· SPECIALIST LECTURE ·

Noninvasive respiratory support in neonates: A brief review

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Abstract: In the era of gentle ventilation and open lung strategy noninvasive ventilatory support in neonates has gained momentum and its use in nurseries around the world is also increased. This paper reviews various modalities of noninvasive respiratory support in some details and its relevance in the recent evidence based use. Continuous positive airway pressure (CPAP) is a mode of ventilatory assistance in which positive pressure is delivered to the airway throughout the respiratory cycle. It is also referred to as continuous distending pressure (CDP) or positive end expiratory pressure (PEEP) when applied through a ventilator along with intermittent mandatory ventilation (IMV). It has been proven over the years to be an effective mode of ventilatory support and as such has gained widespread use in the management of a variety of neonatal respiratory diseases. It is relatively cheap and easy to apply and certainly feasible for routine use in underdeveloped world. Besides improving oxygenation CPAP often functions as an airway stabilizer of the trachea thus helping to decrease the frequency of neonatal apneas, particularly the obstructive variety. There is good to fair quality supportive evidence from several studies that the use of primary CPAP can reduce the need for intubation and mechanical ventilation in infants less than 32 weeks gestation. In this review, we will attempt to describe different delivery devices and pressure generating systems and discuss different ways in which CPAP can be applied. Although it is unclear that primary use of CPAP can reduce overall neonatal mortality and morbidity it is becoming increasingly clear that early CPAP use is less invasive, baby friendly and decreases the need and frequency of the use of surfactants. Besides, clinical indications for CPAP, its advantages and limitations will also be explored. CPAP adjuncts such as nasal intermittent positive pressure ventilation (NIPPV) and infant flow driver will also be discussed. [**Chin J Contemp Pediatr, 2012, 14(9):643 – 652**]

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Gregory et al[1] first described continuous positive airway pressure (CPAP) in the neonatal literature in 1971. Although this mode of ventilation was first used on large and relatively mature infants, over the years it has been successfully applied to more premature and even immature infants as well[2-3]. Over the last few years several strategies has been applied to neonatal care in an attempt to decrease neonatal morbidities and mortalities and noninvasive ventilation has been one of them. It has been proven to be an effective mode of ventilation in neonates and has secured a comfortable position in the neonatal respiratory support technology. Implementation of early CPAP in neonatal intensive care units (NICUs) will need experienced nurses and extended education and training programs. The use of CPAP as a primary intervention and mode of respiratory support is indeed an option for relatively mature infants ie greater than 32 weeks gestation. However this strategy may also be successfully used to avoid intubation in infants born between 27 to 32 weeks gestation[4]. Successful use of CPAP could avoid ventilator induced lung injury and may decrease bronchopulmonary dysplasia (a major NICU morbidity) and potentially decrease neonatal care costs and as such is quite appealing to all neonatologists and newborn caregivers. Recent publications[5-8] have tried to revisit these clinical issues reminding us that traditional approach of neonatal respiratory management can indeed be altered for the benefit of the ill neonates. The majority of the studies published were observational using historical controls or no controls with fair quality[4]. The dynamic nature of its use and its potential prompted us to report the state of the art as it stands today.

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1 Principles and mechanisms

The adult lung has 300 million alveoli and can be regarded as tiny air bubbles with around 0.3 mm in diameter, so it is extremely unstable. Because of surfactant and the fact that each wall can anchor and support each other the stability of the alveoli is enormously increased. However in disease states air spaces can collapse or distend. In many neonatal diseases and even in its absence the neonatal lung air spaces tend to collapse causing hypoxemia and lung injury. Obviously CPAP keeps the lung open. Additionally it supports and anchors larger airways reducing obstructive apneas[9]. In the 1970's, CPAP was delivered through an endotracheal tube as an adjunct to intermittent mandatory ventilation (IMV) and as the infant's condition improved, CPAP alone was used leading to extubation and post extubation care. Over time, several other nasal delivery devices have been tried with varying degrees of success. Delivery devices that are now fallen out of favor are the face mask and head box with neck seal. The nasal route is preferred as newborns are obligate nose breathers.

Single nostril prong is usually an endotracheal tube cut short and placed 1-2 cm inside the nose or in the nasopharyngeal area[10]. The disadvantage of this method is the leak of pressure out of the opposite nostril, accumulation of mucus and obstruction of the prong.

Binasal prongs are the most commonly used. They are available in different sizes to ensure optimal fit to the nostril. They have been found to be more effective than the single nostril prong in ensuring extubation success as well as improving oxygenation and weaning of ventilation[11]. An appropriate fit is essential to prevent leakage around the device. Trauma to the nose may occur if too large or if improperly fitted[12].

Nasal masks are less traumatic to the nose internally. However, it can be difficult to maintain a seal, and it has a tendency to cause nasal airway obstruction. They often press very hard against newborns' face[8], causing pressure sores. Dermal protection can be achieved using stoma care products.

Nasal canullae with an outer diameter of 3 mm and flows up to 2 L/min can be delivered creating CPAP with a mean pressure of 9.8 cm of water in infants with 30 weeks gestation at 28 days of age[13]. This is an attractive option as it is less traumatic to the nose. However, concerns have been raised about the possibility of delivering too much pressure because the system is not pressure regulated. As well there is a risk of temperature problems in the infant if the system is not heated and humidified properly. It can also potentially cause dryness, bleeding, obstruction to airway and sometimes infection[14]. The use of Vapotherm — a double lumen tubing system, where high flow humidified heated air is supplied through an inner tube while heated by warm air running through an outer tube, may address some of those concerns described.

All the nasal devices are limited in the fact that pressure is lost if the mouth is kept open. Chin straps and pacifiers have been tried to minimize this problem. Also, the delivery of CPAP has to be interrupted for suctioning of the airway. Secretions plugging the device can be problematic with suboptimal pressures being delivered leading to clinical deterioration of the infant and sometimes leading to intubation and mechanical ventilation. The most advantageous posture of the infant that will ensure maximal delivery of CPAP to the lungs is yet to be determined. Generally, infant positioning is rotated according to nursing requirements.

There are several ways of generating CPAP. These CPAP generating systems include a conventional ventilator, an underwater bubbling system, the infant flow driver (IFD) and Benveniste's device[15]. They work by supplying a flow of gas that is used to generate the needed pressures. The actual amount of gas that reaches the alveoli is dependent on the amount of leak in the system. These leaks could be through the nose and around the delivery device or through the infant's mouth[9]. The amount of leakage can be quite significant and has been indirectly measured by assessing the esophageal or pharyngeal pressure while on CPAP[16]. The optimal amount of flow required remains unknown and ultimately depends on the condition of the lung that is being treated, the size of the infant and the amount of leak in the system[17].

A CPAP generating system usually consists of a gas flow source, oxygen blender, heated humidifier, an inspiratory and expiratory circuit and a manometer or a pressure detector. This system is then attached to the delivery device of choice. The systems in use widely differ mainly in the expiratory circuits.

CPAP using a conventional ventilator — the ventilator delivers a fixed amount of flow to provide the desired positive pressure. It is the most commonly used mode of delivering CPAP in NICUs around the world. Most standard ventilators have a CPAP feature. A flow of 3-10 liters is needed to generate CPAP pressures of 3-10 cm of water[8].

Underwater bubble CPAP has been used since the early 1970s. It is the simplest method of generating CPAP. The tubing is immersed in sterile water in a transparent bottle to a specified depth to produce and maintain the desired pressure. As gas flows through the underwater seal, the bubbling of the water sets the gas into vibration and is postulated to create an oscillatory effect similar to, but of less amplitude than that seen in high frequency oscillation mode of ventilation. The CPAP bubble system was compared to ventilator derived CPAP in intubated premature infants and was found to augment ventilation and decrease respiratory rate and thereby decrease the work of breathing and susceptibility to fatigue[18-19]. The studies have not yet been expanded to infants using nasal delivery devices[8]. The underwater bubbling in this mode of CPAP generation serves as a visual cue that the intrathoracic pressure is being appropriately supplied.

IFD has a unique patented design that works in synchrony with the infant's respiratory effort using the Fluidic Flip technology and the Coanda effect. This fairly new discovery has been applied in the fields of aerodynamics and jet engine design. The Coanda effect occurs when a jet of fluid leaves a nozzle at high speed; fluid from the body that it enters is entrained, or drawn in by the momentum of the flow. If there is obstruction to this action, such as a wall, there is less fluid to be drawn in with resultant drop in pressure on one side of the jet. This pressure drop causes a deflection in the flow and redirects the jet until it attaches to the wall. IFD generator demonstrates this effect by utilizing the baby's breathing effort to induce the Coanda effect and trigger the Fluidic flip inside the device[20].

When the patient makes a spontaneous inspiratory breathing effort the flow driver senses this and the generator assists the patient by converting the air/gas mix flow to pressure energy and delivers this via CPAP to the lungs. This pressure energy is modifiable and the rate of breaths is also adjustable. When the baby makes a spontaneous expiratory effort, pressure at the nasal attachment of the generator causes the flow to flip around and leave the generator via the expiratory limb. When expiration stops, the flow flips back to the inspiratory position. By so doing, there is no mechanical impedance and interference of flow seen in conventional CPAP, hence the airway/system resistance is much lower and the airway pressure remains constant[21-22]. The expiratory limb of IFD opens to the atmosphere. Potentially, the baby can inspire with higher flows than that delivered through the inspiratory limb by drawing extra gas from the expiratory limb, thus reduces the chance of pressure falling within the system with large inspirations. This is an added feature to maintain constant pressure within the system.

IFD has been shown to reduce work of breathing more effectively than conventional systems while providing greater and more stable lung recruitment. It also has been shown to decrease respiratory rate and oxygen requirement compared to conventional CPAP systems. A non-statistically significant trend towards reduced need for mechanical ventilation, shorter clinical recovery time, shorter duration of treatment has also been described. A comparison of IFD with a conventional CPAP system however showed no statistically significant difference in preventing re-intubation in extremely low birth weight infants with birth weight less than 1000 g[23]. This may be for several reasons including lack of sufficient numbers, severity of illness etc. IFD therapy in these infants was associated with fewer days on supplemental oxygen and shorter lengths of hospitalization[24]. This may be important in terms of further reducing the cost associated with caring for these infants.

Benveniste's valve when applied to the nasal delivery device of choice, vents the expired air to the surrounding atmosphere as soon as a pressure difference is detected and works well with lower respiratory rates. This device eliminates the need for expiratory tubing and generates more constant pressure, may reduce over-distension of the lungs and consequent complications. There have been no studies comparing this device to other available CPAP systems or IFD.

The breathing pattern of the neonate with respiratory distress is quite disorganized. Some of the observed patterns in them include increased respiratory rate, continued contraction of the inspiratory muscles during expiration, active expiratory laryngeal narrowing and tonic activity of the diaphragm and intercostal muscles. Premature babies have compliant chest walls causing "paradoxical breathing" where the ribcage collapses inward with the contraction of the diaphragm[25]. CPAP works by improving the breathing pattern in neonates. It achieves this by increasing functional residual capacity and tidal volume thereby decreasing work of breathing[26-27]. It also helps to stabilize the upper airway thereby improving the function of the "bellow" (chest wall and diaphragm). CPAP increases the mean airway pressure and optimizes lung recruitment and as such decreases ventilation-perfusion mismatch. CPAP stents the upper airway, decreases proximal airway resistance, reduces the physiologic dead space, improves synchrony of thoracoabdominal motion and improves diaphragmatic function.

CPAP is therefore effective in the treatment of obstructive/mixed apnea of prematurity, respiratory distress syndrome, respiratory distress of other etiology, atelectasis, tracheomalacia and other types of upper airway obstruction, and ensures successful extubation.

In neonatal intensive case units across the world, CPAP is being used more and more commonly as an alternative to endotracheal intubation and intermittent positive pressure ventilation. Obviously, by using CPAP in the spontaneously breathing infant, the adverse effects of intubation and mechanical ventilation can be avoided. Laryngoscopy and intubation are associated with untoward physiological responses such as desaturation, bradycardia, increased intracranial pressure and hypotension with the added risk of cerebral hemorrhage and neuronal injury in premature infants. Mechanical ventilation predisposes to lung injury; such as atelectrauma, barotrauma, volutrauma, pneumothorax, inadvertent hyperventilation and long-term airway side effects such as stricture and subglottic stenosis. Avoiding intubation can also minimize nosocomial infections and ventilator-associated pneumonias.

2 Clinical application of CPAP

2.1 CPAP and respiratory distress syndrome

CPAP has been shown to be effective in the treatment of respiratory distress syndrome (RDS) even in very low birth weight infants. In particular, it has demonstrated effectiveness in resuscitation, avoidance of intubation and facilitating weaning from the ventilator. It is particularly attractive for the hospital settings of developing countries due to its ease of use and low cost. Severe and moderate surfactant deficiency will need more than CPAP as treatment in such cases. And in and out intubation for the purpose of surfactant delivery and extubation to CPAP has been proposed[27]. The downside to this practice is that laryngoscopy and intubation and their untoward effects, however, the effects of long-term ventilation may be avoided. The use of nebulized surfactant has been suggested as an alternative in the literature but the early studies did not show any benefit. With more babies receiving antenatal steroids and improvement in antenatal and perinatal care, more babies are likely able to tolerate CPAP alone. The idea of CPAP only in the very premature infant is attractive because intubation and surfactant administration may be traumatic and potentially dangerous.

2.2 CPAP and weaning from the ventilator

This is the area in which CPAP is mostly used usually with pressure support ventilation. CPAP has been proven effective in preventing re-intubation[2, 7].

2.3 CPAP and resuscitation

The effects of CPAP such as stenting upper airways, increasing FRC, reducing airway resistance recruitment of lung and decreasing work of breathing, is known to keep an "open lung" strategy after birth. This will improve the chances of success of resuscitation and alleviate lung injury. The IFDAS trial published as an abstract, randomized 234 premature babies from 27 to 29 weeks gestation into 4 arms: a) early CPAP following intubation and surfactant, b) early intubation and ventilation with prophylactic surfactant, c) early CPAP with or without subsequent intubation and surfactant and d) management at physician's discretion. They looked at the use of CPAP right from the delivery room and found it to decrease the duration and need for mechanical ventilation. However, there was no difference in the incidence of chronic lung disease[27].

2.4 CPAP and apnea of prematurity

The clinical management of apnea of prematurity is not different today from what it was two decades ago. Three types of apnea of prematurity have been described, central, obstructive and mixed apnea. Central apnea is continues to be treated with methylxanthines. Nasal CPAP continues to be useful in the treatment of obstructive or mixed apnea treatment. In milder cases, cutaneous stimulation by the bedside nurse may help. Alternative noninvasive modes of ventilation available for treatment of AOP are nasal intermittent positive pressure ventilation (NIPPV) over CPAP and high flow nasal canula (1-2 L/min).

NIPPV is a technique of noninvasive ventilations where a higher level of CPAP is delivered at intervals to simulate a ventilator breath[27] often synchronous to a spontaneous breath. It is used in conjunction with CPAP to augment its effect. It is used to treat preterm infants with resistant or severe apneas. Two Cochrane reviews have found such use of NIPPV reduces the frequency of apneas more effectively than CPAP alone[26-27]. Case reports of gastrointestinal perforation have curtailed its use to some extent, however there have been no reports of this type of adverse event when the breathing rate is synchronized with the infant's breath. The mechanism of action of NIPPV in improving apnea of prematurity is still under investigation. NIPPV is not delivered directly into the distal airways as in the case of endotracheally intubated infants. It is possible that NIPPV may influence or alter respiratory mechanics, providing its benefit in this way. More studies are needed to further define its mode of action. NIPPV has also been used in infants to provide respiratory support after extubation. Studies show NIPPV to be more effective than nasal CPAP alone in preventing extubation failure.

2.5 Limitations of CPAP

Similar to other neonatal therapies CPAP is also associated with problems. There is a risk pulmonary air leak. Obstruction of the nasal device by secretions needs to be watched for on a regular basis. Nasal irritation or injury, gastric and intestinal distension may occur and should be monitored. Over-distension of the lungs may result from increased work of breathing and struggling, causing hypercapnia, increased pulmonary vascular resistance, decreased cardiac output, and intrapulmonary right to left shunts causing hypoxemia and persistent apneas. CPAP and other airway distending pressures have been implicated in inappropriate ADH secretion and hyponatremia. It is worthwhile to remember that as lung conditions (e. g. RDS) improve the applied pressure may be transmitted to the heart resulting in increased secretion of atrial natriuretic factor. It may also cause decreased venous return and or decreased stroke volume.

2.6 Contraindications to CPAP

Contraindications to CPAP include agonal respiration (gasping), secondary apnea, persistent cardiovascular instability, upper airway abnormalities (such as choanal atresia, tracheo-esophageal fistula, diaphragmatic hernia)[2]; congenital anomalies involving the face such as choanal stenosis, micronostril, arhinia (absent nose), cleft lip and palate and unrelenting apneas.

2.7 An approach to the use of CPAP

■ The first step in the use of CPAP is choosing the right patient bearing in mind the indications, contraindications and limitations of CPAP.

■ Choose the right situation; resuscitation, long term management of respiratory distress, post-extubation, apnea of prematurity etc.

■ Choose the right CPAP system and decide on whether to augment CPAP with NIPPV. At our institution, we use conventional CPAP using Star ventilators. We also use IFD in very low birth weight infants exhibiting multiple and frequent apneas and bradycardias. The system should be with heated humidity (37°C) to prevent damage to nasal mucosa and to decrease temperature instability.

■ Choose the right delivery device. The binasal prongs are best supported in the literature for effectiveness. New nasal masks work well. It is essential that staff be trained in the correct placement and maintenance of delivery devices to avoid unnecessary injury to the infant and other problems.

■ The pressure used is between 4-10 cm of water. The determination of the pressure will depend on the clinician's familiarity and infant's condition.

■ Monitor work of breathing, respiratory rate and oxygen requirements. If the infant's clinical state deteriorates a blood gas and chest X-ray may be indicated. It is important to ensure that the equipment is working appropriately and ensure potency of the upper airway and the device before embarking on these investigations.

■ There is no data available to guide the clinician in weaning or discontinuation of CPAP. It is generally by trial and error. The most prevalent approach is to conduct a weaning test by decreasing the distending pressure and then on to high or low flows via nasal canula.

3 Summary and conclusions

In summary, CPAP is an effective, gentle mode of ventilation. It is gaining widespread use in NICUs around the world. Due to its ease of use and low cost, it is particularly suited for units in the developing world, with appropriate training and education. There are different nasal delivery devices and CPAP systems available for use. The infant flow system has been shown to be more effective in lowering respiratory rate, oxygen requirement and work of breathing. For infants with residual RDS or in early extubation cases, NIPPV may be of additional help than CPAP alone. CPAP should be considered for use in resuscitation rooms and for treatment of mild to moderate respiratory distress syndrome. It is effective in apnea of prematurity, and to facilitate successful extubation.

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附中文译文(新生儿无创辅助呼吸支持介绍):

[摘　要] 随着新生儿微创辅助通气时代的到来及“开肺策略”的提出,新生儿的无创通气技术理念在世界范围内的NICU得到普及。该文复习了近年来新生儿无创通气技术的有关文献并作简要综述。持续气道正压通气(CPAP)主要原理为在呼气末予以压力支持的一种通气模式,又称之为持续扩张压或呼气末正压通气,经过世界范围内多年的临床实践, CPAP已被证实是一种有效的对患有呼吸系统疾病的新生儿实施呼吸支持的辅助通气模式。由于CPAP价格相对便宜,且易于在临床应用,因此更适合于在发展中国家推广。CPAP辅助通气,除可显著地改善患儿机体的氧合外,对有不同程度气道阻塞的患儿,它可以减轻气道塌陷,因此有助于减少患儿呼吸暂停的发生。文献研究表明,对于32周以下的早产儿,早期应用CPAP可减少患儿气管插管机械通气的机率。该文将试图介绍几种不同的CPAP应用装置和几种不同的CPAP应用方法。虽然对于早期应用CPAP是否能够降低新生儿死亡率及患病率目前尚不十分清楚,但临床实践已经表明,与有创通气比较, CPAP对患儿的损伤小,是一种较为舒适的通气模式,早期应用CPAP还可减少肺泡表面活性物质的使用频率。另外,该文还介绍CPAP的应用指征、优点及其局限性,CPAP的衍生模式如经鼻间歇正压辅助通气以及infant flow CPAP装置等。

[关键词] 无创辅助呼吸支持;持续气道正压通气;新生儿

Gregory等学者于1971年首次报道了持续气道正压通气(CPAP)的应用,虽然CPAP的使用最初只是在相对大的成熟足月儿,后来该无创通气模式逐渐成功地应用在早产儿或低龄早产儿。在最近几年,一些学者提出了降低新生儿的死亡率和患病率的监护策略,其中之一就是应用新生儿的无创通气技术。临床实践已经证实,CPAP无创通气对新生儿而言是一种易于固定、较为舒适且能够有效改善患儿通气的技术。但在新生儿重症监护病房(NICU),早期CPAP的应用不仅需要训练有素的团队,对医护人员进行大量的培训,且需要具有经验的护士护理患儿。对于胎龄大于32周的早产儿,CPAP无创通气确实是首先考虑的呼吸支持模式,这一无创通气模式还可用于27~32周的早产儿,可减少或避免气管插管机械通气的需要。由于CPAP的成功应用,避免了有创通气所致的相关肺损伤,降低了NICU早产儿支气管肺发育不良的发生率以及新生儿的治疗费用等,因此该通气方法受到新生儿专家及新生儿护理人员的普遍推崇。最近发表的文献在对无创辅助通气患儿的治疗效果进行随访后得出的结果表明,以往对新生儿采取的有创通气呼吸管理模式确实有必要改为无创通气,从而可减轻有创通气所致的相关并发症。但这些文献大部分为一般的临床资料回顾性分析,仅部分研究设立了对照组。本文对CPAP的一些动态特征及潜在的问题进行了一些更为深入的分析。

1　CPAP应用原理和机制

成人肺组织共有约30亿个肺泡,这些肺泡也可被看作是微小的空气气泡,直径约0.3 mm,所以稳定性极差。由于肺泡表面活性物质的作用以及每个肺泡之间形成的相互支撑,因此,正常成人的肺组织肺泡的稳定性相当大。然而,当肺组织发生病理改变的时候,肺泡可发生塌陷。但与成人不同,新生儿的肺组织在各种病理状况下,甚至在没有疾病的情况下,肺泡也容易塌陷导致低氧血症和肺损伤。而CPAP的通气原理为在呼气时给予正压通气,因此CPAP辅助通气,有助于肺泡扩张,避免塌陷;此外,CPAP还可扩张大气道。因此,CPAP的应用可减少患儿阻塞性呼吸暂停的发生。在上世纪70年代, 应用CPAP通气前,需要先给患儿气管插管间歇指令机械通气(IMV),待患儿情况好转后才能拔出气管插管改为单独的CPAP辅助通气支持。随着科学技术的进步,其他几种经鼻通气装置的问世取得不同程度的成功,目前面罩和固定在颈部的头罩CPAP装置也已经被淘汰,经鼻塞通气的CPAP装置更受欢迎,主要是因为婴儿用鼻呼吸。经鼻塞通气的方式主要有以下几种。

(1)单鼻孔鼻塞:通常是将剪短后的气管插管放置在患儿鼻腔内1~2 cm或鼻咽部区域,但这种方法的缺点是患儿对侧鼻孔容易漏气, 且鼻塞易被分泌物堵塞。

(2)双鼻孔鼻塞:是目前最常用的鼻塞,根据患儿体重的不同,有各种型号大小的鼻塞。与单鼻孔鼻塞比较,双鼻孔鼻塞漏气少,通气压力更稳定,效果更好,更有利于患儿机体的氧合和成功拔管,但使用时一定要注意选择合适大小的鼻塞以防止漏气,如果鼻塞太大或不合适容易引起鼻黏膜损伤。

(3)鼻罩:不易损伤鼻黏膜,但缺点是固定比较困难,且鼻腔分泌物容易堵塞鼻罩。有时如果面罩压迫时间太长,可导致颜面皮肤损伤,但如果使用有气孔的胶布固定,可减轻

皮肤损伤。

(4)鼻导管:对于 30 周的早产儿在 28 日龄时,如果用直径 3 mm 的鼻导管上氧,在氧气流量达 2 L/min 时,可产生平均 9.8 cm H_2O 的 CPAP 压力。这种鼻导管给氧方法的优点在于对鼻黏膜的损伤小,但也有学者担心这种通气方法由于没有压力调节装置,在气体流量过大时会导致压力过高,此外该法不能对吸入的气体进行加温加湿,容易导致鼻黏膜干燥、出血和气道分泌物堵塞,甚至感染。但随着 Vapotherm 蒸汽加温加湿双腔管的问世这一问题得以解决。

在应用 CPAP 辅助通气时,整个系统都必须处于密闭的状态才能保证压力的恒定。如果患儿口张开则可致压力泄露,因此,在患儿哭吵时需要用安慰奶嘴或在口腔不能闭合的情况下,用一些方法如带子等固定下颌,以保证通气压力的稳定。但在 CPAP 辅助通气过程中,有时也不得不取出鼻塞给患儿吸痰,这时 CPAP 的压力不得不被中断,因为在患儿呼吸道分泌物太多时,如果不及时清除痰液,痰栓可堵塞管道导致通气压力下降,使患儿临床状况恶化,最终需要改为气管插管机械通气。因此,在对患儿使用 CPAP 辅助通气时,最佳的体位是保证气体能最大限度地进入患儿肺部。通常情况下,在进行 CPAP 辅助通气时,患儿的体位也需根据护理的要求进行变换。

现有的几种装置都配有 CPAP 通气功能模式,如常频呼吸机、简易水封瓶、Infant Flow 装置(IFD)和 Benveniste 装置等,这些机器的工作原理主要是通过一定的气体流量产生治疗所需要的压力。但到达肺泡的实际气体流量主要取决于 CPAP 装置气体的泄露量,气体泄露越少,到达肺泡的气流越多。一般情况下,气流泄露的主要部位在婴儿的口、鼻和气体的输送管道等。因此,在使用 CPAP 辅助通气时,通过上述部位所泄露的气体量有时相当大,可通过测定食道或咽喉部位的压力间接评估泄露的气体流量。因此,临床上 CPAP 辅助通气时所需要维持的最佳流量,主要取决于患儿肺部病变状况、婴儿的大小、体重及各部位的漏气情况等。

CPAP 装置通常包括以下几个部分:气源、空氧混合仪、加湿加温装置、吸气和呼气管道以及压力表等,然后通过一个支架把上述几个装置固定起来,目前各种不同的 CPAP 设备间的差异主要在于呼气管道的差异。

(1)常频呼吸机的 CPAP 模式:常频呼吸机可通过调节气体的流量设定 CPAP 压力,这是目前世界范围内 NICU 常用的模式,大多数标配的呼吸机均配有 CPAP 模式,气体流量 3 ~ 10 L/min,可产生 3 ~ 10 cm H_2O 的压力。

(2)简易水封瓶 CPAP:自从上世纪 70 年代起就已经开始应用,是最简易的 CPAP 装置。方法是将气流管道浸没在一个透明的装有无菌注射用水的瓶子里,CPAP 压力的大小取决于管子浸没在水面下的深度。当气流通过密闭的水面时产生的水泡可使气流发生振荡,产生类似高频振荡呼吸机的效果,但振幅不及高频呼吸机。用水封瓶简易 CPAP 给早产儿实施辅助通气,与常频呼吸机气管插管下 CPAP 辅助通气的效果进行比较发现,前者可增加通气量,降低呼吸频率,从而减轻患儿呼吸做功和呼吸疲劳,但此项研究尚未扩大到婴儿。这种简易水封瓶 CPAP 装置的压力与管道浸没在水下的长度有关。

(3)IFD:该装置有一个专利设计,其原理是利用气流切换和射流附壁技术,通过传感器捕捉患儿的呼吸冲动,从而使机器设定的呼吸与患儿的呼吸同步。这种新型设计已经在航空动力学及喷气发动机设计领域得到应用。当液体以高速喷出时,射流因为管壁受阻,导致压力的下降,压力的下降导致射流方向的偏离和重新调整,直到射流到达管壁,这就是射流附壁技术的原理。IFD CPAP 装置发生器的工作原理就是通过利用患儿的呼吸冲动诱导射流附壁技术和触发气流切换。

当患儿发出自主呼吸冲动时,机器的流量传感器捕捉到这一变化,立即给予患儿呼吸支持,经过将空气或混合气体的流量转换为压力,通过 CPAP 装置将气体传送到患儿肺组织,机器的压力和呼吸频率是可以调节的。当患儿开始呼气时, 位于鼻部的传感器捕捉到这一压力变化,然后终止吸气,机器切换到呼气相,呼气开始。当呼气结束时,流量又切换到吸气位置。通过这样的气流切换作用,与常频呼吸机的 CPAP 模式比较,IFD 没有机械的阻力与气流干扰,所以气道阻力相对较低,气道压力较为稳定。由于 IFD 的呼出端是开放的,所以患儿在吸气时吸入的气量较大,高于吸入端实际量,主要是因为患儿吸入了部分呼出的气体,也因此减少了因为大口吸气导致的压力下降的机会,这也是 IFD 能保持系统内部压力较为恒定的原理。

将 IFD 效果与常频呼吸机 CPAP 比较,其有更强大和更稳定的肺复张作用,可更有效地减轻患儿的呼吸做功。与常频呼吸机的 CPAP 模式比较,IFD 还可降低患儿的呼吸频率和氧的需要量。有文献报道由于 CPAP 的应用减少了气管插管机械通气的机会并缩短了疾病的恢复和治疗时间,但差异尚无统计学意义。将 IFD 的通气效果与常频呼吸机 CPAP 模式比较,在降低出生体重小于 1000 g 的极低出生体重儿重新气管插管方面差异无统计学意义。其原因可能与肺组织发育不成熟,肺泡数量少以及疾病的严重程度等有关,对这些患儿予 IFD 辅助通气支持,可减少上氧的天数及缩短住院时间, 以及降低住院费用和减少相关的婴儿护理费用。

(4)Benveniste's 装置:当用 Benveniste's CPAP 通气装置给患儿进行辅助通气时,呼气孔在将气体呼出到外界环境中时,该装置的压力检测器可检测到这种压力变化,从而给呼吸频率低的患儿予呼吸辅助支持,这个装置不需要呼气管道也能够使系统维持更稳定的压力,从而降低肺的过度通气及相关并发症。但目前还没有发现有研究将 Benveniste's CPAP 装置与其他 CPAP 装置或 IFD 的效果进行比较的文献报道。

呼吸困难的新生儿其呼吸困难表现形式多样,如呼吸频率增快、呼气性凹陷、呼气时咽喉部狭窄、膈肌和肋间肌紧张, 早产儿可出现"反常呼吸",即当膈肌收缩时胸廓向内塌陷。应用 CPAP 辅助通气支持可改善患儿的呼吸,其作用机制主要是通过增加功能残气量和潮气量,从而减轻患儿呼吸功,CPAP 可通过稳定患儿上气道,有助于胸壁和膈肌的稳

定,CPAP 可增加平均气道压力,有助于肺组织的复张,降低肺组织血液灌注和通气比例失衡。CPAP 还可降低近端气道阻力, 减少生理无效腔,使胸腹呼吸运动同步,改善膈肌功能。

CPAP 辅助通气适应症为:早产儿阻塞性或混合型呼吸暂停、新生儿呼吸窘迫综合征(RDS)及其他原因导致的呼吸困难、肺不张、气管软化和其他类型的上气道阻塞、拔管后的呼吸支持等。

目前在世界范围内的 NICU, CPAP 辅助通气技术已经广泛应用于临床,且已经部分替代气管插管机械通气。对有自主呼吸的婴儿采用 CPAP 无创通气技术可避免气管插管机械通气的副作用,因为对于早产儿,喉镜下气管插管可导致氧饱和度下降、心率减慢、颅内压增加和低血压等,使患儿颅内出血和脑损伤的风险增加;另外与 CPAP 辅助通气相比,气管插管机械通气易导致肺损伤,如肺的塌陷伤、气压伤、容量伤和长时间的插管引起的气道狭窄和声门下梗阻等并发症,避免气管插管还可以降低呼吸机相关性肺炎和院内感染。

2 CPAP 的临床应用

2.1 CPAP 与 RDS

大量临床实践表明 CPAP 是治疗 RDS 的有效措施,即使是对于极低出生体重儿,CPAP 无创辅助通气不仅可用于患儿出生时复苏、早期使用,还可避免气管插管有创通气,有助于早日撤离呼吸机,且 CPAP 价格便宜,临床医师容易掌握,特别适合在发展中国家推广。但是对于中重度 RDS,单纯的 CPAP 辅助通气尚不足以解决问题。因此,对于中重度 RDS 患儿可先行气管插管给予肺表面活性物质后,再拔出气管插管行 CPAP 辅助通气。这样可能会带来由喉镜及气管插管产生的损伤及其相关的并发症,尽管存在这些风险,但可减少早产儿对呼吸机的长期依赖。有文献报道采用喷雾肺表面活性物质可避免气管插管,但早期的研究没有发现有何益处。随着越来越多的早产儿在产前母亲接受激素治疗,且在产前和围产期的状况得到改善,因此,很多患儿出生后不需要气管插管机械通气,仅给予 CPAP 辅助通气即可,尤其对于低胎龄低体重的早产儿,生后早期使用 CPAP 无创通气,可避免气管插管的损伤和潜在风险。

2.2 CPAP 与呼吸机撤离

目前临床上多主张采用 CPAP 或 CPAP + 压力支持无创辅助通气,许多的临床实践也已经证实拔出气管插管撤离呼吸机后予患儿 CPAP 通气支持,可降低患儿重新气管插管的机率。

2.3 CPAP 与复苏

CPAP 的作用,如可扩张上气道、增加肺组织的功能残气量、降低气道阻力、降低患儿呼吸作功等均有助于患儿出生后肺的扩张。CPAP 的这些作用可提高患儿复苏的成功率和减轻肺组织损伤, IFDAS 发表的临床试验研究, 将 234 名孕周 27 ~29 周的早产儿分为 4 组: a) 气管插管 + 肺表面活性物质(PS)后改用 CPAP 组; b) 早期插管预防性使用 PS + 机械通气组; c) 早期 CPAP 伴或不伴气管插管使用 PS 组;d) 在医师的指导下进行早产儿管理。研究结果发现出生后及时行 CPAP 无创辅助通气,可降低患儿气管插管机械通气的机率和缩短机械通气的时间,但不能降低支气管肺发育不良(BPD)的发生率。

2.4 CPAP 和早产儿呼吸暂停

现在临床上对于早产儿呼吸暂停的管理与 20 年前不同,早产儿呼吸暂停分三类:中枢性、阻塞性和混合型。对于中枢性呼吸暂停一直都用甲基嘌呤类药物如咖啡因治疗,鼻塞 CPAP 对于阻塞性和混合型呼吸暂停有效。对程度较轻的呼吸暂停病例,叩弹患儿后,呼吸暂停可得到缓解,但是对于较重的病例,则需要予间歇鼻塞气道正压通气(NIPPV)支持或大流量的鼻导管上氧 (1 ~2 L/min)。

NIPPV 是一种对有自主呼吸的患儿同步触发呼吸的无创通气技术,它是在 CPAP 基础上叠加的模式,有助于更好地改善通气,可应用该模式治疗早产儿顽固性呼吸暂停。两个 Cochrane 综述发现与单独应用 CPAP 比较,应用 NIPPV 有助于降低早产儿呼吸暂停的发生频率, 但对于胃肠穿孔的患儿不适于使用 NIPPV 。但截止目前,尚未见 NIPPV 引起胃肠穿孔的报道,即使在机器设定的呼吸与患儿呼吸同步时也未见发生。关于 NIPPV 改善早产儿呼吸暂停的确切机制仍不十分清楚,但与气管插管机械通气不同, NIPPV 不能直接将气体送入远端气道, NIPPV 可能只是通过影响或改变呼吸机制,从而减轻呼吸暂停。对于其治疗机制尚需要进行进一步深入的研究。NIPPV 还可用于拔出气管插管撤离呼吸机后患儿的呼吸支持。有研究表明拔管撤机后给予患儿 NIPPV 呼吸支持,与鼻塞 CPAP 比较,能减少患儿重新气管插管的机会。

2.5 CPAP 的局限性

与其他的治疗措施一样,CPAP 也有其局限性。如 CPAP 使用不当可致肺气漏、分泌物堵塞气道、鼻黏膜的损伤或不适、胃肠胀气等。肺过度通气可能与患儿呼吸增快以及哭吵有关,过度通气可使二氧化碳排出过多,导致低碳酸血症,使肺血管阻力增加,心输出量降低等,以及肺内右向左的分流,低氧血症和持续性呼吸暂停。

CPAP 对患儿心血管系统的影响可能与气道扩张压力引起 ADH 的分泌致低钠血症有关,因此新生儿医师必须认识到,随着 RDS 患儿肺扩张的改善,CPAP 的压力可传导到心脏,引起心钠素的分泌增加,过高的 CPAP 压力还可减少静脉系统血液回到心脏,从而减少心脏的搏出量。

2.6 CPAP 禁忌症

CPAP 禁忌症包括:喘息性呼吸、继发性呼吸暂停、心血管系统不稳定、上气道畸形(如后鼻孔闭锁、食管气管瘘、膈疝)、涉及脸的先天性畸形(如后鼻孔狭窄、微鼻孔、无鼻、唇腭裂)及顽固性呼吸暂停等。

2.7 CPAP 的使用步骤

(1)使用 CPAP 前首先一定要选择合适的患儿,了解 CPAP 的适应症、禁忌症和 CPAP 的局限性。

（2）CPAP 可用于下述几种情况：窒息复苏后、呼吸困难的患儿；拔出气管插管后的呼吸支持；早产儿呼吸暂停等。

（3）选择合适的 CPAP 装置，了解在何种临床状况下需将 CPAP 转为 NIPPV 模式。在作者所在的 NICU，采用 Star 牌呼吸机的 CPAP 模式，对于极低出生体重儿复杂和频发的呼吸暂停伴心动过缓，还应用 IFD。临床在使用 CPAP 时，还应注意气体的湿化加热（37°C）以减轻患儿气道黏膜的损伤和对体温的影响。

（4）选择合适的配件：文献报道双鼻塞效果最好，新型的鼻罩效果也不错，但最重要的是要培训医护人员如何安放 CPAP 和在使用 CPAP 的过程中如何加强护理，以保证最佳的通气效果，避免不必要的损伤及其并发症的发生。

（5）CPAP 的压力一般设置在 4 ~ 10 cm H_2O，压力的设置主要根据临床医师对 CPAP 掌握的熟练程度以及患儿肺扩张程度和临床状况。

（6）密切观察患儿的呼吸状况、呼吸频率、氧浓度等，如果 CPAP 应用后患儿的呼吸状况没有改善，医护人员首先需了解机器使用是否得当，如鼻塞是否脱落、上气道是否通畅等，排除这些问题后，需要立即检测患儿的血气分析、拍胸片了解肺扩张情况及机体的氧合情况。

（7）到目前为止，尚没有文献指导临床医师何时降低 CPAP 的条件或停用 CPAP。判断何时撤除 CPAP 都是基于医师的临床经验。通常的做法是待患儿临床状况改善后，先逐渐降低 PEEP，然后再逐渐改为高流量的经鼻导管给氧到低流量鼻导管给氧。

3 小结

总之，CPAP 是一种临床效果好和损伤较小的通气模式，在世界范围内的 NICU 也已经得到广泛应用。由于其价廉物美，因此尤其适合在发展中国家推广，临床医师经过培训后都能够掌握。目前很多呼吸机都配有 CPAP 模式，且有很多鼻塞或鼻罩可供选择，但是 IFD 在降低呼吸频率、氧浓度和呼吸功上优于其他 CPAP 装置，对于 RDS 恢复期或拔管初期的患儿，NIPPV 模式优于 CPAP。在对患儿实施窒息复苏、以及轻度和中度呼吸困难、呼吸暂停等的早产儿可给予 CPAP 通气支持，CPAP 的应用有助于成功拔出气管插管，降低患儿重新气管插管的机率。

（刘玲译）

（本文编辑：邓芳明）

·消息·

小儿神经系统疾病诊疗暨肉毒毒素治疗进展学习班

由首都医科大学附属北京天坛医院主办，汉唐博瑞·医学学术机构承办的国家级继续教育项目《小儿神经系统疾病诊疗暨肉毒毒素治疗进展学习班》，项目编号 2012 -06 -01 -010（京），将于 2012 年 9 月 20 日至 23 日在北京天坛医院举办，授课内容包括肉毒毒素治疗小儿脑性瘫痪研究进展、脑性瘫痪康复及高压氧治疗、脱髓鞘疾病、难治性癫痫及癫痫性脑病、周围神经病、神经肌肉疾病、脑血管病、儿童神经影像、烟雾病的内外科治疗、颅咽管瘤手术治疗及术后监护等。授课教师为小儿神经内科、神经影像、康复医学、神经外科等著名专家教授。

一、参加对象：

主要是开展小儿神经专业诊疗、运动功能障碍康复、妇幼保健科的医、技、护人员。

二、学费和学分：

学费 1200 元（含 220 元讲义费）。食宿统一安排，费用自理。并授予国家继续教育 I 类学分 10 分（30 学时）。

三、详情请联系：

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