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Chapter 4

CPAP Technology: Where Affordability Meets Utility

Jacob M Puliyel, Neeraj Gupta

HISTORICAL BACKGROUND

Ventilation of newborns is now so commonplace that it is difficult to remember that this facility is relatively new. As recently as in 1963, according to an obituary in the New York Times, when Patrick Kennedy was born at 35 weeks (weight 1.8 kg) and had respiratory distress (RDS) [due to surfactant deficient hyaline membrane disease (HMD)] there was little that could be done other than to monitor the baby. Patrick was the son born to President John F Kennedy and First Lady, Jacqueline Bouvier Kennedy. He died of the RDS on the second day. This event focused attention on the problem of prematurity more than anything else and gave impetus for the development of newborn ventilators. From then on we have made great strides.

In 1971, Gregory and colleagues[1] described a simple apparatus to deliver continuous positive airway pressure (CPAP). High pressure oxygen was delivered to the nasopharynx of the baby with a under water T tube interposed in-between, to act as a blow-off valve. Adjusting the height of the water column above the vertical limb of the T tube could regulate the pressure delivered to the baby (Fig. 4.1).

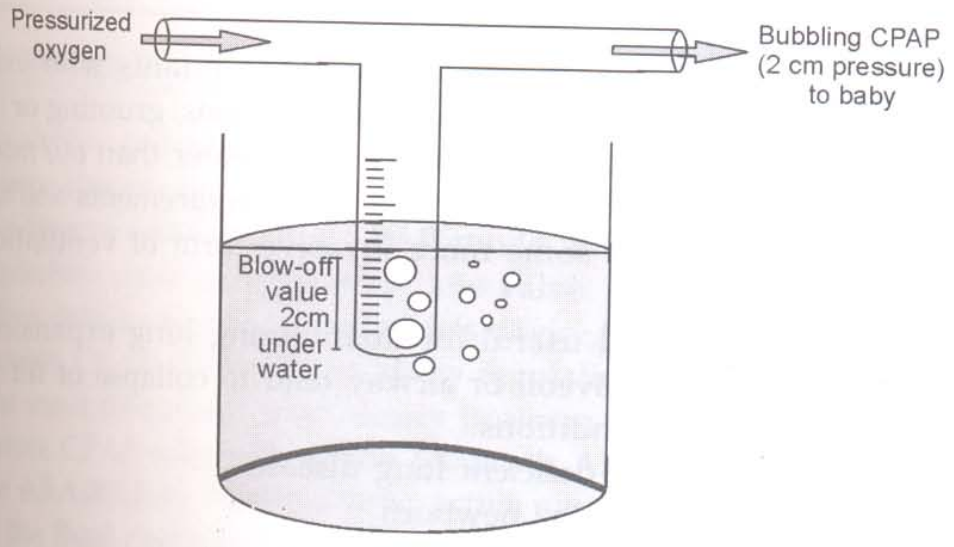

Fig. 4.1: Bubbling CPAP apparatus

It worked well, but soon this crude system was overtaken by more sophisticated ventilators capable of a bewildering range of ventilatory modes. Later it was realized that one-third of all infants who had RDS, and were intubated and ventilated, developed some degree of chronic lung disease.[2] Nasopharyngeal CPAP (NCAP) is less likely to damage the lungs or the airways and as such it remained the favored option in some neonates. Sophisticated machines called flow drivers to deliver NCPAP at constant pressure, where air could be enriched with oxygen in a calibrated manner and delivered to the baby after it was warmed and humidified, were devised as a mode of non-invasive ventilation, to minimize the harm to the infants lungs.

In 1983, two groups of researchers reported on pulmonary gas exchange using high frequency ventilation with very small tidal volumes.[3,4] Following this discovery of high frequency ventilation, interest in the Gregory CPAP model was revived, and it was realized that 'constant pressure CPAP' was not necessarily the best available option. It was realized that the 'bubbling CPAP' of Gregory resulted in a form of oscillatory pressure wherein mechanical vibrations were transmitted to the chest, secondary to non-uniform flow of gas bubbles across the downstream of the water seal[5] and this was similar to the waveforms produced by high-frequency ventilation recorded by transducers attached to the infant's airway. The chest vibrations produced contributed to gas exchange by facilitated diffusion.[6] When using bubbling CPAP vigorous high-amplitude bubbling compared to slow bubbling CPAP did not result in any significant difference with regard to respiratory rate, pulse oximetry and transcutaneous carbon dioxide tension.[7] The era of 'bubble CPAP' had begun.

INDICATIONS FOR CPAP

CPAP is indicated in spontaneously breathing infants who exhibit increased work of breathing[8] in the form of retractions, grunting or nasal flaring, or frequent apnea. A respiratory rate greater than 60/minute, preductal oxygen saturation <93% and oxygen requirements >60%, are indications that CPAP or some more invasive form of ventilation is needed.

CPAP has been found useful for maintaining lung expansion in conditions in which the alveoli or airway tend to collapse or fill with fluid in the following conditions:

- RDS due to surfactant deficient lung disease
- Transient tachypnea of the newborn
- Recent extubation

- Meconium aspiration syndrome
- Infant needing weaning from the ventilator
- Pulmonary edema and congestive cardiac failure
- Pulmonary hemorrhage
- Phrenic nerve palsy
- Apnea of prematurity – obstructive or mixed apnea.
- Tracheomalacia
- Laryngomalacia
- Bronchomalacia

How it Works

- CPAP increases functional residual capacity and prevents alveolar collapse. This allows a greater tidal volume for a given pressure change with subsequent reduction in the work of breathing and stabilization of minute ventilation (V_E).[9]
- It also diminishes alveolar edema and conserves surfactant on the alveolar surface.[10] The improved oxygenation brings down pulmonary vascular resistance which reduces right to left shunting including intrapulmonary shunts and these further improve oxygenation.[11]
- It dilates the larynx and reduces supraglottic airway resistance and it lessens the incidence of obstructive apnea.[12] It stimulates the Hering-Breuer reflex and regulates and slows respiratory rate.[13]
- In apnea of prematurity it stimulates breathing and helps maintain airway patiency.[14]
- A cochrane systematic review showed it is effective in preventing extubation failure (RR 0.57, CI 0.46-0.72). The absolute risk difference was 0.2 and the numbers needed to treat with CPAP to prevent one extubation failure is 5.[15]
- It stimulates increased lung growth (volume and weight).[16,17]

CPAP DEVICES

CPAP can be generated by a number of devices besides the Gregory apparatus (otherwise called Hudson CPAP) described above.

- Ventilators often have a CPAP mode which works by restricting expiration with an expiratory flow valve.
- Other devices like the Benveniste's device,[18] Medijet system and the Carden CPAP device all work by regulating inflow rate.
- The most frequently used steady pressure device is the Infant Flow Driver CPAP called Hamilton Medical's ALADDIN (now known as the ARABELLA). This dynamic, active nasal-CPAP device makes use of the fluid characteristics called the fluidic flip and Coanda effects.

When patient makes a spontaneous inspiratory breathing effort, gas is entrained helping to create a stable mean airway pressure (Fig. 4.2).

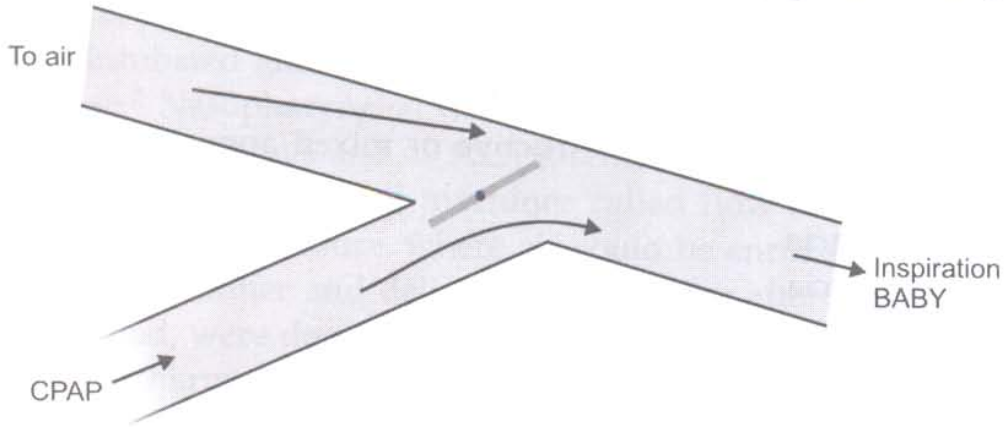

Fig. 4.2: CPAP gas flow during inspiration

When the patient makes a spontaneous expiratory breathing effort, it causes the flow to flip round and leave the generator via the expiratory limb (Fig. 4.3). CPAP pressure is maintained at the nasal connection throughout. When the expiratory breathing effort stops, the flow instantly flips back to the inspiratory position.

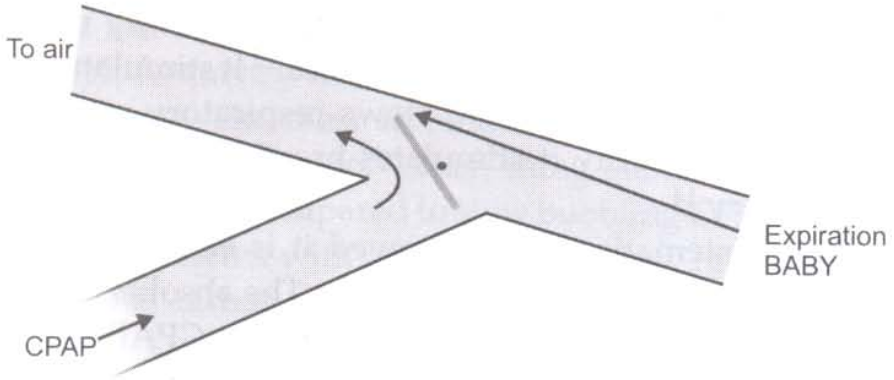

Fig. 4.3: Entrained CPAP gas during expiration

DELIVERY SYSTEMS

CPAP can be delivered by any of the following:

- Face mask
- Head box with seal
- Nasopharyngeal tube
- Nasal prongs (*Single prong "mononasal CPAP" or Double prong "Binasal CPAP")*
- Nasal masks,
- Nasal cannulae
- Endotracheal tube

Early nasal masks lost popularity because of the difficulty in maintaining an adequate seal and tendency to cause airway obstruction.

Short bi-nasal prong devices are more effective than single prongs in reducing the rate of re-intubation. The improvement in respiratory parameters with short bi-nasal prongs suggests they are more effective than nasopharyngeal CPAP in the treatment of early RDS.[19]

However Buettiker et al found CPAP-duration was shorter in very low birth weight infants, when nasopharyngeal prong was used rather than binasal prongs.[20] Nasopharyngeal tubes are less expensive and more widely available and work reasonably well.[21]

The hood CPAP system may represent a potential improvement, as it allows good transmission of the applied pressure without the possible dislodgement of nasal prongs thereby avoiding nasal trauma.[22]

Pharyngeal pressures may fall significantly if the mouth is open slightly. Chin straps have been used to avoid the fluctuations in the delivered pressure seen with intermittent mouth opening.[23,24]

HUMIDIFIERS (Fig. 4.4)

Inspiratory gases are best delivered at or close to body temperature and saturated with water vapor. Whenever saturated air leaves the

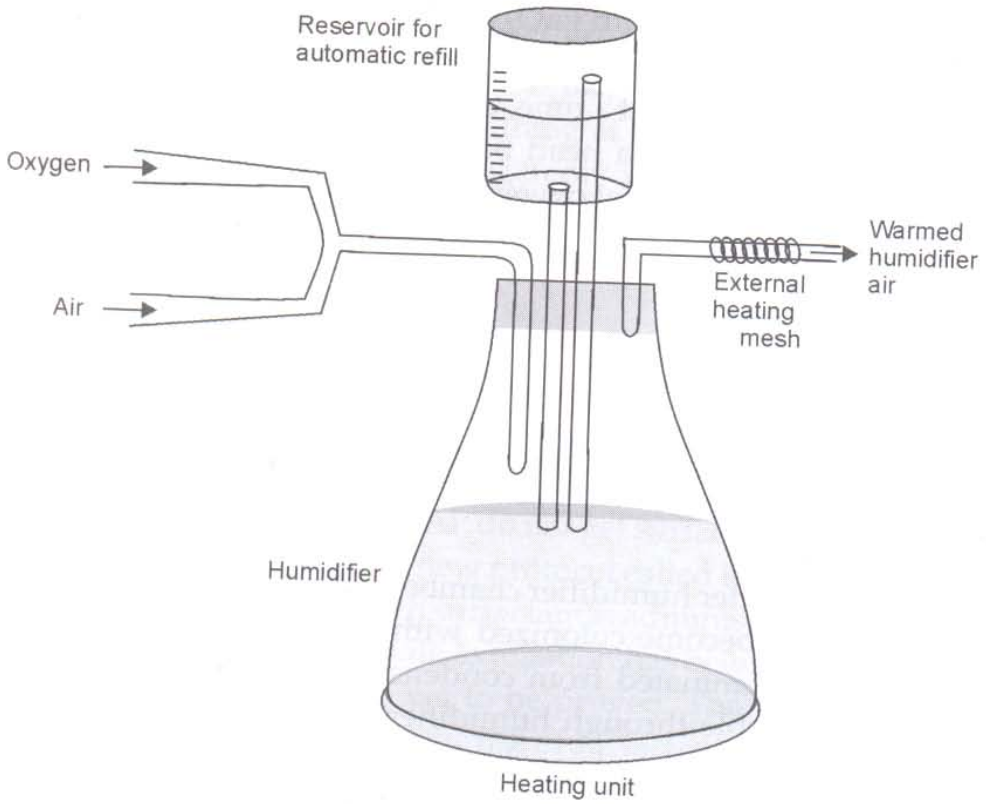

Fig. 4.4: The fully autoclavable humidifier-unit with automatic refill and external tube heating mesh

humidifier chamber at 37°C it tends to condense in the tubing. Heated wires are used within the tubing to prevent this. If these are not available, water traps are included in the dependent part of the circuit to hold the condensate. The water vapor by itself does not promote nosocomial infection but the water in the humidifier and condensate are known to become colonized with infectious agents.[25] The colonization risk may be reduced by the use of sterile closed delivery systems.[26]

Optimizing CPAP Levels

Optimal CPAP pressure is defined as the level of CPAP that produces the highest PaO_2 without complications. No simple and reliable method has been found to detect the optimal CPAP level.

If the infant has stiff lungs or low lung volumes, increase the CPAP pressure from 4 to 5 cm up to 8-10 cm H_2O is recommended. If the pressure is too high over-distension may occur and oxygenation and CO_2 removal may be compromised. Increasing pressure increases CO_2 retention, so there is a trade-off between improving oxygenation and a rise in the CO_2 concentration. If a baby is being treated with CPAP and CO_2 concentrations are high, then reducing the pressure may improve the CO_2.

Weaning from Nasal CPAP

Once the patient is stable with PaO_2 60-70 mm Hg, one can start to wean the FiO_2. Once FiO_2 is down to 40%, start to wean pressures. CPAP may be reduced by 1-2 cm H_2O at a time. Once CPAP is down to 3 cm of water the infant may be kept in a head box with 10% FiO_2 than the FiO_2 on CPAP. The alveolar to arterial oxygen ratio needs to be monitored as also the work of breathing.[27]

Problems with CPAP

- Infection related to CPAP
- Nasal septum damage
- Abdominal distension and feeding intolerance
- Pulmonary air leaks
- Excessive noise

Cold and hot water humidifier chambers, ventilator circuits and circuit condensates may become colonized with infectious agents and airway may become contaminated from condensate flushed inadvertently into the airway. A bubble through humidifier may not only produce water vapor but also some aerosol capable of dispersing infectious particles.[25]

Nasal trauma is reported commonly with dual prongs as high as 20 to 32%.[28,29]

In a study the mean noise level was 88.6 (SD 18.8) dB using CPAP and often it was higher than occupational limits accepted for adult workers.[30]

Abdominal distension and feed intolerance is quite common with CPAP. Gastric decompression is often all that is needed.

Pulmonary air leaks are not uncommon,[31] and may need chest drains.

Failure of CPAP: When to Switch to Mechanical Ventilation

- $PaO_2 < 50$ mm Hg while breathing 80-100% oxygen $PaCO_2 > 65$ mm Hg
- Persistent metabolic acidosis with base deficit of > -8
- Marked retraction on cpap, frequent apnea and bradycardia.

EBM AND CPAP

The incidence of BPD has reduced with increased use of CPAP and there is reduced use of more invasive therapies.[32] Ho et al found CPAP associated with a lower rate of failed treatment (death or use of assisted ventilation) overall mortality.[31]

The COIN study showed that in infants born 25-28 weeks gestation, early nasal CPAP did not significantly reduce death rate or bronco-pulmonary dysplasia as compared with intubation. The CPAP group had more incidences of pneumothorax yet fewer infants received oxygen at 28 days, had fewer days ventilated. 46% infants in the CPAP group were intubated and ventilated in the first 5 days and the use of surfactant was halved. 27-28 week infants breathing at birth benefit the most from NCPAP. Fewer infants received oxygen on day 28; they had fewer days of ventilation and no increase in morbidities despite having more pneumothoraces.[33]

Surfactant, INSURE and NCPAP

Nasal continuous positive airway pressure (NCPAP) is an effective treatment of respiratory distress syndrome and the reduced use of mechanical ventilation has reduced rates of bronchopulmonary dysplasia. However, babies put on early CPAP do not get surfactant therapy because such babies are not intubated. A new protocol called INSURE (INtubation SURfactant Extubation), in which surfactant is administered during a brief intubation followed by immediate extubation has been introduced.[34] The benefits of such a protocol are yet to be proved. The CURPAP study is now underway to see if prophylactic use of surfactant in this context using the INSURE protocol confers any benefits to the neonate compared to early CPAP. The jury is yet out on this.[35]

APPROPRIATE TECHNOLOGY FOR DEVELOPING COUNTRIES

Bubble CPAP is available off the shelf in India but it costs over Rs 1,50,000. A do-it-yourself system to deliver CPAP was described in the *Indian Pediatrics*.[36] The humidifier required is available at Appropriate Technologies Jan Swasthya Sahyoj (1626/33 First floor, Naiwala, Karol Bag, New Delhi. This humidifier costs Rs 5000 compared to the branded variety that costs over Rs 50,000 and it has the added advantage of the unit being autoclavable for sterilization (Fig. 4.5). This reduces the infection risk. It is hoped the system can be used to save newborn lives in developing and resource poor countries.
Patent A/F 907/DEL/2008

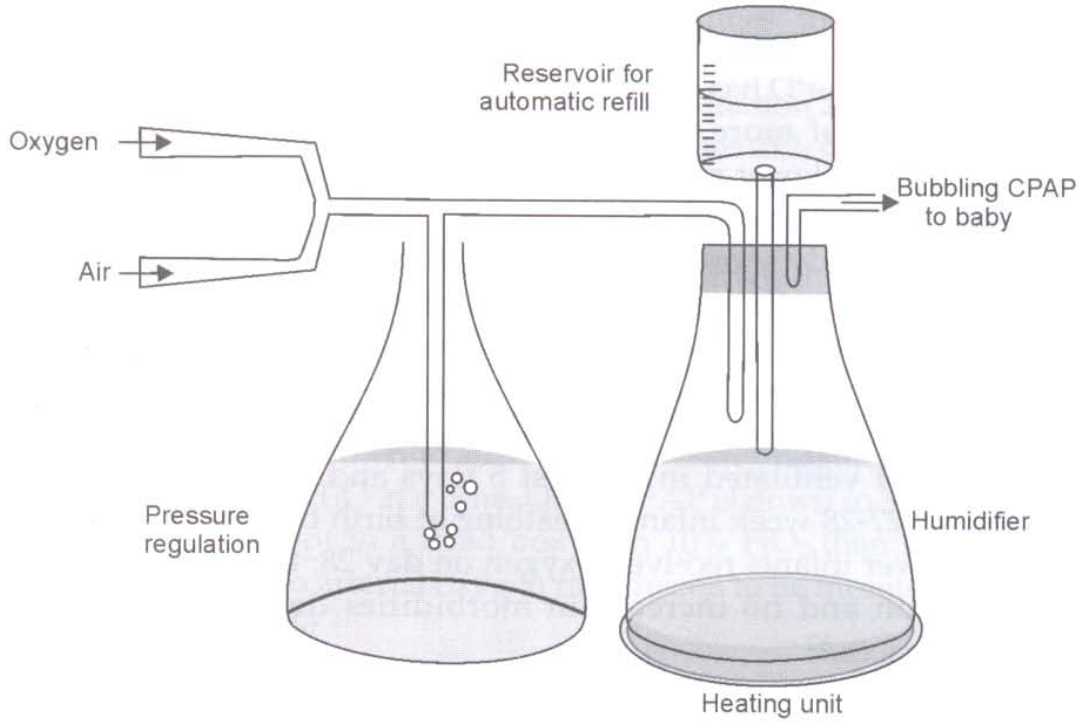

Fig. 4.5: The complete bubbling CPAP unit

KEY LEARNING POINTS

- CPAP is indicated in spontaneously breathing infants who exhibit increased work of breathing in the form of retractions, grunting or nasal flaring or frequent apnea.
- A locally fabricated do-it-yourself system to deliver CPAP using a humidifier costing just Indian Rs. 5000 may well be a good alternative to the costly Bubble CPAP available at Indian Rs 1,50,000.

- The do-it-yourself system has the added advantage of the unit being autoclaved for sterilization, thereby cutting down the risk of infection.
- The projected system can be employed to save critica lly ill neonates in developing and source poor countries.

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