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Automated respiratory support in newborn infants

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SUMMARY

A considerable proportion of premature infants requires mechanical ventilatory support and supplemental oxygen. Due to their immaturity, exposure to these forms of respiratory support contributes to the development of lung injury, oxidative stress and abnormal retinal development. These conditions are associated with poor long-term respiratory and neurological outcome. Mechanically ventilated preterm infants present with frequent fluctuations in ventilation and gas exchange. Currently available ventilatory modes and manual adjustment to the ventilator or supplemental oxygen cannot effectively adapt to these recurrent fluctuations. Moreover, the respiratory support often exceeds the infant's real needs. Techniques that adapt the mechanical ventilatory support and supplemental oxygen to the changing needs of preterm infants are being developed in order to improve stability of gas exchange, to minimise respiratory support and to reduce personnel workload. This article describes the preliminary evidence on the application of these new techniques in preterm infants and animal models.

1. Introduction

A large proportion of infants born prematurely presents with respiratory failure and requires respiratory support in the form of mechanical ventilation and/or supplemental oxygen.[1,2] This is more frequent at shorter gestational ages and these forms of respiratory support carry unintended consequences. Mechanical ventilation increases the risk for bronchopulmonary dysplasia (BPD) while supplemental oxygen, which also contributes to lung injury, is associated with increased risk for retinopathy of prematurity (ROP) and oxidative stress.[3–8] These neonatal morbidities have been linked with long-term pulmonary sequelae and poor neurodevelopmental outcome.[9–12]

During intensive care, the preterm infant's ventilation and oxygenation are continuously monitored. Based on information from these monitors and arterial blood gas status, caregivers have to make frequent adjustments in respiratory support. The variability in ventilation and gas exchange in these infants combined with limitations in resources results in levels of support that do not always adapt and often exceed the infant's actual needs.

The introduction of microprocessor technology in modern ventilators has facilitated the development of advanced and smarter forms of respiratory support. These forms of support combine sensing technology and automation techniques to close the loop between monitored parameters and respiratory support. The following is a review of newly developed automated modes of mechanical ventilatory support and supplemental oxygen delivery that adapt to the preterm infant's variable needs.

2. Automated ventilator adjustment

Most preterm infants require prolonged mechanical ventilatory support beyond the acute phase of respiratory failure which further increases the risk for lung injury. The various degrees of lung disease and immaturity of the respiratory centre are the main factors that prolong the preterm infant's need for ventilatory support. These conditions increase the variability in gas exchange which is reflected in a continuously changing need for the level of ventilatory support.

The incorporation of microprocessors and sensors in neonatal ventilators resulted in the availability of new modes of mechanical ventilation, including patient-triggered ventilation, that were for the most part aimed at improving the infant–ventilator interaction.

These new modes as well as those previously available cannot fully adapt to the frequently changing needs of the preterm infant and require frequent caregiver intervention. During synchronised intermittent mandatory ventilation (SIMV) the infant's own spontaneous breathing contributes to total ventilation. As ventilator frequency and peak inspiratory pressure (PIP) are weaned, the infant's respiratory drive and spontaneous ventilation play a greater role. This is accomplished by the spontaneous breathing effort responsible for generating the tidal volume (V_T) of spontaneous breaths and contribution to the V_T of synchronised mechanical breaths. In assist/control ventilation (A/C), spontaneous breathing effort contributes to the generation of V_T of every

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synchronised mechanical breath. When infants are ventilated using these modes, a reduction or complete absence of spontaneous breathing reduces total ventilation. In addition, these infants also present with acute changes in lung mechanics which further increases ventilation variability.

When spontaneous breathing effort decreases or lung mechanics deteriorate during SIMV or A/C, an insufficient ventilator rate or PIP results in hypoventilation. These changing conditions often lead clinicians to select higher basal ventilator rate or PIP settings to maintain adequate ventilation at times when the spontaneous effort is insufficient. However, elevated ventilator rates or pressures can take over ventilation by inhibiting the spontaneous drive and further increase the risk of ventilator-induced lung injury.

3. Targeted minute ventilation

This is an experimental ventilatory mode where the ventilator rate is continuously and automatically adapted to the varying needs of the infant. If the exhaled minute ventilation (V_E) exceeds the target level, the ventilator rate is reduced. Conversely, if V_E falls below the target level the ventilator rate is increased. The change in ventilator rate is proportional to the difference between the target and measured V_E and the trend in V_E.

This experimental mode was evaluated in preterm infants during the recovery phase of respiratory distress syndrome (RDS). In comparison to SIMV, targeted minute ventilation reduced the ventilator rate by 50%, with a resulting lower mean airway pressure, while blood gases remained unchanged.[13] The reduction in ventilator rate was matched by an increase in the infant's contribution to total ventilation. These preterm infants were able to maintain ventilation with little support for significant periods of time. Only transiently, the ventilator rate was increased in order to maintain minute ventilation at the target as illustrated in Fig. 1. Mechanical minute ventilation was considerably reduced in comparison to SIMV whereas total ventilation remained within the same range (Fig. 2). This is important since it exposes the infants to fewer mechanical breaths, while at times it increases the ventilator rate even above the basal rate provided by SIMV in order to avert hypoventilation. These transient increases can maintain a more stable gas exchange. A subgroup of these infants presented with frequent episodes of hypoxaemia and targeted minute ventilation reduced the duration of these episodes.

In the above-mentioned study, the target ventilation level was set at ~50% of the total minute ventilation during SIMV. This relatively low ventilation level was aimed at providing back-up ventilation during periods when the infant's spontaneous ventilation decreased. A higher target level may be even more effective in maintaining ventilation and gas exchange, but it could delay weaning of the ventilatory support. The effects of different target ventilation levels in this population of preterm infants are yet to be determined.

4. Mandatory minute ventilation (MMV)

In MMV the measured minute ventilation is compared to a set level and, if higher, the ventilator cycling is turned off. Conversely, if the measured value is lower than the set level, the ventilator delivers volume-controlled breaths at a constant rate. The spontaneous breaths in this mode can be assisted by pressure support. MMV was compared to SIMV in near-term infants.[14] In these infants, who were free from lung disease, MMV reduced the ventilator rate and mean airway pressure compared to SIMV while spontaneous breaths were assisted by pressure support ventilation (PSV). This mode has not been yet evaluated in premature infants with lung disease.

5. Apnoea back-up ventilation

Newer neonatal ventilators offer this mode consisting of back-up ventilatory support during apnoeic episodes. When spontaneous breathing is not detected, the ventilator delivers back-up

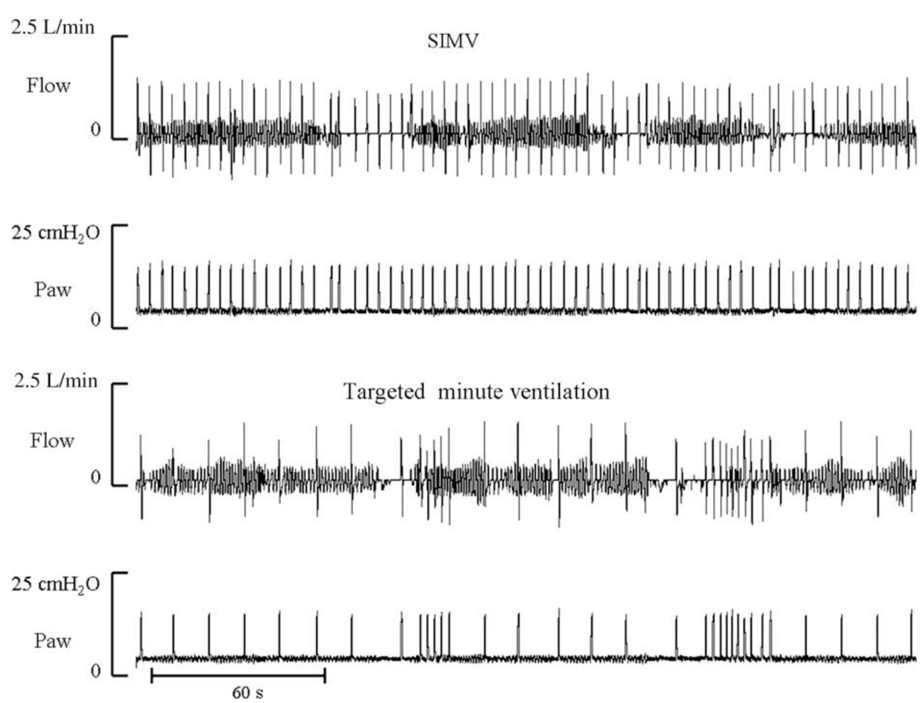

Fig. 1. Synchronised intermittent mandatory ventilation (SIMV) and targeted minute ventilation. Representative recordings of air flow and airway pressure in an individual infant during SIMV and targeted minute ventilation. During targeted minute ventilation, ventilator rate is lower than during SIMV. Ventilator rate is automatically increased during transient periods when spontaneous breathing is not sufficient.