

# CPAP: a guide for clinicians in developing countries

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Despite the provision of oxygen, antibiotics and treatment guidelines, the case fatality rate for hypoxaemic pneumonia is still high in many hospitals in developing countries. Methods of delivering continuous positive airway pressure (CPAP) are now available which are simple to use, safe and relatively inexpensive. This paper describes two methods which may be appropriate where resources are limited: (i) bubble-CPAP using oxygen concentrators with an air-oxygen mix function and low resistance nasal oxygen prongs, and (ii) high-flow nasal cannula oxygen therapy. More research is needed on the implementation, cost and effectiveness of CPAP in the management of pneumonia and in neonatal care in developing countries.

**Keywords:** CPAP, Pneumonia, Bronchiolitis, Acute respiratory infection, Neonatal care, Oxygen therapy, Respiratory distress, District hospitals

## Introduction

Every year, about 1.3 million children die from pneumonia or other acute respiratory infections,<sup>1</sup> and 11–20 million children are admitted to hospital with pneumonia.<sup>2</sup> Hypoxaemia or respiratory failure is the major fatal complication of pneumonia and a major risk factor for death. It is estimated that at least 13% of children with severe pneumonia requiring hospital admission have hypoxaemia.<sup>3</sup>

Furthermore, 40% of the 7 million annual child deaths result from neonatal conditions, the major ones being birth asphyxia, sepsis and low birthweight,<sup>4</sup> and these are commonly complicated by hypoxaemia or respiratory failure. 18–23% of neonates presenting at hospital have hypoxaemia.<sup>3</sup>

Many children with these conditions die because they do not receive the most basic treatment such as antibiotics, either because it is not recognised that they are unwell or because they cannot access health services. Others die because oxygen is not available in health facilities. These fundamental treatment approaches and other preventative strategies must take precedence in public health. However, even at a public health level there is justification for considering respiratory support, such as appropriate models of CPAP, to be a component of efforts to reduce pneumonia and neonatal deaths globally over the coming decade.

While much of the focus of reducing the global burden of pneumonia is on the pneumococcal conjugate

vaccine, evidence suggests that this vaccine may reduce pneumonia admissions by 15%, with an efficacy against clinical pneumonia as defined by WHO of 7–12%.<sup>5</sup> The vaccine has greater efficacy against radiographically defined pneumofnia and pneumococcal bacteraemia.<sup>5</sup> The estimated cost of conjugate pneumococcal vaccine is \$4500 per life saved,<sup>6</sup> against which other interventions – preventative and curative – can be compared. Despite implementation of vaccines against *Streptococcus pneumoniae* and *Haemophilus influenzae*, the common bacterial causes of pneumonia, acute lower respiratory infections (ALRIs) will still be the dominant cause of serious morbidity in children requiring hospitalisation. Further, the changing epidemiology means that strategies to improve quality of care and supportive therapy for respiratory disease will assume greater importance.

In many district or provincial hospitals in developing countries, despite the provision of oxygen, antibiotics and treatment guidelines, the case fatality rate for hypoxaemic pneumonia is still 5–10%. The case fatality rate for severe neonatal respiratory conditions can be as high as 20%. In such hospitals, 'intensive care', i.e. the provision of mechanical ventilation via endotracheal intubation, is not available, feasible or affordable. Having simple and effective methods of providing additional respiratory support could substantially reduce deaths from pneumonia and neonatal illness. Continuous positive airway pressure (CPAP) is one such treatment.

CPAP in neonatal care has been studied in many countries including India, South America,

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Fiji, Malawi, South Africa and Vietnam.<sup>7-12</sup> The first report of CPAP in neonatal care in developing countries was 20 years ago<sup>7</sup> and there have been more trials recently. Most of these reports have been in tertiary hospitals. CPAP in neonatal hypoxaemic respiratory failure can reduce the need to use high concentrations of oxygen. Although oxygen and other technologies can be life-saving in premature infants, the increased survival of premature neonates in developing countries may come at a significant cost if oxygen therapy is not adequately checked. CPAP, if provided using air or minimal additional oxygen titrated to safe oxygen saturation (oxygen saturation SpO<sub>2</sub> >89% and <95%),<sup>13</sup> can help mitigate what has been described as a second epidemic of retinopathy of prematurity in developing countries.

CPAP in children beyond the neonatal period has been reported to be effective in the management of acute respiratory distress from pneumonia, sepsis, malaria and severe anaemia in Ghana<sup>14</sup> and dengue shock syndrome and acute respiratory failure in Vietnam.<sup>15</sup> Its use is wider than this, but there has been little systematic evaluation of its effectiveness in children beyond the neonatal age in developing countries.

In recent years, the number of methods of CPAP has increased, and this paper describes options for providing CPAP which are applicable in developing countries. It is a practical guide for clinicians and technicians and will help balance the pros and cons of different systems. Two mechanisms of CPAP that are promising in resource-limited settings are described in particular: (i) bubble-CPAP driven by oxygen concentrators or other flow generators, and (ii) High-Flow Nasal-Cannula Oxygen Therapy.

### CPAP as Part of High-dependency Care in a Children's Ward

Introducing any method of CPAP is appropriate only when reliable systems for giving and monitoring oxygen therapy are in place, health workers are adequately trained and close monitoring is assured. CPAP, like any technology, can be best introduced by

taking a systems approach. Implementation requires procurement expertise, standardisation, uniformity and compatibility of equipment, maintenance guidelines and basic engineering capacity, and clinical guidelines on how to care for children with severe respiratory infection and neonates with respiratory distress, including when to use oxygen and when to use CPAP.

When CPAP is used in a general children's ward, it should be undertaken in a high-dependency area of the ward which should be near the nursing station for close monitoring. All beds should have oxygen. The method for doing this will vary from concentrators to cylinders or reticulated oxygen from a central source. Pulse oximetry should be available. Children with the following conditions should be nursed in a high-dependency area: hypoxaemia; coma or severe seizures; shock, sepsis or severe dehydration; severe anaemia requiring a blood transfusion. The components of a high-dependency area in a children's ward are shown in the Table 1.

In some larger hospitals, CPAP may be given in an intensive care unit, but the purpose of this paper is to describe simple CPAP systems that can be used safely and effectively by properly trained nursing staff in a general children's ward or a special care nursery.

### CPAP: General Principles

CPAP is indicated in infants or older children with severe respiratory distress or apnoea despite oxygen therapy. CPAP in a spontaneously breathing patient helps to maintain lung volume during expiration, decreases atelectasis (alveolar and lung segmental collapse), improves oxygenation and reduces respiratory fatigue.

### Methods of CPAP

CPAP is generated by exhalation against a constant opening pressure; this produces positive end-expiratory pressure (PEEP). CPAP in intensive care units in developed countries has traditionally been delivered by mechanical ventilators. Virtually all mechanical ventilators have a CPAP mode. With a

**Table 1 Basic components of a high-dependency area in a paediatric ward**

<ul style="list-style-type: none"> <li>● Oxygen at all beds, and oxygen tubing</li> <li>● Pulse oximeter and sensor probes</li> <li>● Monitoring charts</li> <li>● Nasogastric tubes for feeding</li> <li>● Intravenous (IV) fluid administration sets (IV poles, fluid, burettes, intravenous cannulae, etc.)</li> <li>● Guidelines for:               <ul style="list-style-type: none"> <li>○ which children should be nursed in the high-dependency area</li> <li>○ management of common diseases, e.g. WHO <i>Pocketbook of Hospital Care for Children</i></li> <li>○ use of pulse oximetry</li> <li>○ use of oxygen concentrator or cylinders</li> <li>○ safe administration of blood products</li> </ul> </li> <li>● Local drug compendium</li> </ul>	<ul style="list-style-type: none"> <li>● Blood glucose monitor</li> <li>● Sharps disposal container</li> <li>● Sphygmomanometer</li> <li>● Equipment cupboard</li> <li>● Bookshelf for reference books</li> </ul> <ul style="list-style-type: none"> <li>● Electricity outlets</li> <li>● Hand basin and tap</li> <li>● Signs:               <ul style="list-style-type: none"> <li>○ 'No smoking'</li> <li>○ 'Wash your hands before and after touching patients'</li> </ul> </li> <li>● Resuscitation trolley</li> </ul>
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ventilator, CPAP is generated by exhalation against a mechanical one-way valve on the expiratory limb of the ventilator circuit. However, ventilators are complex, expensive machines that require much training to use and maintain, and much oxygen or medical air to run. If not used appropriately, mortality rates are high from complications, including complications of anaesthesia, under- and over-sedation, ventilator-associated pneumonia, accidental extubation, trauma to the lungs from high pressures or large tidal volumes, or lung injury from exposure to excessive oxygen.

CPAP can also be delivered by commercially available pressure drivers. These generally require tightly fitting nasal prongs or a CPAP face mask. If there is air-leak around the nasal or facial connection, the CPAP effect will be lost.

A form of CPAP can also be delivered by connecting the expiratory limb of a breathing circuit to a column under water (bubble CPAP). The distance the column is underwater is the pressure (in cmH<sub>2</sub>O) that will be in the system to generate bubbles. Excess pressure building up in the system is prevented by bubbling the expired air through water. This system is explained in detail below.

Most CPAP systems provide for a variable amount of additional oxygen, but all CPAP drivers and mechanical ventilators require separate sources of oxygen. The source may be a cylinder, a reticulated (piped) source of oxygen, or an oxygen concentrator. CPAP can also be driven by an oxygen concentrator that can deliver variable oxygen and air mix at flow rates sufficient to generate CPAP. The latter is a fully contained system that may be most appropriate for settings where oxygen is expensive or difficult to access.

In recent years it has been shown that variable levels of CPAP can also be generated by humidified high-flow nasal cannula (HFNC) oxygen therapy. Observational or controlled clinical studies in developed countries have shown that effective respiratory support can be provided with HFNC therapy for premature neonates with respiratory distress,<sup>16</sup> and

for older children with bronchiolitis, pneumonia and other causes of moderate-to-severe respiratory distress.<sup>17–20</sup>

Bubble CPAP and HFNC oxygen therapy are two methods that may be most appropriate to resource-limited settings in developing countries. These are described in detail below, and all commonly used methods for delivering CPAP are compared in Table 2.

### Bubble-continuous Positive Airway Pressure

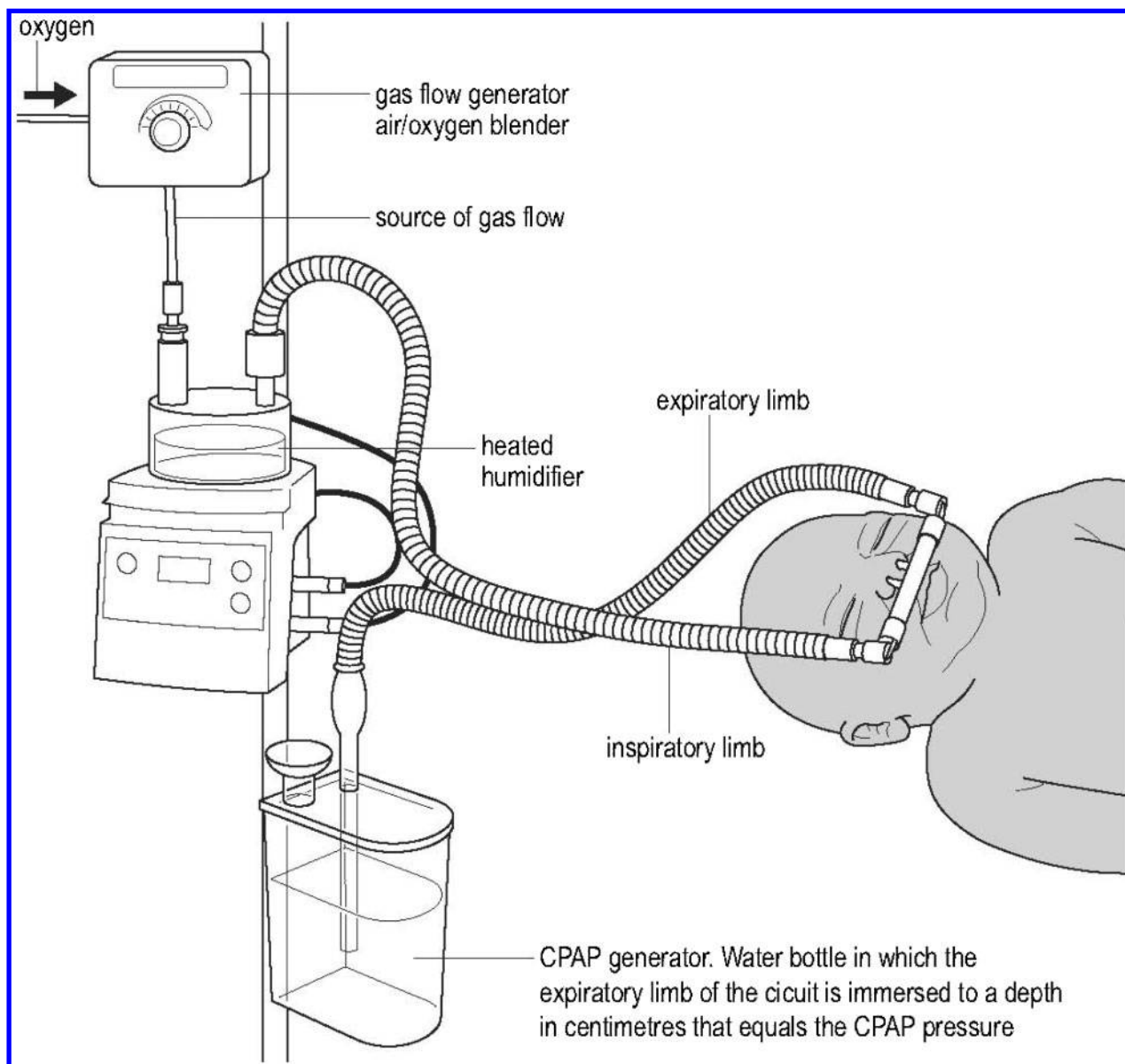
Bubble-CPAP has been used successfully in some referral hospitals in developing countries.<sup>12,21,22</sup> There are several devices to deliver bubble CPAP which range from commercial machines (Fig. 1) to 'home-made' devices.

A bubble CPAP system consists of three components:

- (i) A source of continuous gas flow which most commonly is from an air compressor but can be from an oxygen concentrator. The gas flow rate required for generating CPAP is usually about 5–10 L/min. An air compressor alone can generate CPAP with a fractional inspired oxygen (FiO<sub>2</sub>) of 21%. However, many children with pneumonia and unwell neonates require some supplemental oxygen. Therefore, bubble CPAP also usually requires an oxygen blender that connects an oxygen source (cylinder or concentrator) with the continuous airflow to increase the FiO<sub>2</sub>. When an oxygen concentrator is used as the flow generator for bubble CPAP, the system is self-contained, not requiring extrinsic sources of medical air or oxygen.
- (ii) A nasal interface connecting the infant's airway with the circuit (Fig. 1). These can be short nasal prongs, a nasopharyngeal airway, or nasal or face mask. Face masks are often used in developed countries, but require intensive nursing input to keep them well fitting and attached. The most appropriate for use in a developing country are nasal prongs which are similar to standard oxygen prongs. The nasal interface and circuit tubing must be of sufficiently low resistance not to generate pressure (as manifested by bubbles in the bottle) before connection to the patient. Some oxygen prongs will be too narrow and not distensible, thus providing too much

**Table 2 Comparison of methods of delivering CPAP, with considerations relevant to developing countries**

	Mechanical CPAP driver or ventilator	Bubble CPAP with air driver	Bubble CPAP via concentrator that delivers air/oxygen mix	High-flow nasal-prong oxygen therapy using commercial devices
Nasal interface	Nasal prongs or mask	Nasal prongs	Nasal prongs – standard	Nasal prongs – standard
Oxygen	Additional source of oxygen required	Additional source of oxygen required	oxygen cannula can be modified	oxygen cannula can be modified
Humidification	In-built heated humidifier	In-built heated humidifier	Intrinsic	Additional source of oxygen required
Electricity	Required	Required	Room temperature water humidification	In-built heated humidifier
CPAP delivered	Precise	Precise	Required	Required
Cost	Very high+ oxygen costs	Medium+ oxygen costs	Precise, based on water level	Variable and uncertain
			Low-medium	Low-medium +/- oxygen costs



**Figure 1** Schematic diagram of commercially available bubble CPAP system connected to an infant using close-fitting nasal prongs

resistance to be used for bubble CPAP. Newer nasal prongs are available that take higher flows and have lower resistance and can be used for bubble CPAP. Nasal oxygen prongs need to be carefully inserted to minimize air leakage (otherwise CPAP will not be achieved) and to reduce nasal trauma.

- (iii) An expiratory limb with the distal end submerged in water to generate end-expiratory pressure. In bubble CPAP, the positive pressure is maintained 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.

Several commercial bubble CPAP machines are available (see Fig. 1). These vary in price from several hundred dollars to US\$10,000.

A relatively inexpensive bubble CPAP device can be made using low-resistance nasal oxygen prongs, or

modified standard nasal oxygen prongs driven by an oxygen concentrator. The method is illustrated in Figs 2–5. This system is being used in several hospitals in Asia (Dhaka Children's Hospital, Bangladesh and elsewhere) and Papua New Guinea, and is working effectively.

Gas (oxygen) flow rates of 5–10 L/min are needed for older children with pneumonia. For small neonates, sometimes 3–4 L/min is sufficient to generate CPAP using most bubble CPAP devices. Using a 10-L/min oxygen concentrator that can deliver both oxygen and air as the flow generator is much more efficient (Fig. 3).

In premature neonates <32 weeks, it not safe to use pure oxygen as giving high-concentration oxygen can cause retinopathy of prematurity (ROP). Another source of air flow such as an air compressor or an oxygen blender is required for premature infants, or a concentrator which delivers an air/oxygen mix.

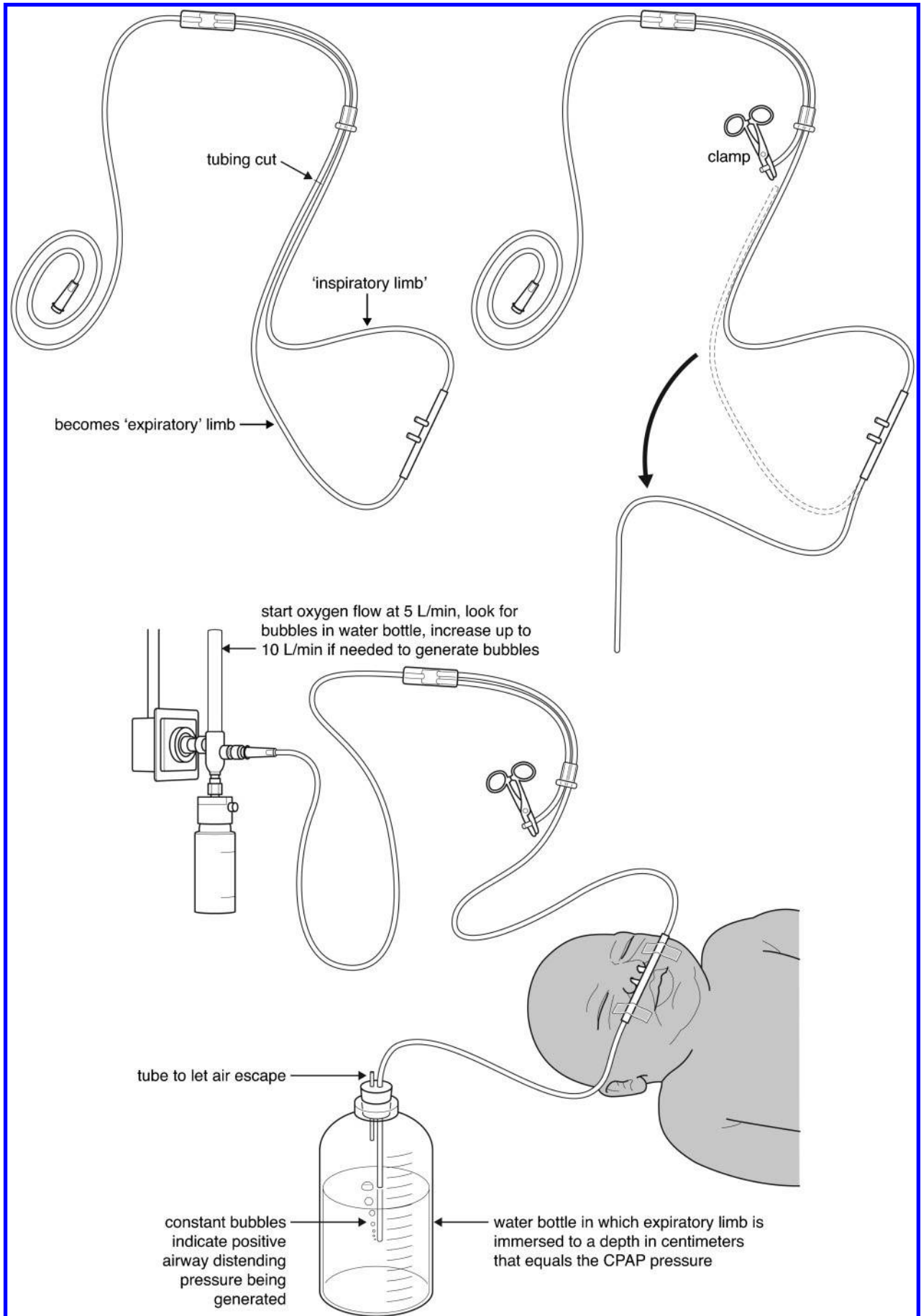


Figure 2 An inexpensive bubble CPAP set-up using modified nasal prongs

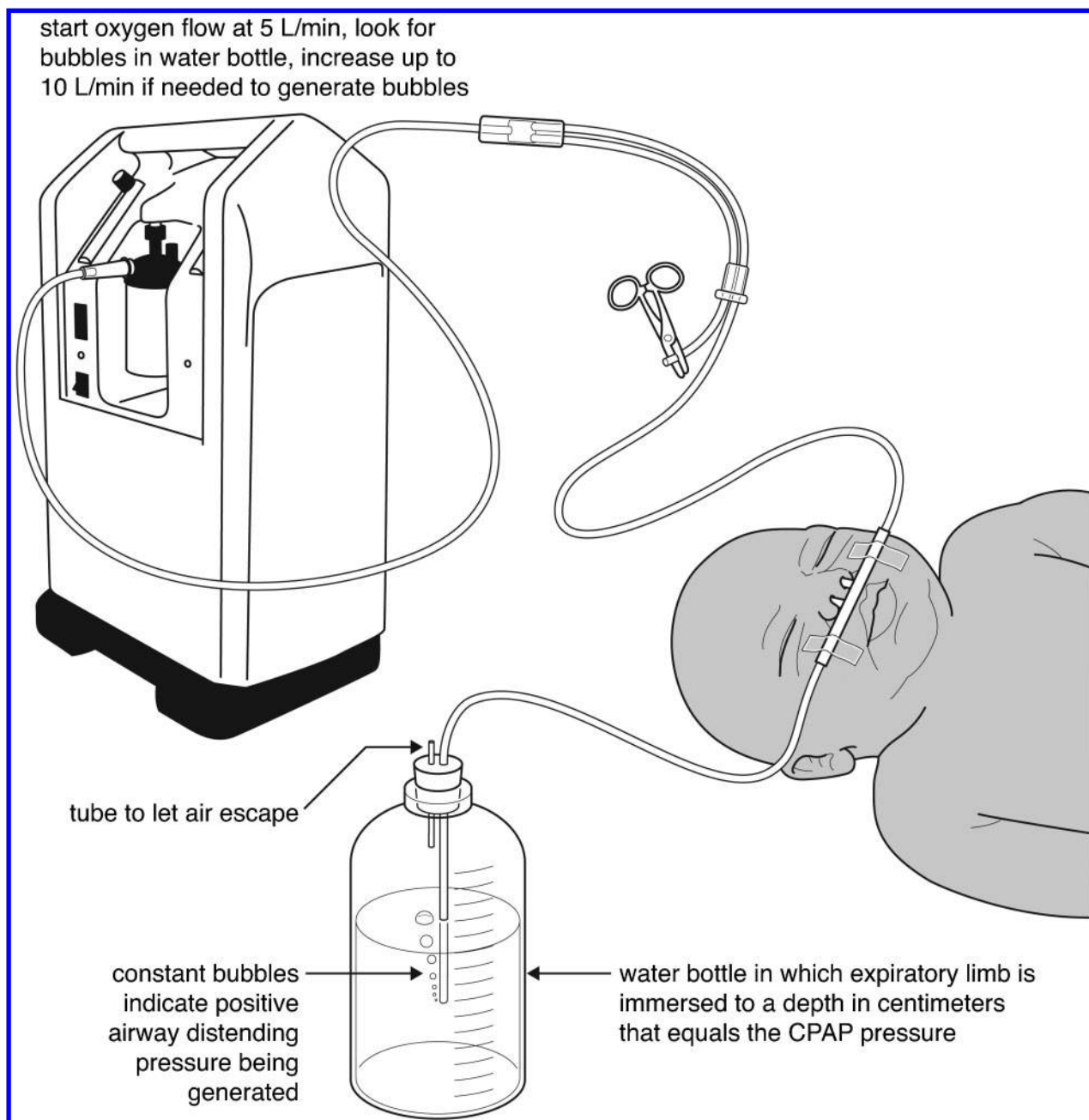


Figure 3 Bubble CPAP using inexpensive modified nasal prongs can also be run using an oxygen concentrator

In older infants requiring higher flows to generate CPAP (up to 10 L/min), using pure oxygen in cylinders is expensive and inefficient, and supplies may run out, leading to interruption of CPAP. Furthermore, with any form of CPAP, running high flows of 100% oxygen can lead to the masking of type II respiratory failure; in children, the oxygen saturation may be maintained above 90% because the child is on high-flow pure oxygen, but progressive hypercarbia and acidosis may lead to an unanticipated collapse in settings in which blood gas analysis cannot be done.

### High-flow Nasal Cannula Oxygen Therapy

HFNC is a recent, relatively simple method of delivering positive pressure using high gas flow (up

to 2 L/kg/min) through nasal oxygen prongs. The gas source can be an air/oxygen mix (which could be supplied by concentrators or cylinders +/- a blender), or a flow generator in which air flow rates can be selected according to the child's weight, and blended oxygen may or may not be used, depending on the clinical need.

Although PEEP can be generated by this method, it is not as simple as dialling higher flows from an oxygen source such as a cylinder or concentrator. The HFNC method requires highly effective humidification to prevent drying of nasal mucosa which can lead to bleeding and nasal obstruction. A heated water humidifier is necessary. An unheated cold water bubble humidifier will provide minimal humidification.



**Figure 4** A newborn infant in Papua New Guinea managed with bubble CPAP using a concentrator and low-resistance nasal oxygen prongs



**Figure 5** A 10-month-old infant with severe pneumonia and hypoxaemia despite oxygen therapy, managed with bubble CPAP using a concentrator that provides an air/oxygen mix

If supplemental oxygen is needed in addition to the CPAP, HFNC also requires an oxygen/air blender. It is dangerous to give high-flow oxygen to a preterm infant as the fractional inspired oxygen achieved would be very high, putting the baby at risk of eye damage,<sup>21</sup> and, for the reasons explained above for CPAP in older children, HFNC using 100% oxygen may mask the signs of hypercarbic respiratory failure.

Unlike with bubble CPAP, one cannot be certain with HFNC what distending pressure is being

delivered. Although there is a risk of pneumothorax and gastric distension, this has been uncommon in studies of HFNC.<sup>16–20</sup> There is limited evidence on what the upper limit of gas flow should be, especially in children beyond 2 years of age, and less evidence on safety and efficacy in other pathologies more commonly affecting older children, such as asthma. The maximum flow will usually be determined by the equipment available, for example a 10 L/min oxygen concentrator will deliver 2 L/kg/min to a child up to 5 kg, beyond that weight the flow per kg will be less, but still adequate in the majority of children with pneumonia. Adult studies of HFNC therapy have used 30–50 L/min (around 0.5–1 L/kg). Therefore, when using HFNC oxygen therapy in older children, to avoid excessive flows and their potential consequences, such as pneumothorax, the following upper limits are suggested:

2 L/kg/min for the first 10 kg: i.e. 6-kg child=12 L/min; 8 kg=16 L/min;

10-kg child=20 L/min

0.5 L/kg/min for each kg above that: 16-kg child will receive 20 + 3 = 23 L/min;

30 kg = 20 + 10 = 30 L/min;

40 kg = 20 + 15 = 35 L/min;

60 kg = 20 + 25 = 45 L/min

High flow should be used with caution in older children who have asthma, who have gas trapping and high levels of intrinsic PEEP, and are at higher risk of pneumothorax.

### Monitoring

All methods of CPAP require careful monitoring. Some machines have alarms, but simple clinical evaluation of respiratory rate, degree of respiratory distress and adequacy of oxygenation is what is required, and it can be done easily by nurses at the bedside. In a study of infants and children receiving CPAP or HFNC oxygen therapy, if the child in the 2 hours after initiation of therapy had two or more of (i) reduction in respiratory rate by 20% or to within the normal range; (ii) reduction in heart rate by 20% or to within the normal range; (iii)  $\text{FiO}_2$  was able to be reduced to <50%, they were very unlikely to require

**Table 3** Respiratory distress score. A score out of 12 can be calculated using the components in each box (three grades of severity for each of four variables). A change in respiratory distress score can indicate whether an infants is improving on CPAP

		Mild=1	Moderate=2	Severe=3
1	Oxygen	Mild hypoxaemia $\text{SpO}_2$ 90–93%	Hypoxaemia $\text{SpO}_2$ 85–90%	Severe hypoxaemia $\text{SpO}_2$ <85%
2	Chest wall retraction	None or minimal	Moderate chest wall retraction	Marked chest wall retractions, tracheal tug
3	Respiratory sounds	None or minimal	Intermittent grunting and/or nasal flaring	Grunting with every breath and nasal flaring
4	Feeding	Normally	Difficulty with feeding or reduced feeding because of respiratory distress	Unable to feed because of respiratory distress or lethargy

escalation to a higher form of respiratory support.<sup>20</sup> Having a simple assessment of respiratory distress can also be useful (Table 3) to guide nurses in the bedside monitoring of improvement or deterioration.

### Feeding and Fluids

Infants and children on CPAP in moderate respiratory distress should be fed by nasogastric tube, ideally using expressed breast milk from their mothers. There is some risk of aspiration if fed by mouth, but it is minimal if fed by a well sited nasogastric tube. In a large study of infants with moderate bronchiolitis who were fed via a nasogastric tube, there was no increased risk of aspiration, apnoea or hypoxaemic events compared with infants given intravenous fluids.<sup>23</sup> In another study of CPAP and HFNC therapy, 60–70% of children were fed adequately by nasogastric tube, about 10% were fed orally and 20% received IV fluids.<sup>20</sup> In children with pneumonia on CPAP, anti-diuretic hormone levels are often elevated, and water retention is common. IV fluids can lead to peripheral oedema, increased lung water and worsening lung function. If IV fluid is needed, a total fluid intake of no more than 50% of maintenance is generally required to maintain normal volume status. When enteral nutrition is given, two-thirds to full maintenance fluid volumes can be given. This volume given should be reduced if the child develops facial oedema (particularly eyelid swelling) or hyponatraemia.

### Cleaning of CPAP Circuit Tubing and Equipment

Even simple CPAP or oxygen systems carry a risk of hospital-acquired infection if the equipment is not cleaned appropriately. Cleaning should be done after every patient has used the CPAP equipment, and at least weekly if the same child is on CPAP for over a week. A spare circuit is essential to replace the one that is being cleaned so that treatment is not interrupted. The CPAP circuit (inspiratory and expiratory limb, bottle and lid and connections) should be thoroughly cleaned.

Staff cleaning the equipment should wear protective clothing to avoid splash exposure or contact with dirty equipment: apron, gloves and glasses should be worn. Cleaning should be undertaken in a well ventilated area.

Equipment required:

- Sink or buckets
- Soft brush to clean the outside of the circuit and bottle. The brushes and other cleaning implements should be thoroughly cleaned after use using soapy water and then allowed to drip-dry
- Gown or waterproof apron, mask and waterproof gloves
- Soap
- Disinfectant solution (sodium hypochlorite 0.05% or household bleach, diluted to 0.05% hypochlorite)

- Drying rack

*Wipe off any gross soiling.* In a clean sink or bucket, wash circuit and nasal prongs in soapy water to remove respiratory secretions. Brush the equipment under water to prevent splash and ensure all visible soiling is removed.

*Rinse* with water that has been boiled and allowed to become tepid. Let it dry,

*Wash next in diluted bleach or disinfectant.* Soak in bleach for 1 hour. Soak all items together. Do not re-use bleach – discard after use.

*Rinse again* with water that has been boiled and cooled to tepid. Let the circuit drip-dry; do not leave it coiled on the sink. Check that there is no pooled water in the circuit. Store the equipment in a clean plastic bag (labelled and dated). Store in a dry, clean area.

### Conclusion

There are numerous devices and methods for delivering CPAP to children in developed and developing countries. The choice of equipment can be complex. This paper has described in detail two methods which are appropriate where resources are limited: bubble CPAP using oxygen concentrators that provide an air/oxygen mix and low-resistance nasal oxygen prongs, and high-flow nasal cannula oxygen therapy using a flow generator, humidifier and blender. CPAP using simple technology is likely to be of benefit in managing severe respiratory distress in children of all ages, but more research on its effectiveness in resource-limited settings is needed.

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