied

Case No	Gestational age (weeks) Birthweight (g)	Abdominal condition	Age when HFOV started	Outcome
1	Female, 30, 1190	NEC with gangrenous bowel and multiple perforations; Enterobacter septicaemia and DIC	Day 14	Extubated on day 30
2	Male, 25, 600	NEC with gangrenous bowel and multiple perforations	Day 17	Initial improvement; died on day 22 from uncontrolled sepsis, renal failure and DIC
3	Male, 25, 850	NEC with perforation; Acinetobacter septicaemia and peritonitis	Day 63	Extubated on day 90
4	Female, 32, 1150	Post-NEC ileal stricture resulting in acute bowel obstruction and gangrene; Serratia septicaemia	Day 50	Extubated 4 days later
5	Male, 27, 1155	Enterobacter septicaemia meningitis, and peritonitis; normal intestinal tract	Day 57	Extubated 9 days later
6	Male, 25, 890	Massive hepatomegaly, ascites and liver failure secondary to prolonged TPN	Day 190	Initial improvement; died on day 230 from progressive liver failure
7	Male, 34, 2275	Gastroschisis with primary closure, complicated by Enterobacter septicaemia, peritonitis and DIC	Day 4	Initial improvement; died on day 9 from sepsis and acute renal failure
8	Male, 38, 3200	Malrotation of small gut; necrosis and perforation of stomach; partial gastrectomy	Day 1	Extubated on day 17

HFOV high frequency oscillatory ventilation; NEC necrotising enterocolitis; DIC disseminated intravascular coagulation; TPN total parenteral nutrition.

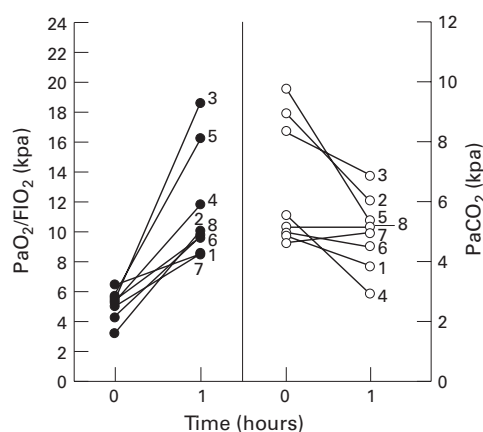


Figure 1 Changes in oxygenation efficiency index ( $PaO_2/FIO_2$ , ●) and  $PaCO_2$  (○) one hour after the start of high frequency oscillatory ventilation.

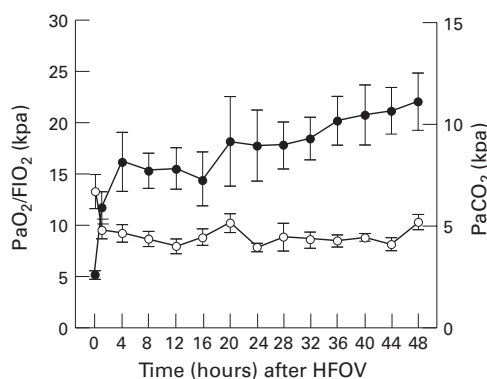


Figure 2 Group means (SEM) of oxygenation efficiency index ( $PaO_2/FIO_2$ , ●) and  $PaCO_2$  (○) immediately before (zero hours) and 48 hours after the start of high frequency oscillatory ventilation. Both parameters were significantly higher than those at zero hours (one way repeated measures: ANOVA oxygenation efficiency index  $P < 0.0001$ ;  $PaCO_2$   $P = 0.0162$ ; pairwise multiple comparison using the Student-Newman-Keuls method  $P < 0.05$  for both parameters).

ventilation. Subsequent weekly cranial ultrasound scans showed no extension of their old haemorrhage, and none of the other infants developed intraventricular haemorrhage after starting high frequency oscillatory ventilation. Three infants died, two from uncontrolled infection (cases 2 and 6) and one from progressive liver failure (case 7). This last infant was suspected to have had hepatic

damage secondary to prolonged total parenteral nutrition, and necropsy confirmed the presence of massive liver necrosis.

## Discussion

Increased intra-abdominal pressure compromises diaphragmatic movement and lung expansion, resulting in restrictive pulmonary insufficiency with reduced lung volumes and compliance. In severe cases conventional mechanical ventilation often fails to achieve adequate lung expansion and ventilation even at high inspiratory pressure. Loss of lung volume is especially severe during expiration when intra-alveolar pressure is decreased. This results in reduced functional residual capacity, ventilation/perfusion mismatch, and hypoxia. Hypercapnia ensues when abdominal distension becomes severe enough to impair alveolar expansion during inspiration, resulting in alveolar hypoventilation. The use of a high positive end-expiratory pressure may reduce alveolar collapse during expiration, but may cause further reduction in tidal volume with an increase in  $PaCO_2$ .<sup>1</sup> A positive end-expiratory pressure of 7 cm  $H_2O$  had been tried in four of the infants but had resulted in further deterioration of hypercapnia without improvement in oxygenation.

High frequency oscillatory ventilation is an efficient mode of ventilation for infants with a variety of lung conditions, including respiratory distress syndrome,<sup>2-6</sup> meconium aspiration syndrome,<sup>2</sup> lung hypoplasia,<sup>2</sup> pulmonary air leaks,<sup>2,7</sup> persistent pulmonary hypertension and congenital diaphragmatic hernia.<sup>8,9</sup> As far as we know, its use in infants with respiratory failure secondary to increased intra-abdominal pressure has not been described. There is a sound theoretical basis for the use of high frequency oscillatory ventilation in this group of infants. Unlike conventional ventilation, it provides a near-constant positive airway pressure that keeps the alveoli open without the loss of end-expiratory volume. This unique mechanism effectively minimises ventilation/perfusion mismatch and improves oxygenation. Carbon dioxide removal is achieved by active exhalation generated by the oscillator and does not seem to be affected by the high resting lung volume. Data from animal studies suggest that

when compared with conventional ventilation, high frequency oscillatory ventilation is associated with more uniform gas distribution within the lungs and less regional hyperinflation or alveolar collapse.<sup>10 11</sup> This, together with the lack of bulk gas movement and substantial reduction in phasic pressure and volume changes in the distal airway, decrease the risk of pulmonary air leaks and chronic lung injury.<sup>6 7</sup> This potential advantage is particularly relevant to infants requiring high pressure ventilation.

While the therapeutic superiority of high frequency oscillatory ventilation over conventional ventilation should ideally be verified with a randomised controlled trial, our observations provide preliminary evidence that high frequency oscillatory ventilation is beneficial to infants with severe abdominal distension. All infants were significantly hypoxic despite treatment with conventional ventilation using various ventilation strategies. Rescue treatment with high frequency oscillatory ventilation was followed by rapid and sustained improvement in oxygenation. Arterial carbon dioxide tension became normal in those infants with pre-existing hypercapnia. All these changes were too extensive and too rapid to be accounted for by spontaneous improvement of the patients.

None of the infants developed lung hyperinflation, a known complication of high frequency oscillatory ventilation: this may impede venous return, resulting in impaired cardiac output and intraventricular haemorrhage.<sup>12</sup> We speculate that the restrictive force imposed by the high intra-abdominal pressure makes lung hyperinflation less likely in these infants than in those with non-restrictive lung diseases, such as hyaline membrane disease and meconium aspiration syndrome. All infants, however, required multiple boluses of volume expander within the first 48 hours of high frequency oscillatory ventilation. This suggested that even in the absence of radiological or clinical evidence of lung hyperinflation, the constantly increased intrathoracic pressure during high frequency oscillatory ventilation may still compromise cardiac output, resulting in hypotension and decreased tissue perfusion and urine output. Close monitoring of circulatory state and prompt correction of any volume deficit

are mandatory, especially in this category of infants who are at risk of severe hypovolaemia due to continuous loss of fluid into the peritoneal cavity.

Three of the infants died, but none from respiratory failure. All three deaths occurred after the infants had shown sustained improvement in their respiratory status. The high mortality merely reflected the severity of their underlying pathologies or intercurrent illnesses. Our experience shows that high frequency oscillatory ventilation provides effective ventilation and rapid improvement in oxygenation in infants with increased intra-abdominal pressure who could not be effectively ventilated with conventional ventilation.

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