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# New insights in mechanical ventilation for pediatric patients

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## Introduction

Acute respiratory failure (ARF) remains an important cause of morbidity and mortality in the pediatric intensive care setting. Mechanical ventilation has contributed substantially to the improved outcome of children with respiratory disorders while maintaining adequate gas exchange until the underlying pathological process has sufficiently resolved. However, how to achieve this is a significant challenge for the practicing intensivist. There is no consensus in the pediatric literature on which practical sequence of ventilatory therapies can be applied over the wide range of disease entities and severity encountered in clinical practice.

The ventilatory management of children with ARF must face the following issues: (a) it is usually applied too late, when severe gas exchange impairment has already occurred; (b) in severe ARF no convincing evidence is available on which ventilatory strategy has to be untertaken in order to limit ventilator-induced lung injury; (c) if a high lung volume strategy with high frequency oscillation ventilation (HFOV) is applied, concern exists about the effect of high airway pressures (Paw) on cardiovascular performance. The following is a brief description of three recent studies dealing with the use of different ventilatory approaches in pediatric patients with acute respiratory failure.

**Padman R, Lawless ST, Kettric RG (1998) Noninvasive ventilation via bilevel positive airway pressure support in pediatric practice. Crit Care Med 26: 169–173**

This is a prospective, nonrandomized study on the use of noninvasive ventilation (NIV) in critically ill children admitted to a pediatric intensive care unit. Thirty-four patients (aged 6 months to 20 years) with impending parenchymal ($n = 17$) or pump respiratory failure of various etiologies were enrolled in the study and received bilevel positive airway pressure (BiPAP) support by nasal mask for a mean duration of 6.1 days. Initially, the mask was gently positioned over the nasal bridge with minimal flow and pressure was increased in increments of 2 cm $H_2O$. Predetermined maximal inspiratory and expiratory airway pressures were 20 and 10 cm $H_2O$, respectively. Criteria for exclusion included absent cough and gag reflex, multiple organ system failure, age < 6 months, vocal cord paralysis, and noncooperation with nasal mask. At 72 h after BiPAP application, all patients showed a significant reduction in heart rate, respiratory rate, and dyspnea score, and improvement in oxygenation. Intubation was avoided in 32 (91 %) of 35 episodes of respiratory failure and only 3 of 34 children required subsequent tracheal intubation. The authors concluded that noninvasive ventilation should be considered as a valuable tool for preventing tracheal intubation in pediatric patients with impending acute respiratory failure but without other organ dysfunctions.

**Tibby SM, Cheema IU, Sekaran D, Hatherill M, Murdoch IA (1999) Use of permissive hypercapnia in the ventilation of infants with respiratory syncytial virus infection. Eur J Pediatr 158: 42–45**

This is a retrospective study evaluating the effect of permissive hypercapnia (PHY) in infants with acute respiratory failure due to respiratory syncytial virus (RSV) bronchiolitis. Nineteen control infants were

**Table 1** Ventilatory management guidelines for ventilated RSV infants (*$PaCO_2$* arterial carbon dioxide tension, *PEEP* positive end-expiratory pressure)

| | Conventional ventilation | Permissive hypercapnia |
|---|---|---|
| Mode | Pressure-controlled, time cycled | Pressure-controlled, time cycled |
| Oxygen saturation | $\geq$ 88 % | $\geq$ 88 % |
| $PaCO_2$ | 4–6 kPa | No specified limit if pH adequate |
| pH | 7.30–7.45 | > 7.25 |
| PEEP (cm $H_2O$) | 5 | 5 |
| Peak inspiratory pressure | To achieve above goals | Minimum to achieve above goals |
| Ventilator rate | Low rate, long expiratory time | Low rate, long expiratory time |

treated with conventional ventilation (April 1991–January 1994) and 28 further infants were successively treated with PHY (January 1994–April 1996), according to management guidelines indicated in Table 1.

Patients were well matched between groups for demographic data, presence of chronic lung disease, and severity of illness as measured by both Pediatric Risk of Mortality and worst Oxygenation Index [OI = mean airway pressure (cm $H_2O$) $\times$ fractional inspired oxygen/ arterial oxygen tension (mm Hg)]. The PHY group showed a significantly higher mean arterial carbon dioxide tension (7.6 ± 1.4 vs 5.2 ± 0.5 kPa, $p < 0.0001$), a lower mean pH (7.34 ± 0.04 vs 7.40 ± 0.04, $p < 0.0001$), and a reduction in maximal peak inspiratory pressure (25 ± 4.2 vs 30 ± 5.1 cm $H_2O$, $p < 0.001$). Despite this, no appreciable differences in mortality and barotrauma were detected between the two groups. The authors emphasized that the PHY strategy does not show any improvement in outcome and in the incidence of barotrauma in infants with RSV-related bronchiolitis.

**Goodman AM, Pollack MM (1998) Hemodynamic effects of high-frequency oscillatory ventilation in children. Pediatr Pulmonol 25: 371–374**

HFOV is frequently used as an alternative to conventional mechanical ventilation (CMV) to minimize ventilation-induced lung injury. With this mode of ventilation, low tidal volumes are applied at rapid respiratory rates, and higher mean airway pressures are used in order to maintain optimal lung volume. The present study evaluates the hemodynamic effects of transitioning a group of children with ARF from CMV to HFOV. All children were sedated, paralyzed, and equipped with a pulmonary artery catheter. All hemodynamic and respiratory physiological variables were obtained on CMV and at 1 and 4 h after the transition to HFOV. There were no changes in fluids infusion or in the doses of sedative and vasoactive agents during the study. Mean airway pressure was significantly higher on HFOV than with CMV according to the “high volume” strategy (26 ± 5 vs 21 ± 6 cm $H_2O$). No changes in cardiac index, oxygen delivery, and oxygen utilization were found despite the inclusion of patients with cardiovascular instability. A significant reduction in mean arterial pressure and systemic vascular resistance index was found at 1 h after transition from CMV to HFOV. This finding has been attributed to the concomitant occurrence of respiratory acidosis immediately after the initiation of HFOV, a relatively common circumstance when HFOV settings are adjusted. All these variables normalized after 4 h. The authors concluded that in children with ARF and unstable cardiovascular status, the transition from CMV to HFOV was not accompanied by a reduction in cardiac function or oxygen delivery.

## Discussion

Noninvasive ventilation by mask has been extensively used and validated in alert and cooperative adult patients with various types of respiratory failures, whereas only a few studies have been performed in children, mainly because of their lack of tolerance to the machine-interface system. However, intensivists are now more familiar with NIV and a greater variety of masks (or other interfaces) are available. Besides, novel pressure-limited ventilators provide a better patient-machine synchronization and this could explain why NIV is well tolerated in the pediatric population. Patient selection is essential to avoid treatment failures; the percentage of children who refused the mask has not been reported in the paper by **Padman et al.** NIV allows early institution of ventilatory care and this may change the clinical course and avoid the subsequent need for mechanical ventilation in children with impending ARF.

In the more severe forms of respiratory failure, once endotracheal intubation has been performed, clinicians must face the possibility of ventilator-induced lung injury. It has been suggested that inadequate levels of positive end-expiration pressure (PEEP) (below the lower inflection point in the static P-V curve) may allow for lung collapse of the dependent regions with application of tremendous shear stresses during consequent alveolar re-expansion. Furthermore, the use of large tidal volumes (above the upper inflection point) has the potential to cause overdistension of the nondependent, more compliant regions **(Muscedere et al. (1994) Crit Care Med 149: 1327).** The repetitive cyclic stretch of the injured lung contributes to most of the ventilator-induced lung damage, with subsequent macro- and microscopic air leaks. A number of novel approaches to achieve adequate tissue oxygenation while minimizing the risk of further lung injury have been recently proposed. Among them, PHY and HFOV are currently being used. A number of studies in adult patients with the acute respiratory distress syndrome (ARDS), including a recent trial by **Amato et al. (N Engl J Med 1998; 338–347),** suggested that the use of PEEP values above the lower inflection point and relatively small tidal volumes could be beneficial in terms of reduction of both lung injury and mortality, even though significant hypercapnia may occur. These encouraging results were not confirmed in this first retrospective study by **Tibby et al.** where PHY was applied in children with bronchiolitis. However, it is worth noting that management guidelines during PHY in this group of children are quite different from those proposed by **Amato et al.** In particular, neither static pressure-volume curves nor tidal volume measurements were provided, and the PEEP value was arbitrary fixed at 5 cm $H_2O$. Besides, this study was not randomized and the results should be interpreted with this in mind. However, because other trials in adult patients with ARDS suggest no advantage of this strategy over conventional ventilation **(Brower et al. (1999) Crit Care Med 27: 1492; Stewart et al. (1998) N Engl J Med 338: 355; Brochard et al. (1998) Am J Respir Crit Care Med 158: 1831),** caution must be used before an unproven therapy becomes common practice.

The small phasic volume and pressure change of HFOV represents another intriguing tool in order to prevent volutrauma. There is an increasing body of evidence in the pediatric literature showing that HFOV, when used with an optimal lung volume strategy (i. e., high Paw) designed to reverse atelectasis, results in significant improvements in oxygenation and survival when compared with conventional ventilation. This typically requires an increase in mean airway pressure of 5–8 cm $H_2O$ when converting from conventional to HFOV **(Arnold et al. (1993) Crit Care Med 21: 272; Arnold et al. (1994) Crit Care Med 22: 1530).** However, concern exists about the use of high Paw with this strategy, which may impair cardiac output and blood flow to various organs **(Traverse et al. (1988) Pediatr Res 23: 628; Cowan et al. (1987) Acta Pediatr 76: 239; Mirro et al. (1987) J Pediatr 111: 101).** The study by **Goodman and Pollack** showed that cardiac index, oxygen delivery, and oxygen utilization were maintained (or improved) with the initiation of HFOV, and this finding is consistent with other recent reports by **Arnold et al. (Crit Care Med 1993; 21: 272)** in children and by **Nelle et al. (Intensive Care Med 1997; 23: 671)** in neonates.

In conclusion, a trial of noninvasive ventilation should be considered in cooperative children with mild ARF. In the more severe forms in which ventilator-induced lung injury may occur, PHY with pressure-volume limited ventilation and HFOV with “open lung strategy” are attractive options, although further studies are warranted to evaluate fully their clinical impact with respect to efficacy, safety, complexity, and cost.