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Review

Strategies for the prevention of continuous positive airway pressure failure

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SUMMARY

Progress in neonatal intensive care is closely linked to improvements in the management of respiratory failure in preterm infants. Current modalities of respiratory support range from the more benign continuous positive airway pressure (CPAP) to various modes of mechanical ventilation. Data from recent randomized control trials suggest that the use of nasal (n)CPAP as the initial mode of respiratory support in critically ill very low birth weight infants is associated with a lower incidence of chronic lung disease. The practice of early initiation of nasal-prong CPAP in all spontaneously breathing infants at Columbia University has resulted in very low rates of chronic lung disease for decades. Many institutions have attempted to replicate the practices and results at Columbia University. However, success rates with nCPAP are highly variable, which may in part be attributable to how well it is utilized. With recent renewed interest in non-invasive respiratory support, particularly bubble nCPAP, it is essential to evaluate strategies for the prevention of CPAP failure. This review discusses strategies that address these issues and shares the practical aspects for replicating success with bubble nCPAP. In addition, it reviews desirable features, major components, and physiological consequences of various bubble CPAP systems along with clinical experience of CPAP use.

1. Introduction

Continuous positive airway pressure (CPAP) has been used since the early part of the twentieth century for resuscitation and stabilization of preterm infants with respiratory distress syndrome (RDS). In 1968, Harrison et al. showed that intubation (without end-distending pressure) led to a fall in oxygenation; the oxygenation improved when the endotracheal tube was removed and the infants were allowed to grunt [1]. Two years later at the Society for Pediatric Research meeting, Llewellyn and Swyer [2] showed that the addition of positive end-distending pressure improved oxygenation in ventilated preterm infants with RDS. Finally, in 1971, Gregory et al. [3] published a small clinical trial demonstrating that CPAP improved oxygenation in preterm infants with RDS. However, prior to 2008, there was little evidence to support the use of CPAP as a strategy to reduce the incidence of bronchopulmonary dysplasia (BPD) other than observational data associating the use of CPAP with better respiratory outcomes [4]. In a landmark study published in 1987, the Babies Hospital at Columbia University was reported to have the lowest incidence of chronic lung disease compared to seven other centers. A number of care practices were suggested to explain those differences; early institution of CPAP in infants with respiratory distress, avoidance of mechanical ventilation by using permissive hypercapnea and allowing infants to breathe spontaneously were all viewed as important. Other investigators [5] reached similar conclusions when respiratory outcomes at two Boston Hospitals were compared to those at Columbia. The authors concluded that most of the increased risk of chronic lung disease in the two Boston neonatal intensive care units (NICUs) could be explained simply by the initiation of mechanical ventilation at the two Boston centers. In the 1990s, interest in using CPAP as an initial mode of respiratory support waned because of the strong evidence demonstrating that endotracheal intubation and administration of surfactant improved survival, and decreased the incidence of air leaks [6]. It is noteworthy that none of the clinical trials studying surfactant at that time had a control group randomized to CPAP. Furthermore the widespread acceptance of surfactant administration as an

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evidence-based therapy did not lead to a decline in the incidence of BPD.

In 2008, the first of five randomized clinical trials was published, comparing early use of CPAP with routine endotracheal intubation and surfactant administration [7]. A meta-analysis of those trials has recently been published, demonstrating a decrease in the combined outcome of death or BPD when CPAP is used as an initial mode of respiratory support [8]. The authors concluded that one additional infant could survive to 36 weeks without BPD for every 25 babies treated with nasal (n)CPAP in the delivery room. Furthermore a recent Cochrane review concluded that prophylactic administration of surfactant compared with stabilization on CPAP and selective surfactant administration was associated with a higher risk of death or BPD (risk ratio: 1.12; 95% confidence interval: 1.02–1.24) [9]. Therefore, it is somewhat surprising that nCPAP is not used more widely [10] and that the outcomes from centers such as Columbia University cannot be easily replicated.

In this review, we will address five topics: (i) desirable features and major components of CPAP systems, (ii) physiologic consequences of device selection, (iii) randomized trials of CPAP use, (iv) Columbia experience with nCPAP, and (v) practical aspects of nCPAP application and strategies for success.

2. Desirable features and major components of CPAP devices

The goal of any CPAP delivery device is to prevent atelectasis and airway closure. An ideal CPAP delivery system should have the following characteristics: a patient system that is easily and rapidly applicable and is readily removable and re-connectable; causes the least trauma to the infant; is capable of producing stable, desired pressure levels; readily accepts humidification and supplementary oxygen at the desired temperature; is associated with low resistance to breathing; offers minimal dead space; is easily understood, maintained, and sterilized; and is safe and cost-effective. Bearing in mind the infrequent use of non-nasal methods of CPAP in current clinical practice, this review will focus exclusively on nasal interfaces and modes of pressure generation utilized in nCPAP delivery systems.

The CPAP delivery system consists of three components:

2.1. Heated and humidified circuit for continuous flow of inspired gases

Oxygen and compressed air sources provide inspired gases at the desired inspired oxygen concentration. The flowmeter controls the rate of flow. The minimum flow rate used should be sufficient to prevent rebreathing of carbon dioxide, i.e. usually two and half times the infant's minute ventilation. The flow should also compensate for leaks around connectors and the CPAP prongs. Usually a flow rate of 5–10 L/min is sufficient in infants. The inspired gases are warmed and humidified prior to delivery to the infant to avoid mucosal injury.

2.2. Nasal interface to connect the CPAP circuit to the infant's airway

Nasal interfaces are most frequently selected and are usually the most appropriate route for the delivery of CPAP. Single and binasal tubes/prongs of varying lengths, ending in the nares or nasopharynx, have also been used as nasal interfaces. Nasal masks have been used to deliver CPAP to infants [11,12]; however, they are difficult to keep in place and to maintain an adequate seal. Nasal cannulae are often used in infants to deliver supplemental oxygen at low flows (<0.5 L/min) with no intention of generating CPAP. Short binasal prongs, initially used by Wung et al. [13], are simple to use, effective and safe, but they have the potential to cause nasal trauma resulting in nasal deformities if inappropriately applied or infrequently monitored. Several binasal devices are now widely used, including Hudson prongs [13], Argyle prongs [14] and INCA prongs [15].

Excessive flow through the circuit generates high pressure against which the infant must exhale. To lower the work of breathing, variable-flow devices such as Infant Flow Driver (Electro Medical Equipment Ltd, Brighton, UK) and Arabella Generators (Hamilton Medical, Graubünden, Switzerland) are designed to allow the jet flow to flip between inspiratory and expiratory routes (Coanda effect). They aim to provide sufficient demand flow on inspiration while minimizing expiratory resistance. Work with lung models and a small study on preterm infants with minimal lung disease [16] demonstrated reduced work of breathing when compared with conventional devices. Limited randomized crossover [17] and non-randomized clinical studies [18], in preterm infants, have compared the Infant Flow nCPAP system with single-prong nCPAP. They found no significant difference in short-term measurement of physiological variables.

2.3. Modes of positive pressure generation in the CPAP circuit

The CPAP pressure is usually achieved by varying the resistance to flow in expired tubing. In neonates this can be done by several techniques and a variety of nCPAP systems. The main methods used to create nCPAP in neonates are:

2.3.1. Constant flow

- Electronic feedback control valve (e.g., ventilator or Air Life (Cardinal Health, Dublin, OH, USA) nCPAP system).
- Water-seal (bubble CPAP (Fisher & Paykel Healthcare, East Tamaki, New Zealand); Babi-Plus (A Plus Medical, Carlsbad, CA, USA); home-made).
- Flow opposition, where the patient's expiratory flow opposes a constant flow from nasal prongs (conventional ventilator-provided neonatal CPAP).

2.3.2. Variable flow

- Flow opposition with fluidic flow reversal during expiration, where gas is entrained during inspiration to maintain stable pressure and expiratory flow is diverted via a separate fluidic “flip-flop” (Arabella generator and Infant Flow Driver).

Bubble CPAP represents the simplest form of CPAP, requiring only provision of a constant bias flow, a patient interface and creation of flow opposition and pressure by submerging the tip of the expiratory limb a set distance under the surface of the liquid. Flow escapes beneath the liquid surface via creation of bubbles. Pressure oscillation created by the bubbles is transmitted back to the nares, delivering a variable rather than constant pressure to the airway opening. Compared with constant-pressure flow-opposition CPAP, variable flow-opposition CPAP systems may offer important and relevant clinical advantage in the infants with chronic respiratory disease, especially in the presence of impaired respiratory muscle contractility and susceptibility to fatigue. As evident from the above description, there exists a multiplicity of nCPAP delivery systems. Not all devices are similar and success with nasal CPAP may be device specific. Further studies need to focus on the most effective nasal CPAP interface and the best mode of pressure generation for the delivery of nasal CPAP.