Bubble CPAP devices for infants and children in resource-limited settings: review of the literature

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Introduction

Nearly three million newborns die each year in the first month of life, most of them in low- and middle-income countries (LMIC). The main causes are prematurity, complications during labour and birth and infections [1,2], all of which can lead to severe respiratory distress. In LMIC, as many as 20% of infants with severe respiratory distress die [3].

Continuous positive airway pressure (CPAP) is widely used in high-income countries (HIC) and has reduced neonatal morbidity and mortality as well as the need for mechanical ventilation and surfactant [4–6]. All forms of CPAP require the patient to exhale against a constant opening pressure, which produces positive end-expiratory pressure (PEEP). CPAP, therefore, delivers continuous positive pressure into the airways that distends the lungs, prevents alveolar and lung collapse, improves oxygenation and ventilation and reduces respiratory fatigue [3,6]. CPAP is typically delivered via mechanical ventilators or commercial pressure drivers in high-resource hospitals; however, it can also be delivered via high-flow nasal cannula (HFNC) therapy as well as bubble CPAP (bCPAP) [3].

Both HFNC and bCPAP may be useful in resource-limited settings [7]. The amount of distending pressure delivered via HFNC varies and is difficult to measure, whereas in bCPAP, the end of the expiratory limb of the respiratory circuit is immersed to a depth of water in centimetres that indicates the delivered CPAP pressure [6]. Furthermore, bubbling generated by exhalation against the column of water produces noisy pressure oscillations superimposed over pressure fluctuations (stochastic resonance effect) which promotes further alveolar recruitment aiding oxygenation (Figure 1) [8].

bCPAP can be a low-tech, safe and easy-to-use alternative to conventional CPAP, making it an ideal

**ABSTRACT**

**Background:** Early management of respiratory distress is critical to reducing mortality in infants and children in resource-limited settings. Bubble continuous positive airway pressure (bCPAP) can offer effective and affordable non-invasive respiratory support.

**Objective:** To determine the best physical components of bCPAP circuits for respiratory support of children in low-resource settings. Methods: Using PubMed, CINAHL and LilACS, studies of any design in any language published before June 2017 which examined the physical components of bCPAP circuits were identified and reviewed.

**Results:** After screening, the review included 45 articles: 17 clinical trials, 11 literature reviews, 10 technical assessments of bCPAP components, three reports of real-world implementation in low-resource settings, three cost analyses and one case report. There is no ideal bCPAP circuit for all settings and patients, but some choices are generally better than others in designing a circuit for low-resource settings. Oxygen concentrators are usually the best source of oxygen. As yet, there is no affordable and accurate oxygen blender. Nasal prongs are the simplest patient interface to use with the fewest complications but are not the cheapest option. Expiratory limbs should be at least 1 cm in diameter. Home-made pressure generators are effective, safe and affordable.

**Conclusion:** This narrative review found many studies which evaluated the real clinical outcomes with bCPAP in the target population as well as technical comparison of bCPAP components. However, many studies were not blinded or randomised and there was significant heterogeneity in design and outcome measures.

**Abbreviations:** bCPAP, bubble continuous positive airway pressure; CPAP, continuous positive airway pressure; FIO$_2$, fractional oxygen concentration; HFNC, high-flow nasal cannula; HIC, high-income countries; LMIC, low- and middle-income countries; NP, nasopharyngeal; O$_2$, oxygen; PEEP, positive end-expiratory pressure; PICO, Population, Intervention, Comparison and Outcome
choice in LMIC. Current commercially available bCPAP can be relatively affordable at 15% of the cost of a mechanical ventilator [9]. However, most bCPAP models remain prohibitively expensive for resource-limited settings at prices ranging from approximately US$800 to US$6000 [10]. Non-commercial, locally improvised bCPAP devices assembled from materials found in local hospital and community settings may cost as little as US$3–5 per single unit [11,12]. Such non-commercial devices, however, may have important design limitations such as the absence of a blender or a pressure regulator [6,13]. Furthermore, these prices do not include the cost of oxygen (O$_2$).

While the effectiveness and safety of bCPAP are well documented [14,15], including in randomised controlled trials in resource-limited settings [16–18], no comprehensive literature review has evaluated the individual components of bCPAP for feasibility and clinical outcomes in LMIC. This review sought to examine the evidence and determine the best physical components of bCPAP circuits in LMIC.

**Methods**

A review protocol was employed that searched PubMed, CINAHL and LILACS databases using the search terms outlined in Table 1. The grey literature was also searched using the British Library and Google advanced search engine using similar terms. The reference lists of all identified articles were also searched and reviewed. The search strategy was based on the Population, Intervention, Comparison and Outcome (PICO) format (Table 1).

The literature was searched up to June 2017 with no limits applied to year of publication. The grey literature was searched up to December 2017. To maximize the search sensitivity, search terms pertaining to population age and specific outcome categories were not used to generate search results.

Studies that examined various components of a bCPAP circuit and described how they affected the O$_2$ delivery to infants and children were included for systematic review. bCPAP circuit components identified for review throughout various sources were O$_2$ source, inspiratory and expiratory limbs, patient interface and pressure generator (e.g. water reservoir). In addition, relevant device parameters such as flow and O$_2$ concentration were also examined as a part of circuit components. Studies that examined the mentioned circuit components in conjunction with non-invasive ventilatory support other than bCPAP were also reviewed.

AW and DS independently reviewed the titles, abstracts and full texts using Covidence (Melbourne, Victoria, Australia) as the main citation managing tool. Each conducted a preliminary screening of titles to exclude studies clearly unrelated to the topic. The remaining abstracts were screened for appropriateness and relevance, followed by perusal of the full text for further exclusion of irrelevant papers. During each step of the title, abstract and full-text screening, the two reviewers resolved conflicts by holding discussions and reaching consensus in consultation with the other authors. Studies not relating to infants or
children were excluded. No studies were excluded on the basis of language or design. Various causes of respiratory distress were considered, including respiratory distress syndrome, pneumonia, sepsis and transient tachypnoea of the newborn, but studies addressing congenital anomalies and structural pathologies were excluded. Studies exclusively involving HIC and those examining the efficacy of commercial devices without adding to the originally published data regarding their individual components were also excluded. A summary of the findings from the included studies was compiled in Microsoft Excel (Redmond, WA, USA).

**Results**

After screening, the review included 45 articles: 17 clinical trials, 11 literature reviews, 10 technical assessments of bCPAP component, three reports of real-world implementation in low-resource settings, three cost analyses and one case report (Figure 2).

**Oxygen source**

The two common sources of O₂ for bCPAP are O₂ cylinders and O₂ concentrators. O₂ cylinders contain liquid O₂ that is distilled at very low temperatures and high pressures in a special facility and, therefore, must be transported back and forth from the hospital for regular refilling. O₂ concentrators are suitcase-sized electrically powered machines which draw in ambient air and extract nitrogen, leaving 90–95% pure O₂ for use [19]. A simple comparison is summarised in Table 2.

Field studies of O₂ concentrators implemented in large-scale programmes in low-resource settings found that the majority remained in use years afterwards [20–22]. However, these studies were typically using standard-flow oxygen delivery and not the higher flow rates typically required in bCPAP. Under the demands of bCPAP, many concentrators fall short of the requisite robustness. One study evaluated seven commercially available concentrators and found that only one performed acceptably well in the conditions specified by WHO for low-resource settings, although the study did not specifically assess performance at the higher flow rates used in bCPAP [13]. In a randomised clinical trial of bCPAP in Bangladesh, the study’s specific concentrator model failed 21% of the time during bCPAP, requiring back-up O₂ supplies to continue patient treatment [16].

The main challenge with O₂ concentrators is the need for constant electricity [23] and solar power is emerging as a potential solution [24,25]. Another solution reported is an O₂ reservoir which consists of a non-elastic balloon connected to an O₂ concentrator which fills the reservoir and can be used in the event of power failure [26].

**O₂ flow meter and flow splitter**

Flow rates in bCPAP circuits affect the delivered pressure. Flow can be regulated either by controlling the amount of O₂ from an O₂ source or at the point of blending air and O₂ [27]. The literature review did not find any direct comparison of different flow meters, although the majority of reports of bCPAP included flow meters that could deliver child-appropriate flow rates.

Flow through a bCPAP circuit is influenced by the circuit’s diameter, length and integrity, including the degree of seal at the nasal interface. The approximate flow can be visually assessed by observing the rate of

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**Table 1. PICO search strategy used for literature search.**

<table>
<thead>
<tr>
<th>PICO terms</th>
<th>Description</th>
<th>Search terms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>Newborns and infants with respiratory distress in low- and middle-income countries</td>
<td>Child, children, infant(s), infancy, paediatric, neonate(s), neonatal, newborn, developing country, underdeveloped country, low income country, low income countries, middle income country, middle income countries, resource poor, resource limited, low resource</td>
</tr>
<tr>
<td>Intervention</td>
<td>Bubble CPAP</td>
<td>Bubble CPAP, bubbling CPAP, bCPAP, bubble continuous positive airway pressure</td>
</tr>
<tr>
<td>Comparison</td>
<td>Other forms of non-invasive oxygen therapy, including nasal CPAP and standard oxygen via nasal cannula</td>
<td>Continuous positive airway pressure, positive-pressure respiration, positive airway pressure device, nCPAP, nasal continuous positive airway pressure, oxygen therapy, respiratory support device, nasal cannula, nasal cannulae, non-invasive respiratory support, non-invasive ventilation</td>
</tr>
<tr>
<td>Outcome</td>
<td>Treatment failure, treatment complications, improvement in respiratory parameters (e.g. respiratory rate), rate of intubation, rate of invasive/mechanical ventilation, severity of respiratory distress, mortality/survival to discharge</td>
<td>Outcome-based search terms were not applied in the search process</td>
</tr>
<tr>
<td>Question</td>
<td>For newborns and infants with respiratory distress treated in resource-limited settings, what are the best components of a bubble CPAP circuit and other related non-invasive ventilation methods that contribute to improved outcomes?</td>
<td>PICO terms and outcome-based search terms were not applied in the search process to maximize the search sensitivity.</td>
</tr>
</tbody>
</table>

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*Similar search terms were used for other databases with adaptations as needed. Age-specific search terms and outcome-based search terms were not applied in the search process to maximize the search sensitivity.*
bubbling in the circuit. While strategies for choosing flow rates were beyond the scope of this review, one study reported that using a fixed flow delivered accurate pressures to patients as opposed to titrating flow to produce bubbling [27].

Managing O₂ flow is also important for conserving O₂ supplies [28]. If multiple children can tolerate the same flow rate, a flow splitter device can be used to maximize O₂ supplies and decrease the overall cost of O₂ [22,29,30]. CPAP usually requires O₂ flow rates of 2–10 L/min, whereas a concentrator can usually provide only up to 5–8 L/min and, when split, will have a proportionally lower flow. For example, one group measured actual flow rates for each identical limb of a four-way flow-splitter and found that a concentrator set at 4 L/min would deliver 0.5 L/min to each limb [22]. One innovative system used an O₂ concentrator for CPAP by adding an air compressor via a Y-piece to

Table 2. Comparison of oxygen delivery systems.

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Cylinders</th>
<th>Concentrator</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infrastructure</td>
<td>Reliable transportation to/from central processing centres</td>
<td>Continuous electrical supply</td>
<td>20,22,23,30,50</td>
</tr>
<tr>
<td>Additional equipment</td>
<td>Pressure regulator (~US$200/cylinder), flow meter (~US$400), humidifier</td>
<td>None</td>
<td>20,22,23,30</td>
</tr>
<tr>
<td>Cost</td>
<td>~US$1500 for 1 million L oxygen, cost of cylinder may be higher in LMIC</td>
<td>~US$1500 per machine which can produce ~1 million L oxygen in 6 mths</td>
<td>20,22,23,30</td>
</tr>
<tr>
<td>Ongoing costs of transportation for frequent refilling: standard cylinders lasting 2–3 days with continuous use</td>
<td>Moderate up-front costs of procuring initial equipment and installation, but small ongoing costs (electricity, maintenance)</td>
<td>A 2-year operational cost of ~US$168,500 (large provincial hospital) and ~US$102,000 (small district hospital) in Papua New Guinea</td>
<td>20,22,23,30,50</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Minimal; in central facility where oxygen is compressed at high pressure and low temperature</td>
<td>Local maintenance and repair, spare parts</td>
<td>20,21,22</td>
</tr>
</tbody>
</table>

*Approximated by conversion from values in Papua New Guinea’s currency, Kina (PGK).

*Operational cost in a small district hospital not including the cost of an anaesthetic machine required for major surgery.
increase the total flow rate, making it suitable for CPAP [29]. No studies comparing use of a flow splitter with not using a flow splitter were identified.

**O2 blender**

In low-resource settings, air–O2 blenders that incorporate ambient room air and pure O2 to supply precisely mixed FiO2 are not usually available [11,12,28,29,31,32]. Without an O2 blender, several authors reported no ability to regulate FiO2 or difficulty in maintaining target FiO2 as well as differences between predicted and measured FiO2 [11,28,31–33]. Some commercially available bCPAP systems do include an air–O2 blender, which allows for use with premature newborns, but homemade bCPAP usually does not [6]. Air–O2 blenders also require a high pressure O2 source beyond the capability of most O2 concentrators, which produce low-pressure O2 [33].

For patients such as premature newborns who are at particularly high risk of O2 toxicity and retinopathy of prematurity, WHO recommends blended O2 with FiO2 of 0.3 or room air (0.21 FiO2) [34,35]. However, data show that excessive use of oxygen in adults is also associated with excess mortality [12,36].

Several authors reported innovative systems to adjust the concentration of O2 without a blender. A Y-tubing set-up delivers a mixture of air and O2 from two separate supplies with independent flow meters and can be used to change the relative concentration of O2 [29,33]. Kaur et al. tested calculated O2 concentrations of 19–95% using such a Y-tubing system and found actual O2 concentrations of 21–98% with variable accuracy [33]. Alternatively, an air pump can add O2 from a concentrator to air, with separate flow control for pure O2 to control the FiO2 [27,37].

Another option is an entrainment device which uses a small jet of O2 and draws in ambient air through an adjustable inlet hole, thus mixing the O2 and air to achieve a set concentration. However, one common entrainment device designed for adults did not deliver an appropriate O2 concentration or flow when used with nasal cannula-like tubing at a child-appropriate flow rate [28].

**Patient interface**

Four patient interface devices for bCPAP were identified: nasal prongs/cannulas, nasal catheters, nasopharyngeal (NP) catheters and nasal/face mask [3,7]. A comparison of their basic characteristics is shown in Table 3. In this review, the most common patient interface used for bCPAP was nasal prongs. Nasal and NP catheters may also be used for CPAP, although they require more nursing intervention and are more prone to complications [33,38,39].

When used to deliver low-flow O2, nasal cannulas on average require higher O2 flow rates than NP catheters to achieve the same partial pressure of O2 [12]. At equal flow rates, NP catheters deliver the highest FiO2 compared with nasal catheters and prongs [38]. NP catheters produce increased PEEP with lower O2 flow rates than nasal prongs [40]. Larger NP catheters were found to produce PEEP in infants; for example, size 8 Fr catheters produce PEEP (6.3 cm at 1 L/min, 10.6 at 2 L/min) while size 6 Fr do not [12,40].

Nasal prongs are the easiest to use with the least serious complications that can occur with catheters such as displacement into the airway and gastric distension [38,41]. High-flow air through nasal prongs does require a humidification device, however, as do

Table 3. Comparison of patient interface devices for bCPAP.

<table>
<thead>
<tr>
<th></th>
<th>Nasal prong/ cannula</th>
<th>Nasal catheter</th>
<th>Nasopharyngeal catheter</th>
<th>Face mask</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>O2 flow required*</td>
<td>1.26x</td>
<td>~1x</td>
<td>1x</td>
<td>Higher flow requirements</td>
<td>12,41</td>
</tr>
<tr>
<td>Cost per device</td>
<td>~US$2–5</td>
<td>~US$0.10</td>
<td>~US$0.10</td>
<td>Higher cost</td>
<td></td>
</tr>
<tr>
<td>Humidification</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>12,51</td>
</tr>
<tr>
<td>Risk of airway</td>
<td>Low/Slight</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>38,41</td>
</tr>
<tr>
<td>obstruction by mucus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complications</td>
<td>Dislodgement; tube breakage</td>
<td>Nasal bleeding; small risk of displacement and gastric distension</td>
<td>Displacement and gastric distension; airway perforation</td>
<td>Carbon dioxide accumulation</td>
<td>12,38,39</td>
</tr>
<tr>
<td>Limitations</td>
<td>Not easy to determine precise FiO2</td>
<td>Higher nursing demand</td>
<td>Highest nursing demand; highest complication rate</td>
<td>Special ordering required – not generally available; incompatible with feeding tube</td>
<td>38,40,41</td>
</tr>
<tr>
<td>Other</td>
<td>Reservoir prongs can conserve oxygen</td>
<td>Nasogastric tube required</td>
<td>Nasogastric tube required</td>
<td></td>
<td>45</td>
</tr>
</tbody>
</table>

*O2 flow required compared with nasopharyngeal catheter.
nasal and NP catheters since they bypass the nasal passages which typically provide humidification. Studies of bCPAP have included humidified O₂ for use with all three interfaces [3,6,33].

Several comparisons of different types of nasal prongs were identified. Short binasal prongs are more effective in CPAP than single prongs, with less resistance to flow, and they are more effective at preventing re-intubation [7,42,43]. Commercially available prongs are equally effective for reaching target PEEP and O₂ saturation [43]. When tested on a lung model, standard infant- or newborn-sized nasal prongs delivered consistently higher mean CPAP than thinner-walled prongs [44].

Nasal prongs are 20–50 times more expensive than catheters at an estimated cost of US$2–5 per set of prongs compared with US$0.10 for a paediatric nasogastric tube or suction tube which can be used as a catheter [38]. If O₂ conservation is a priority, reservoir cannulas include an inline compliant reservoir that captures exhaled O₂ between breaths and delivers it during inhalation, which can further conserve O₂ supplies [45].

### Expiratory limb

The expiratory limb for bCPAP is a tube of non-collapsible plastic leading from the patient interface to the pressure generator where it is immersed in water. When different diameters of the expiratory limb were compared in a lung model, a larger expiratory limb (>10 mm) with greater depth caused greater oscillations in pressure and volume, especially in infants with low lung compliance, which should improve gas exchange [46].

The expiratory limb should be emptied at least every 2–3 h since condensation collecting in the limb increased the delivered pressure beyond set levels [47].

### Water reservoir or pressure generator

The water reservoir used to generate pressure may be home-made or commercially produced. Home-made water reservoirs consist of a water-filled bottle (e.g. intravenous solution bottle, shampoo bottle or glass graduated cylinder). The expiratory limb is submerged and stabilised in the bottle, and the water column height within the limb determines the pressure. Several field studies have reported the feasibility, affordability and effectiveness of home-made pressure generators in LMIC [6,11,16,27,29,32,48].

Commercial models have different mechanisms for controlling the pressure generated by the water column [49]. Fisher and Paykel’s system has a rigid tube moulded to fit inside the reservoir which generates pressure. Babi Plus has a rotation mechanism inside the expiratory limb that changes the depth and controls pressure. WaterPAP uses a water bottle with a corrugated tube with a plastic lid that holds the corrugated tubing in place.

Home-made water reservoirs tested in low-resource settings accurately delivered pressures within 1 cm across a range of pre-set pressures [32]. In one study comparing home-made systems with commercial ones, a home-made pressure generator had more variable airway pressure and volume oscillations with the least increase in pressure at increasing flows but the home-made system is not as foolproof [49].

One lung model using different home-made pressure generators found that a smaller bottle such as a 500-ml graduated cylinder should be used to increase pressure and volume oscillations [46].

### Discussion

The ideal bCPAP device for low-resource settings would be safe, effective, affordable, reusable, readily available and simple to use. On reviewing the individual components of bCPAP in LMIC, the evidence points to several superior choices while highlighting areas for further studies with potential for innovation and development.

O₂ concentrators are safe and cost-efficient, potentially making them the best choice as a source of O₂ in most low-resource settings. They do not require layers of widescale infrastructure, whereas for O₂ cylinders, there is a chain of infrastructure from the financing of high-energy production of liquid oxygen at an oxygen plant to reliable road and transportation systems [20,30,50]. The need for an uninterrupted power supply, however, can be a limiting factor in LMIC. Solar power or O₂ reservoirs may allow concentrator use even without reliable electricity. Furthermore, while the initial cost of installing a solar-powered system is high, operational costs tend to be low with only air and sun being required [24]. It is essential, however, to ensure the purchase and implementation of O₂ concentrators that meet the performance standards outlined by the WHO guideline for technical specifications for O₂ concentrators in low-resource settings [34]. It is also essential to thoroughly assess a facility’s O₂ requirements, conduct local training in maintenance and repair and ensure the presence of back-up power or O₂ supply.

Traditional commercially available O₂ blenders are too expensive for low-resource settings and home-made blending systems have limited precision and accuracy. Low-resource settings need an affordable and reliable O₂ blender in order to expand the safe use of bCPAP, especially for premature infants who are vulnerable to retinopathy of prematurity owing to O₂ toxicity. O₂ concentrators with built-in blenders are currently the best choice for premature infants.
However, an air entrainment device designed on the basis of the Venturi effect – a pressure differential generated by a simple manipulation of oxygen inlet and outlet orifices that can lead to variable air–oxygen blending capacities – is a potentially powerful and revolutionary tool [28]. Future studies should optimise the design and application of such entrainment devices with attention to cost-efficiency as well as reported limitations.

For the patient interface, nasal prongs are the simplest to use with the fewest serious complications. The most common complications of nasal prongs are dislodgement and nasal irritation, whereas complications associated with catheters include displacement into the lower airways with the risk of airway perforation and gastric distension. However, nasal prongs do require more O2 flow, and they are much more expensive than nasal and NP catheters. Another possible limitation with narrow, high-resistance nasal prongs is a pseudo-CPAP bubbling effect. Our review revealed a lack of data that specifically analyses the bubbling effect of bCPAP with variables that determine the resistance of the circuit.

Home-made pressure generators are reliable, accurate and affordable and in some respects (such as in creating oscillation in pressure and volume which encourages gas exchange) may be superior to commercially available devices. The diameter should be narrow, approximately 5–6 cm, to increase pressure and volume oscillation. Lastly, the expiratory limb should be at least 1 cm in diameter for increased pressure and volume oscillations to facilitate gas exchange in the lung.

The limitations of this review include its limited scope. Best practices for system-wide implementation of bCPAP and training of clinical staff were not directly part of the search strategy, although the authors discussed the importance of good training in its use as well as maintenance and repair. One element of safe bCPAP implementation, as with any use of supplemental O2, is monitoring with pulse oximetry. WHO guidelines support this recommendation [34,51,52]. This review also included a limited grey literature search and there is probably a wealth of information from innovative providers not widely published and not seen in this review. Finally, this was a narrative review that aimed to assess all of the relevant data published but it did not include systematic evaluation of the quality of the literature included.

CPAP is a safe and effective method of treating infants and young children with life-threatening respiratory distress and can be successfully adapted for use in resource-limited settings. This literature review found that the most feasible, safe and cost-effective bCPAP system in LMIC would be an O2 concentrator connected to short binasal prongs with an attached humidifier, with a large-diameter expiratory limb submerged into a small-diameter home-made pressure generator such as a graduated cylinder. There is a need for an affordable O2-blending device to expand the use of bCPAP to premature infants and others. Successful bCPAP implementation will depend on the establishment of reliable infrastructure such as electricity, strong clinical training and local training in device maintenance and repair.

Disclosure statement

No potential conflict of interest was reported by the authors.

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**References**


