

# High-frequency oscillatory ventilation as a rescue for severe asthma crisis in a child

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## Abstract

Mechanical ventilation in the asthmatic child may be complicated by dynamic air trapping leading to hemodynamic compromise and cardiac arrest. High-frequency oscillatory ventilation is relatively contraindicated because it may cause hyperinflation compared to conventional mechanical ventilation. A 2-year-old girl (weight, 11 kg) with a history of asthma was admitted because of status asthmaticus. Despite treatment with intravenous methylprednisolone, continuous albuterol, terbutaline, aminophylline, and magnesium sulfate, she had persistent respiratory distress. She required endotracheal intubation and mechanical ventilation because of worsening respiratory fatigue and hypercarbia ( $\text{PCO}_2$ , 96 mmHg). Severe airflow obstruction persisted, and the hypercarbia worsened despite conventional mechanical ventilation ( $\text{PCO}_2 > 134$  mmHg). It was judged that the patient was at risk for dynamic air trapping leading to hemodynamic compromise and cardiac arrest. High-frequency oscillatory ventilation was started to overcome airflow obstruction, and a decrease in arterial  $\text{PCO}_2$  to 87 mmHg was observed within 2 h. High-frequency oscillatory ventilation was discontinued after 5 h, and conventional mechanical ventilation resumed. The patient was extubated after 5 days without further complications. In summary, this case shows that high-frequency oscillatory ventilation may be considered as a rescue treatment in children who have severe status asthmaticus with persistent airflow obstruction and hypercarbia unresponsive to pharmacological therapy and conventional mechanical ventilation.

## Keywords

Status asthmaticus, open airway strategy ventilation, obstructive airway disease, intensive care

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## Introduction

Status asthmaticus is a known cause of acute respiratory failure. When pharmacologic therapy does not reverse severe airflow obstruction caused by status asthmaticus, respiratory fatigue may develop, and mechanical ventilation may be required to support breathing.<sup>1</sup> However, mechanical ventilation may be associated with dynamic air trapping leading to pneumothorax or cardiac arrest.<sup>2,3</sup>

In adult status asthmaticus patients who were admitted to an intensive care unit, 25% of them required intubation and most of them were ventilated in volume-cycled mode.<sup>4</sup> The children who required intubation had previous hospital admission in most of the cases.<sup>2</sup> Asthma is a cause of significant morbidity and mortality both in children and adults.<sup>1,5</sup> The identification of high-risk patients, promoting compliance with controller medications, and starting early treatment during an acute exacerbation are vital to prevent respiratory failure.<sup>6,7</sup>

High-frequency oscillatory ventilation (HFOV) is mechanical ventilation with constant and high distending pressure, small tidal volume, and high respiratory rate, and may function by recruiting atelectatic lung tissue.<sup>8</sup> In adults, HFOV has been used as rescue therapy for refractory hypoxemia, avoiding the need for extracorporeal membrane oxygenation (ECMO).<sup>9</sup> In premature neonates, HFOV may improve long-term lung function with comparable neurodevelopmental outcomes compared with conventional mechanical ventilation.<sup>10,11</sup>

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**Table 1.** A 2-year-old girl who had status asthmaticus: ventilator settings and blood gas tests after admission to the pediatric intensive care unit.

Time (h) <sup>a</sup>	Ventilation mode	Delta P (cmH <sub>2</sub> O)	FiO <sub>2</sub> <sup>b</sup>	pH	PCO <sub>2</sub> (mmHg) <sup>c</sup>	PO <sub>2</sub> (mmHg)
5:00	HFNC		0.6	7.05	96	129
6:00	PC/SIMV <sup>d</sup>	38	1	6.90	134	255
7:00	PC/SIMV <sup>d</sup>	38	0.6	6.91	134	114
7:25	PC/SIMV <sup>d</sup>	38	1	6.84	134	202
9:00	PC/SIMV <sup>d</sup>	38	1	6.81	134	392
9:25	HFOV <sup>e</sup>	62	1	6.96	111	318
10:00	HFOV <sup>e</sup>	62	1	6.98	101	330
11:00	HFOV <sup>e</sup>	62	1	7.05	87	372

PCO<sub>2</sub>: partial pressure of carbon dioxide; Delta P: pressure above PEEP or amplitude; HFNC: high-flow nasal cannula at 15 L/min; HFOV: high-frequency oscillatory ventilation; PC/SIMV: pressure-controlled synchronized intermittent mandatory ventilation.

<sup>a</sup>Duration of admission to PICU in hours.

<sup>b</sup>Fraction of inspired oxygen (FiO<sub>2</sub>) during ventilation; source of blood gas was arterial.

<sup>c</sup>PaCO<sub>2</sub> = 134 mmHg was the highest measured value in our blood gas laboratory.

<sup>d</sup>PC/SIMV settings: maximum peak inspiratory pressure, 43 cm of water (H<sub>2</sub>O)/pressure control, 38 cmH<sub>2</sub>O; synchronized intermittent mandatory ventilation rate, 24 breaths per minute; positive end-expiratory pressure (PEEP), 5 cmH<sub>2</sub>O; inspiratory time (iTime), 0.5 s (inspiration-to-expiration (I:E) ratio, 1:4); return tidal volume, ~60 mL; total respiratory rate, 24; mean airway pressure (MAP), 13.

<sup>e</sup>HFOV settings: amplitude, 62 cmH<sub>2</sub>O; MAP, 20 cmH<sub>2</sub>O; frequency, 3 Hz; I:E ratio, 1:2 or iTime, 33%; flow, 20 L/min; FiO<sub>2</sub>, 1. HFOV was switched at 5 h in anticipation of transport.

In children who have acute respiratory failure, duration of mechanical ventilation may be longer with HFOV than conventional mechanical ventilation, but mortality may be comparable between the 2 types of ventilation.<sup>12</sup> However, HFOV typically is contraindicated in children who have severe obstructive disease because of the risk of developing air trapping.<sup>13–15</sup> A previous report of a 21-month-old boy who had tracheobronchomalacia showed that HFOV was successful in small airway disease due to its stenting effect and open airway strategy ventilation.<sup>16</sup> However, a literature search showed limited use of HFOV in treating pediatric status asthmaticus patients who needed mechanical ventilation to support acute respiratory failure.<sup>3,12,15,17</sup> In a propensity score analysis of early HFOV use in pediatric respiratory failure, 4 out of 210 patients had a primary diagnosis of asthma or reactive airway disease. Clinical characteristics, severity, and type of respiratory failure in those patients are not available.<sup>12</sup> A case report and two poster presentations have described three small children who needed HFOV when conventional mechanical ventilation failed, but clinical data are limited (Table 2).<sup>3,15,17</sup> More published reports would help understand the use of HFOV in intubated asthmatics. We treated a young child who had severe asthma crisis and was ventilated successfully with HFOV when conventional ventilation was ineffective.

## Case report

A 2-year-old girl (weight, 11 kg) who had a history of moderate persistent asthma developed a 5-day history of cough and rhinorrhea that progressed to difficulty breathing and wheezing. There was no history of fever or exposure to any allergens. The patient was brought to the emergency department and treated with albuterol nebulization, ipratropium

bromide, and methylprednisolone but had no significant improvement. The patient was admitted to the pediatric intensive care unit (PICU). Physical examination showed that she was somnolent but arousable, and she had marked suprasternal, intercostal, and subcostal retractions with diminished air entry bilaterally. Laboratory studies showed white blood cell (WBC) 12.7 × 10<sup>3</sup> per microliter and C-reactive protein 0.7 mg/dL (ref range <0.3 mg/dL), and multiplex polymerase chain reaction (BioFire Diagnostics, Salt Lake City, UT, USA) was positive for rhinovirus. The endotracheal aspirate culture showed *Moraxella catarrhalis*. Chest radiograph showed right-sided perihilar opacities but no obvious consolidation.

The patient was initially started on high-flow nasal cannula, continuous albuterol, magnesium sulfate, terbutaline, and aminophylline drip. All medical therapy was maximized within a few hours. She had persistent respiratory distress and poor air entry. Blood gas analysis showed marked hypercarbia (partial pressure of carbon dioxide (PCO<sub>2</sub>), 96 mmHg) at 5 h after PICU admission (Table 1). She required endotracheal intubation (cuffed endotracheal tube; internal diameter, 4 mm) because of respiratory fatigue and worsening respiratory failure. She was sedated with fentanyl, midazolam, and ketamine drips and paralyzed with vecuronium drip to prevent patient-ventilator asynchrony and high peak pressure. She was ventilated with pressure-controlled synchronized intermittent mandatory ventilation (PC/SIMV) (Table 1), but air entry was diminished even with high peak pressure on mechanical ventilation. The tidal volume was ~60 mL (less than 6 mL/kg) in the context of peak pressure 43 cm of water, but silent chest on auscultation suggested significant alveolar hypoventilation. The respiratory rate was maximized depending on expiratory flow waveform. On several occasions, the patient was

**Table 2.** Published reports of children with acute respiratory failure secondary to status asthmaticus who were treated with high-frequency oscillatory ventilation.<sup>a</sup>

Age (years)	Sex	Wt (kg)	Et tube size	Highest PCO <sub>2</sub>	HFOV (days)	Ventilation (days)	Past history	Reference
2.5	F	9.5	4.5 uncuffed	79	5	8	Allergy, eczema, 1 hospitalization	Duval and van Vught <sup>15</sup>
3.5	M	NA	NA	110	4	6	NA	Van Heerde et al. <sup>3</sup>
2.5	M	NA	NA	>146	3	10	Ex 33 weeker, 5 previous hospitalizations	Schiltz et al. <sup>17</sup>

PCO<sub>2</sub>: partial pressure of carbon dioxide; HFOV: high-frequency oscillatory ventilation; NA: not available. References 3 and 17 are poster presentations.

<sup>a</sup>Literature search performed with PubMed and review of references in published studies.

ventilated manually with an Ambu bag for 5–10 min to deliver aerosol puffs directly, with only minimal improvement in air entry. Blood gas analysis showed marked respiratory acidosis with pH < 7.0 and PCO<sub>2</sub> 134 mmHg, which is the maximum measurable value in our blood gas laboratory. Various ventilator settings were trialed with lower SIMV and lower positive end-expiratory pressure (PEEP) because of concerns of air trapping, but there was no improvement in air entry and blood gases. A chest radiograph showed hyperinflation with diaphragm margins at ribs 8–9 but no radiographic evidence of lobar or segmental atelectasis, infiltrate, or pneumothorax.

It was judged that the persistence of severe airflow obstruction would continue with dynamic air trapping leading to hemodynamic compromise and cardiac arrest. HFOV (Sensormedics 3100A, Yorba Linda CA, USA) was started, and arterial PCO<sub>2</sub> decreased to 111 mmHg within 25 min, indicating improvement in alveolar ventilation and gas exchange and further to 87 mmHg within 2 h (Table 1). The rationale was to overcome persistent airflow obstruction by open airway strategy. The continuous infusions of magnesium sulfate, terbutaline, aminophylline, and ketamine remained unchanged. As we do not have immediate availability of ECMO in our institute, this use of HFOV was considered as a rescue. The patient remained on same HFOV settings (mean airway pressure (MAP), 20 cmH<sub>2</sub>O; frequency, 3 Hz; and amplitude, 62 cmH<sub>2</sub>O) for 5 h until the patient was transitioned to conventional mechanical ventilation. The PCO<sub>2</sub> continued to decrease on conventional ventilation, and the patient was extubated after 5 days without any further complications. She was discharged after 12 days of hospitalization on inhaled steroid therapy.

## Discussion

In this patient who had severe respiratory failure from status asthmaticus, HFOV reversed the clinical trajectory that likely would have been fatal, and the need for ECMO was avoided. Despite the availability of well-established asthma treatment guidelines, some patients still present with severe status asthmaticus as observed with our patient. In status asthmaticus, the best management strategy is to start treatment early at home.<sup>6,7</sup>

Endotracheal intubation of the patient who has status asthmaticus typically is avoided unless absolutely necessary. Positive pressure ventilation may cause dynamic air trapping in the lungs that may cause a decrease in venous return and hypotension leading to cardiac arrest.<sup>1</sup> HFOV usually is contraindicated due to the inherent adverse event of hyperinflation caused by the high pressures used in HFOV.<sup>14,18</sup> However, in the present patient, HFOV may have been helpful because of the stenting effect from constant distending pressure, minimizing airway collapse and resultant improvement in gas exchange and CO<sub>2</sub> removal.<sup>8,15,17</sup> The HFOV alters the respiratory mechanics by stenting the airway and minimizing time constants.<sup>16</sup> In contrast to conventional mechanical ventilation, HFOV can deliver tidal volume smaller than respiratory dead space to alveoli.<sup>19</sup> HFOV transfer gas by various mechanisms which includes turbulent vortices in larger airways, asymmetric velocity profiles during inspiration and expiration, radial mixing in main bronchi, laminar airflow with Taylor dispersion in higher generations of the respiratory tract, pendelluft, direct ventilation of central alveoli, and molecular diffusion.<sup>19,20</sup> All these mechanisms are interdependent, and the open airway strategy may improve airflow at larger airways initially and small peripheral airways over time.<sup>16,19</sup>

Contrary to conventional ventilation, HFOV creates negative pressure during expiration by piston movement.<sup>21,22</sup> Active exhalation with the help of negative pressure may improve ventilation despite airflow obstruction and avoid air trapping in patients who have small airway disease.<sup>16</sup> The HFOV settings are selected to optimize MAP to provide a stenting effect and low amplitude with high frequency to avoid high-pressure fluctuations.<sup>15,17</sup> The higher frequency may deliver smaller tidal volume and minimize pressure fluctuations in the small airways.<sup>23–25</sup> In certain situations, when ventilation is not sufficient, lower frequency and higher amplitude may be needed.<sup>15</sup> It is important to keep euvolemic status as increased MAP in HFOV can cause hypotension. Close hemodynamic monitoring and chest radiographs are vital to detect pulmonary hyperinflation.

The question may arise whether we can apply open airway strategy on conventional ventilation. It may theoretically be possible but practically very challenging. In order to

generate effective MAP in conventional ventilation to stent airway, it needs a high PEEP and a high peak pressure which may result in high pressure swings and barotrauma.<sup>16</sup> The ventilation with open airway strategy by HFOV was found to play an effective role in small children, as seen in our case and other reported cases.<sup>3,15,17</sup> This case report will lend further support for the use of HFOV in an asthmatic crisis.

## Conclusion

HFOV might be used as a rescue maneuver for the refractory patient who cannot be ventilated adequately with conventional ventilation, in part because HFOV may help overcome persistent airflow obstruction by open airway strategy. However, the patient should be observed carefully for potential complications such as air trapping and hemodynamic compromise. Further studies are needed to evaluate the benefits of HFOV for treatment of refractory airflow obstruction in intubated asthmatic children.

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