

The Use of Bubble CPAP in Premature Infants: Local Experience

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Abstract Bubble continuous positive airway pressure (CPAP) was introduced more than 30 years ago for infants with respiratory distress. With this, there had been reports of decreased incidence of mechanical ventilation and chronic lung disease among the premature, as well as less failure of extubation. This report described how this treatment modality was adopted locally and showed it might be associated with less apnoea among very low birth weight (VLBW) and extremely low birth weight (ELBW) infants post extubation with improved non-pulmonary outcomes.

Key words Apnoea of prematurity; Bubble CPAP; Chronic lung Disease; ELBW babies; VLBW babies

Introduction

Continuous positive airway pressure (CPAP) is a method of delivering positive end-expiratory pressure with a variable amount of oxygen to the airway of a spontaneously breathing patient to maintain lung volume during expiration, so as to reduce atelectasis, respiratory fatigue and to improve oxygenation. It was first reported in 1971 for supporting breathing of preterm neonates.¹ Clinical benefits have been associated with the use of CPAP in the premature newborn. Even in the pre-surfactant era and when antenatal steroid usage was uncommon; there was some evidence that early application of CPAP might reduce subsequent use of mechanical ventilation and the associated adverse outcome.² Infants extubated to nasal CPAP experienced a reduction in respiratory failure necessitating assisted ventilation.³

CPAP system consists of a source of humidified blended oxygen, the pressure generator and the airway interface

device. Pressure can be generated from the following three ways.⁴

Firstly, the expiratory valve of the ventilator is used to adjust the expiratory pressure. Secondly, the pressure is generated by adjusting the inspiratory flow or altering the expiratory resistance (e.g. Infant Flow[®] Nasal CPAP system, VIASYS Healthcare, Inc. USA). Thirdly, the bubble CPAP system produces a positive pressure by placing the far end of the expiratory tubing under water. The pressure is adjusted by altering the depth of the tube under the surface of the water.

In the seventies, Dr. Jen-Tien Wung at the Columbian Presbyterian Medical Center, New York developed the bubble CPAP system using short nasal prongs. In 1987, Avery et al⁵ published a retrospective study of 1625 neonates at eight tertiary centers. Columbia University, where the predominant mode of respiratory support was the use of nasal CPAP, had the lowest incidence of chronic lung disease (CLD) without any significant difference in mortality.

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The Bubble CPAP System

Essentially, the bubble CPAP system consists of three components: a continuous gas flow into the circuit, an expiratory limb with the distal end submerged into a liquid to generate positive end expiratory pressure,⁶ and the nasal

interface connecting the infant's airway with the circuit (Figure 1). As the gas leaves the circuit via the expiratory limb, it bubbles (Figure 2).

Oxygen blender connected to wall oxygen and compressed air supply is used for supplying appropriate concentration of inspired oxygen. Optimal gas flow is maintained with a flow meter to prevent rebreathing of carbon dioxide, increased work of breathing related to insufficient flow available for inspiration and to compensate for leakage in the CPAP system.^{7,8} Flow rate of 5 to 10 liters per minute is optimal for CPAP delivery in the neonates.⁸

Pressure in the bubble CPAP system is created by placing the distal expiratory tubing in water. Designated pressure is determined by the length of expiratory limb being immersed.⁸ When the pressure is delivered to the baby



Figure 1 The nasal interface



Figure 2 The expiratory limb

without leakage, it results in continuous bubbling and the pressure oscillates in the circuit.⁹ Leakage is not obvious in ventilator (Infant Star) CPAP. Though the pressure oscillation was once suggested to facilitate gas exchange,¹⁰ this postulation was not supported in another recent report.¹¹

Short binasal prongs are commonly used for the nasal interface between the circuit and the infant's airway as they are found to have the lowest resistance¹² and their use has been supported by a meta-analysis as the better device for delivery of effective CPAP.¹³ Choosing the right prong and keeping it in place not only increase the effectiveness of CPAP support but can also prevent nasal trauma. The resistance increases proportionately with increasing length of the prongs and exponentially with decreasing radius. Shorter and wider binasal prongs that can fit snugly in the nares without causing blanching of the skin is a good option. Hudson[®] (The Hudson RCI infant nasal CPAP cannula system, Teleflex Incorporated, USA) and Inca[®] (Ackrad Laboratories, Cranford, N.J., USA) prongs are similar in design. Similar sized prongs (actual measured size, not nominal size as designated by the manufacturer) of either type are likely to have similar resistance. Inca prongs are straight, whereas Hudson prongs are anatomically curved. Theoretically, the latter might fit the airway better, directing the flow more appropriately down the airway.

Nursing Care of Infants on Bubble CPAP

Elaborate nursing care is pivotal for the success for applying bubble CPAP to premature infants. Proper positioning of the prongs can be secured by putting on an appropriate size hat which rests along the lower part of the infant's ears and across his forehead with the circuit fastened on it. It has to be snugly fitted and stationed on the infant's head, otherwise the circuit and the prong will move with the motion of the loosely fit hat. Tissue necrosis was observed if one was unable to keep the prong in the nostrils of an active infant.¹⁴

Nasal trauma is common when the prong rests on the septum of the nose or on the columella.¹⁵⁻¹⁷ Application of a Velcro mustache placed over a piece of Duoderm on the philtrum can prevent the accidental incarceration of the prong onto the nasal septum or the columella. Besides, adequate airway humidification and gentle nasal suctioning is paramount in maintaining a clear airway without jeopardising the tissue integrity of the nostrils. Lightweight ventilator circuits with dual heated wire

(e.g. Airlife®, Allegiance Healthcare Corp., USA) and servo-regulated humidification system is necessary for the delivery of warm and humidified inspired gas to the CPAP supported infant.¹⁸ "Rain-out" (condensation) affects the gas flow and resistance. It should be checked and drained regularly. The probe and chamber temperature and the positioning of the temperature probe can be manipulated to minimise the "rain-out".

Consistent bubbling is important to recruit alveoli, maintain functional residual capacity, and reduce airway resistance and work of breathing, especially in the early acute phase of respiratory distress. If the bubbling stops it means that there is a pressure leak in the system, usually around the nostrils. It has been reported that the pharyngeal pressure drops markedly when the CPAP supported infant opens his mouth.¹⁹ Recent study demonstrated that the prong pressure, though not totally transmitted to the pharynx, was more effectively transmitted when the mouth was closed.²⁰ The use of chin strap or pacifier has been recommended to reduce mouth leak for effective CPAP support.²⁰ However, it should not be so tight as to prevent the infant from yawning or crying but tight enough to prevent leaking at rest.

The infant's respiratory status has to be assessed at regular interval to evaluate effectiveness of the treatment and plan for subsequent care. CPAP has to be temporarily interrupted during chest auscultation as the bubbling sound may interfere. However, caution has to be taken as the infant may present with apnoea and bradycardia when CPAP support is suspended for just a brief period.

Gastric distension is common in the CPAP supported infant (CPAP Belly Syndrome).²¹ Frequent decompression of the stomach with an oro-gastric tube is necessary to promote comfort, preventing the distended stomach from splinting the diaphragm and compromising respiration.

The bubble CPAP system and practice of the Columbia University were introduced to the Neonatal Intensive Care Unit of United Christian Hospital, Hong Kong in October, 2002. A retrospective survey with historic control was carried out after the change to evaluate the effects of bubble CPAP on the respiratory and non-respiratory outcomes in premature infants in the unit.

Patients and Methods

The short term outcome of CPAP supported premature infants who were delivered in United Christian Hospital with birth weight less than 1499 gram born between

October, 2000 and end of March, 2002 (Period 1) were compared with those born between October, 2002 and end of March, 2004 (Period 2). Babies with major congenital anomalies such as cranio-facial cleft or requiring transfer to other centres for various reasons were excluded.

This study aimed to evaluate the following respiratory outcomes after the change:

1. duration of mechanical ventilatory support
2. number of infants who required mechanical ventilation within 24 hours after extubation (failed extubation)
3. duration of CPAP support
4. number of days with significant apnoea (cessation of respiration ≥ 15 seconds with $\text{SaO}_2 < 50\%$ and associated with bradycardia, heart rate < 100 beats per minute) during CPAP
5. duration of oxygen therapy
6. the postmenstrual age (PMA) of the infants when oxygen therapy was terminated
7. number of infants requiring $\text{FiO}_2 > 30\%$ at PMA of 36 weeks.

The non-respiratory outcomes were also reviewed which included:

1. duration on total parenteral nutrition (TPN)
2. postnatal age of the infants when full enteral feeding was tolerated
3. number of infants with necrotising enterocolitis (NEC)
4. number of infants with grade 3 to 4 intraventricular hemorrhage (IVH)
5. body weight at PMA of 36 weeks

During both study periods, there was no major change in technology and medical management of the premature infant in the unit. The only difference was the use of bubble CPAP in Period 2 which substituted for the ventilator (Infant Star®, Tyco Healthcare) CPAP support in Period 1. All of the study population except 6 very low birth weight (VLBW) infants, 3 in each period, required intubation. They were extubated and maintained on CPAP when their synchronised intermittent ventilator (SIMV) settings were < 10 breaths per minute, peak inspiratory pressure (PIP) was < 15 cmH_2O , positive end-expiratory pressure (PEEP) was 5 cmH_2O , fractional inspired oxygen (FiO_2) was < 0.3 with no respiratory acidosis and minimal respiratory distress. Apnoea, cessation of respiration for 15 seconds or more with or without desaturation ($\text{SaO}_2 < 90\%$), and cardio-respiratory status of the subjects were monitored continuously with physiological monitors (Spacelab Healthcare). During the study periods, caffeine citrate was

given to infants with repeated apnoea (i.e., more than three apnoea episodes per hour) with $\text{SaO}_2 < 50\%$ or they required frequent bag and mask ventilation. Reintubation was considered when infants on CPAP developed marked retraction, FiO_2 requirement > 0.6 with $\text{PaO}_2 < 50$ mmHg, $\text{PaCO}_2 > 65$ mmHg with intractable metabolic acidosis, prolonged apnoea with $\text{SaO}_2 < 50\%$ and required bag and mask ventilation, frequent apnoea not responsive to drug therapy or at the discretion of the attending clinician depending on the infant's clinical status. Infants without significant retractions would be weaned off from CPAP when their FiO_2 requirement < 0.3 , free from apnoea for 24 hours and tolerated gentle nasal-pharyngeal suctioning without increasing FiO_2 requirement with CPAP removed.

Two babies, one with cranio-facial cleft in Period 1 and one baby required interhospital transfer in Period 2 were excluded in the study. A total of 80 infants were analysed and they were further stratified into the very low birth weight (VLBW) group with birth weight between 1000 gram to 1499 gram and the extremely low birth weight (ELBW) group with birth weight less than 1000 gram. The outcomes of 45 VLBW and 35 ELBW premature infants were reviewed. Results were analysed by the independent sample *t*-test for normally distributed continuous variables, Chi Square analysis for dichotomous variables and Mann-Whitney *U*-test for non-parametric data at the 5% significance level.

Results

There was no difference in the characteristics of both

groups of premature infants between the two study periods (Table 1). Around 85% of the VLBW infants and all of the ELBW infants were initially intubated in both study periods. The infants in Period 2 were extubated to bubble CPAP and those in Period 1 were given ventilator (Infant Star) nasal CPAP post extubation.

In the VLBW group, there was no difference in duration of mechanical ventilatory support or extubation failure in both study periods. Though the duration of CPAP was significantly shorter in babies in Period 1, the number of days with significant apnoea during bubble CPAP was significantly less (Table 2). There was no difference in duration of oxygen support in both periods and the infants were weaned off oxygen at the mean PMA of 35 weeks. Around 20% of the VLBW infants required oxygen support greater than 30% at PMA of 36 weeks. However, all of them survived and could successfully wean off oxygen therapy before PMA of 40 weeks.

Similar results were obtained in the ELBW group (Table 3). There was no significant difference in failed extubation and duration for mechanical ventilation. Again, there was a significantly longer duration of CPAP support in Period 2. The number of days with significant apnoea during bubble CPAP was significantly less during Period 2. There was no difference in duration of oxygen support in both periods and the neonates were weaned off oxygen at the mean PMA of 39 weeks. Thirty percent of ELBW infants in both study periods require oxygen therapy greater than 30% at PMA of 36 weeks. The majority of them could be weaned off oxygen successfully at PMA of 44 weeks. The longest duration of oxygen therapy in ELBW in Period 1 and 2 were PMA of 64 weeks and PMA of 54 weeks respectively.

Table 1 Characteristics of the study infant

	VLBW (N=45)		P	ELBW (N=35)		P
	Period 1 (N=21)	Period 2 (N=24)		Period 1 (N=19)	Period 2 (N=16)	
Gestation in weeks (mean±SD)	30.36±1.87	30.44±1.89	0.89	26.7±2.69	27.3±1.78	0.45
Birthweight in gram (mean±SD)	1243.71±162.29	1226.79±155.94	0.72	765.63±136.13	828.44±102.61	0.14
Number of males (%)	12 (57%)	13 (54%)	0.84	9 (47.37%)	7 (43.75%)	0.83
Antenatal steroids						
None (%)	1 (4.76%)	1 (4.17%)		1 (5.26%)	1 (6.25%)	
Partial (%)	7 (33.33%)	6 (25%)	0.54	8 (42.11%)	5 (31.25%)	0.61
Complete (%)	13 (61.9%)	17 (70.83%)		10 (52.63%)	10 (62.5%)	
Apgar score 1 minute (mean±SD)	7.14±2.67	7.25±1.68	0.87	5.67±2.17	6.19±2.14	0.49
Apgar score 5 minute (mean±SD)	8.62±1.6	8.79±0.88	0.65	7.56±1.46	8.25±1.07	0.13
No. with intubation (%)	18 (85.71%)	21 (87.5%)	0.86	19 (100%)	16 (100%)	NS
No. given surfactant (%)	18 (85.71%)	19 (79.17%)	0.79	19 (100%)	16 (100%)	NS

NS, not significant

The non-respiratory outcome of both groups of premature infants was similar (Tables 4 & 5). As soon as the infants were medically stable, trophic feeding was instituted. In both study periods, when the infants tolerated

enteral feeding as measured by gastric residue less than half of the feeding volume with no vomiting or gastric distention, total enteral feeding was gradually advanced by 10 ml to 20 ml/kg/day. Both groups of infants who were

Table 2 Respiratory outcome of the VLBW infant (N=45)

	Period 1 (N=21)	Period 2 (N=24)	P
Duration of mechanical ventilation in days (mean±SD)	2.17±2.44	3.43±11.47	0.6
No. of failed extubation (%)	0 (0%)	0 (0%)	NS
Duration of CPAP support in days (mean±SD)	7.97±10.21	18.34±14.93	0.009
No. of days with significant apnoea during CPAP (mean±SD)	2.29±3.52	0.54±1.32	0.029
Duration of oxygen therapy in days (mean±SD)	32.45±22.15	28.23±7.47	0.48
PMA off oxygen (mean±SD)	35.04±2.61	34.55±2.14	0.496
No. required FiO ₂ > 0.3 at PMA 36 weeks (%)	5 (23.81%)	5 (20.83%)	0.88

NS, not significant; PMA, postmenstrual age

Table 3 Respiratory outcome of the ELBW infant (N=35)

	Period 1 (N=19)	Period 2 (N=16)	P
Duration of mechanical ventilation in days (mean±SD)	21.51±24.66	15.67±16.48	0.097
No. of failed extubation (%)	1 (5.26%)	0 (0%)	0.81
Duration of CPAP support in days (mean±SD)	20.29±15.85	38.44±18.08	0.004
No. of days with significant apnoea during CPAP (mean±SD)	6±6.18	2.1±2.9	0.028
Duration of oxygen therapy in days (mean±SD)	87.41±57.92	87.38±48.35	0.778
PMA off oxygen (mean±SD)	39.88±6.91	39.21±6.62	0.616
No. required FiO ₂ >0.3 at PMA 36 weeks (%)	7 (36.84%)	5 (31.25%)	0.736

PMA, postmenstrual age

Table 4 Non-respiratory outcome of the VLBW infant (N=45)

	Period 1 (N=21)	Period 2 (N=24)	P
Duration on TPN in days (mean±SD)	28.2±9.7	15.6±4	<0.01
Age when full enteral feeding tolerated in days (mean±SD)	28.3±10.4	16.4±4.6	<0.01
Necrotising enterocolitis (%)	2 (9.52%)	0 (0)	0.23
No. with IVH grade 3-4 (%)	0 (0)	0 (0)	NS
Body weight at PMA 36 weeks in gram (mean±SD)	2061.24±317.04	2232.71±443.21	0.14

TPN, total parenteral nutrition; PMA, postmenstrual age; IVH, intraventricular haemorrhage; NS, not significant

Table 5 Non-respiratory outcome of the ELBW infant (N=35)

	Period 1 (N=19)	Period 2 (N=16)	P
Duration on TPN in days (mean±SD)	47.7±22.8	31.6±13.2	0.018
Age when full enteral feeding tolerated in days (mean±SD)	46.4±20.2	31.1±11.7	0.012
Necrotising enterocolitis (%)	1 (6.25%)	0 (0)	0.29
No. with IVH grade 3-4 (%)	2 (10.53%)	0 (0)	0.17
Body weight at PMA 36 weeks in gram (mean±SD)	1734.83 ± 406.57	1935.63 ± 394.17	0.154

TPN, total parenteral nutrition; PMA, postmenstrual age; IVH, intraventricular haemorrhage

on bubble CPAP had shorter duration of TPN support and they could tolerate full enteral feeding sooner. Most important of all, there was no increase in incidence of IVH. No baby on bubble CPAP suffered from NEC. These were consistent with the findings reported in 2001 at New Zealand.²²

No infant had any injury or trauma to the nose. No significant airleak was encountered in both study periods.

Discussion

When bubble CPAP was used after extubation in our unit in Period 2, the neonates had significantly less number of days with significant apnoea, although they were on CPAP for longer duration. There was no significant difference in other respiratory outcomes in the VLBW and ELBW babies in the two time periods. The bubble CPAP supported premature infants achieved full enteral feeding earlier, thus the duration for TPN was significantly reduced. This might be related to the decrease in significant apnoea, which is a sign of medical instability for which the attending clinician might be more cautious in increasing the amount of enteral feeding. Nevertheless, we are aware that the small sample size and the retrospective nature of this case-control study impose important limitation.

In 2000, Van Marter²³ observed marked differences in the incidence of CLD at Columbia University (4%) vs that at two Boston hospitals (22%). With bubble CPAP, newborns at Columbia University were less likely to require mechanical ventilation, and those who did were ventilated for significantly shorter time. There were no differences in short-term morbidities such as periventricular leukomalacia (PVL) and IVH between centres.

De Klerk AM and de Klerk RK published another retrospective study in 2001 suggesting that the use of a CPAP based approach to respiratory support of the preterm infant resulted in a shorter and less invasive respiratory course, less chronic lung disease at 28 days and no increase in non-respiratory morbidities, such as the NEC, grade 3-4 IVH, PVL and stage 3 or worse retinopathy of prematurity (ROP) in infants of 1000-1499 g birthweight.²²

More than 85% of our VLBW and 100% of our ELBW babies were intubated early whereas Columbia University places all spontaneously breathing infants on bubble CPAP as the first mode of respiratory support. The early initiation of bubble CPAP, in combination with a tolerance to higher PCO₂ level might be associated with a lower incidence of CLD to <5% in babies <1500 g there.⁸

A recently published retrospective case-control study from the Netherlands also suggested that a trial of early nasal CPAP, using nasopharyngeal tube or the Infant Flow[®] system, at birth might reduce the incidence of moderate to severe CLD and did not seem to be detrimental in very preterm infant. Thirty-three percent of the very preterm infants (25-32 weeks) were successfully managed with CPAP alone.²⁴ Whether bubble CPAP in the delivery room management of the premature babies will demonstrate differences in chronic lung disease or death at 36 weeks adjusted age may be addressed in multi-centers randomised trials such as the one by the Vermont Oxford Network.

With our experience, we conclude that there was no increase in adverse respiratory outcome in the unit after the change from ventilator CPAP to bubble CPAP. Bubble CPAP is safe to use and it appeared to be associated with less apnoea and more favorable non-respiratory outcome. However, because of the small sample size, a larger scale prospective study is warranted to determine the long term benefits.

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