Respiratory support in the newborn

Respiratory support of the newborn infant is a challenging situation in neonatology. The immature lung is especially prone to develop bronchopulmonary dysplasia (BPD), a multifactor disease related to the use of mechanical ventilation and oxygen therapy in very preterm newborn infants. The role of respiratory support is still not well established, but the evidence suggests that less invasive respiratory support is associated with the highest survival without BPD. Different modalities of respiratory support will be discussed in terms of improving lung function with a low risk of lung damage.

Keywords

mechanical ventilation; CPAP; noninvasive respiratory support; high-frequency ventilation

Key points


1. Noninvasive respiratory support can decrease the risk of lung damage in preterm infants, but nasal CPAP alone is probably not enough to prevent bronchopulmonary dysplasia.

2. Exogenous surfactant administration in combination with noninvasive respiratory support appears to be an effective therapy in preterm infants with RDS.

3. Noninvasive mechanical ventilation, synchronised with the patient, can decrease the need for invasive mechanical ventilation and also probably the risk of BPD.

4. New invasive respiratory support systems adapted to the patient’s needs will probably decrease ventilator-induced lung injury and decrease the duration of mechanical ventilation.

Lung physiology following delivery

Establishing the lung residual capacity is a difficult problem in an immature and wet lung, and once the lung is open, keeping the gas in the lung and recruiting enough numbers of air spaces is a challenging situation. In the term and near term newborn, this is normally done by decreasing the intrathoracic pressure at birth using the respiratory muscles. Once the air comes into the lungs, two important mechanism are involved in keeping air in the lung7:

- pulmonary surfactant – which keeps the airspaces open by counteracting the high surface tension forces within the alveoli, preventing differential inflation of the alveoli and decreasing the work of breathing

- closure of the glottis during expiration. After decreasing the intrathoracic pressure in the thorax during the first inspiration, the glottis closes before expiration is finished and with the glottis closed the respiratory muscles continue to contract, dramatically increasing the intrathoracic pressure. This high pressure equalises across the lungs and overcomes the opening pressure of most of the air spaces so they open and remain open. Both mechanisms are important for alveolar recruitment in the normal lung after delivery, but are probably even more important in the immature lung, where the amount and quality of endogenous surfactant is inadequate and the closing pressure of the lung is higher.

Institution of mechanical ventilation from the first minutes of life by
introduction of an endotracheal tube prevents this normal mechanism occurring after delivery, and may lead to “induced” respiratory distress syndrome (RDS), increasing inflammation and triggering some of the mechanisms involved in the genesis of BPD. Thus prevention of intubation and mechanical ventilation is desirable to decrease the risk of RDS and BPD. However supporting the immature lungs of the preterm newborn without damaging them is one of the most difficult questions to be resolved.

Nasal CPAP

At present there is limited evidence from clinical trials, but data from the literature suggests that some of the smallest preterm newborns can be supported from delivery with nasal continuous positive airway pressure (nCPAP) or noninvasive positive pressure ventilation (nIPPV) to protect their lungs (FIGURE 1). Using this noninvasive approach from delivery decreases the need for invasive mechanical ventilation and exogenous surfactant administration, but there is conflicting data regarding the effect on BPD. There is currently a large randomised trial of NIPPV versus CPAP underway to answer whether or not NIPPV is genuinely better at reducing BPD (NIPPV Trial).

Nasal CPAP has been used for many years and was first described by Gregory and colleagues in 1971 to obviate the need for intubation, to prevent reintubation after extubation and to treat apnoea of prematurity. There are basically two different mechanisms to generate CPAP – by increasing pressure using flow or by increasing pressure using resistance:

- The high flow devices use a low resistance in the expiratory limb of the circuit and increase pressure with flow by generating a differential jet effect. The classical device of this group is the Benveniste jet device. The Infant Flow Driver (IFD) system is a sophisticated variation of the Benveniste jet device, where pressure is generated at the nasal level, by a generator connected directly to short binasal prongs. By adjusting the flow, pressure is controlled.

- Bubble CPAP is a traditional mechanism, introduced in the early 1970s, which provides pressure support by increasing the resistance via underwater gas bubbling. Although there is not enough evidence to determine which of these mechanisms for creating nCPAP is better, some authors do prefer the IFD.

Humidified high flow nasal cannula can also generate pressure at the nasal prongs but it is not a recommended method due to the difficulty in knowing exactly what pressure has been generated and the lack of clinical evidence. More studies need to be done before this therapy can be recommended in preterm infants.

Different nasal interfaces have been used, but the short binasal prong devices are more effective than single prongs in reducing the likelihood of the short-term adverse outcomes of re-intubation and respiratory failure.

Although nasal CPAP can be effectively used even in extremely preterm infants, to prevent intubation at delivery, not all preterm newborns can be managed in this way. Failures of using only nCPAP occur because of the need to treat RDS with surfactant, which requires intubation, and also because of apnoea or inadequate respiratory effort.

Also using only nCPAP can lead in some instances to an increase in the risk of air-leaks and pneumothorax, and there is no evidence that BPD is decreased.

Nasal CPAP and surfactant administration

It has been shown that with the decrease in the use of invasive mechanical ventilation, there is a decrease in the use of surfactant in preterm infants, but probably there is a trend of increasing the risk of BPD. The combined effect of prompt extubation to nCPAP after surfactant administration has been demonstrated to be effective, compared to nCPAP alone, in decreasing the need for invasive mechanical intubation with a trend of reducing the risk of BPD in a group of preterm infants with a gestational age of 27 to 32 weeks.

So the combined effect of nCPAP with surfactant administration soon after delivery would appear to be a good approach to managing RDS. The question then is how to select the target population which requires surfactant – not only to decrease the number of preterm infants who receive surfactant and do not need it, but because the administration of surfactant needs to be done through an endotracheal tube, although there are some instances from the literature of giving surfactant without intubation.

A recommended approach is to give surfactant when the FiO2 is 45% or higher, but also any time there is a need for intubation in the preterm infant and probably the earlier the surfactant is given the more effective it is.

Synchronous non-invasive mechanical ventilation

Nasal CPAP relies on the spontaneous minute ventilation generated by the patient to be effective, so in some instances sending pressure cycles of ventilation through a nasal interface can be a better support to the infant. There is some evidence to show that noninvasive ventilation produces less inflammation compared to conventional invasive ventilation in neonatal animal models. These pressure cycles can be sent to the
patient by a classical intermittent positive pressure ventilator (IPPV), and some authors have demonstrated a beneficial effect of this modality of ventilation.21-23. The efficacy of this noninvasive ventilation can be improved, and some of the side effects described reduced, by synchronising the positive pressure of the device with the inspiration of the infant.24,25.

Some studies have demonstrated the efficacy of this ventilation in preventing reintubation after invasive mechanical ventilation and also there is some evidence that this synchronous noninvasive mechanical ventilation can be effective in decreasing the risk of BPD.26,27. The difficulty lies in the sensitivity of the triggering device detecting the inspiratory effort of the most premature infants with the highest risk of BPD. There are some devices that have demonstrated this efficacy, but large randomised controlled trials are still needed.28

High frequency mechanical ventilation (HFV)

This modality of using a high continuous distending pressure to recruit the lungs, improving oxygenation and using an infratidal ventilation (using tidal volumes smaller than the anatomical dead space delivered at a very high rate of 180 to 900 cycles per minute), to decrease arterial PaCO₂, was initially demonstrated in immature animal models of RDS to be an efficient mode of ventilation with a decreased risk of lung damage. There is even some evidence that noninvasive HFV in a premature animal model with RDS can cause less injury compared to conventional mechanical ventilation.29

This HFV was expected to result in less mortality and less BPD, when used as the primary mode of ventilation in the treatment of RDS in preterm infants, but clinical trials failed to demonstrate such an effect, so there is no evidence that using elective HFV, soon after delivery, can decrease lung injury.30

Caution should be taken when comparing HFV to conventional ventilation, as HFV can be superior or not depending on how the conventional ventilation is managed. Dani and coworkers31 using a low PEEP (5cmH₂O) and a fast rate in assist/control mode with a Dräger Babylog 8000plus, demonstrated that HFV induced less inflammatory response in the airways compared to conventional mechanical ventilation. However Lista and coworkers32 found that conventional ventilation with higher PEEP (5cmH₂O) and a slow rate backup of the ventilator, enabling the infant to trigger the ventilation in each cycle, induced less inflammation than HFV. So currently we can only say that elective HFV is not necessarily preferred to conventional ventilation in the preterm infant.

Since the current trend of respiratory support is to be as less invasive as possible, HFV is often used as a rescue therapy in most neonatal intensive care units. However even as a rescue therapy, there is not much evidence of its superiority over conventional ventilation. Each HFV device is different, but the most important variable in decreasing PaCO₂ is the tidal volume generated by the HFV device.33 There is a great advantage in monitoring HFV tidal volume, particularly in very preterm infants in whom the risk of brain damage due to changes in PaCO₂ is higher. Some devices such as the Dräger Babylog 8000plus can measure it, and the new Dräger VN500 can also adapt the oscillatory pressure (delta pressure) to keep constant the tidal volume and prevent excessive variations in PaCO₂.

These new strategies, such as volume guarantee during HFV, should be studied in clinical trials, but look promising as a method of decreasing the possible deleterious effect of variations in tidal volume and PaCO₂.

New modalities in conventional ventilation

Patient-triggered ventilation was introduced in newborn ventilators a few years ago, and there is evidence to show that this has advantages over controlled non-triggered ventilation. These benefits are not related to an improvement in survival, but to a decrease in the pressure needed to deliver the tidal volume, as the patient when triggering the ventilator decreases the pressure. There is a decreased risk of asynchrony with the ventilator, a lower risk of air leak, and a shorter duration of mechanical ventilation, among other advantages.

Giving the patient the possibility of maintaining minute volume by modifying the spontaneous respiratory frequency is one of the most important modalities in respiratory support for neonates during the last decade. This can be done with assist/control or inspiratory flow synchronisation. Again, to achieve the best synchronisation between the ventilator and the patient, the trigger should be of a high sensitivity and a short delay time in response. Pressure support ventilation (PSV) also modifies the inspiratory time as needed, to ensure enough time to equalise the pressure in the pressure-limiting ventilation modality, or to send the programmed tidal volume in volume-setting ventilation.

So a great advantage has been achieved by enabling the patient to spontaneously control minute ventilation, the duration of the inspiratory time, and decreasing the breath-to-breath tidal volume variation with the new volume objective ventilation. Volume guarantee is probably the most sophisticated method as it uses the expiratory tidal volume to adjust the next inspiratory pressure as needed, weaning the patient as the lung mechanics and the work of breathing improve. New ventilatory modalities, tested a few years ago are now available, using the concept of minute volume guarantee, so that more physiological ventilation can be provided. New ventilators will hopefully adapt to the patient’s needs, not only as if the lung improves, but also as the metabolic demands change over the day. Using these new modalities it is clear that more comprehensive ventilation can be provided to the patients associated with a decrease in the damage caused to the lungs.

References


