Experiences with implementation of continuous positive airway pressure for neonates and infants in low-resource settings: A scoping review

Sara Dada, Henry Ashworth, Alina Sobitschka, Vanitha Raguveer, Rupam Sharma, Rebecca L. Hamilton, Thomas Burke

1 Vayu Global Health Foundation Boston, Boston, Massachusetts, United States of America, 2 Harvard Medical School, Boston, Massachusetts, United States of America, 3 University of Göttingen, Göttingen, Germany, 4 University of Illinois College of Medicine, Chicago, Illinois, United States of America, 5 University of California Los Angeles Kern Medical Center, Bakersfield, California, United States of America, 6 Massachusetts General Hospital, Department of Anesthesiology, Boston, Massachusetts, United States of America, 7 Karolinska Institute, Department of Cell and Molecular Biology, Solna, Sweden, 8 Massachusetts General Hospital, Global Health Innovation Lab, Department of Emergency Medicine, Boston, Massachusetts, United States of America, 9 Harvard T. H. Chan School of Public Health, Boston, Massachusetts, United States of America

Abstract

Background

Continuous positive airway pressure (CPAP) is the gold standard of care in providing non-invasive positive pressure support to neonates in respiratory distress in high-resource settings. While safety has been demonstrated in low-resource settings, there is a lack of knowledge on the barriers and facilitators to proper implementation.

Objective

To identify and describe the barriers, facilitators, and priorities for future implementation of CPAP for neonates and infants in low-resource settings.

Methods

A systematic search (database inception to March 6, 2020) was performed on MEDLINE, Embase, Web of Science, CINAHL, Global Health, and the WHO Global Index Medicus using PRISMA-ScR guidelines. Original research articles pertaining to implementation of CPAP devices in low-resource settings, provider or parent perspectives and experiences with CPAP, cost-benefit analyses, and cost-effectiveness studies were included. Inductive content analysis was conducted.

Findings

1385 article were screened and 54 studies across 19 countries met inclusion criteria. Six major themes emerged: device attributes, patient experiences, parent experiences, provider
experiences, barriers, and facilitators. Nasal trauma was the most commonly reported compi-
lcation. Barriers included unreliable electricity and lack of bioengineering support. Facilita-
tors included training, mentorship and empowerment of healthcare providers. Device
design, supply chain infrastructure, and training models were imperative to the adoption and
sustainability of CPAP.

Conclusion
Sustainable implementation of CPAP in low resource settings requires easy-to-use devices,
ready access to consumables, and holistic, user-driven training. Further research is neces-

sary on standardizing metrics, interventions that support optimal provider performance, and
conditions needed for successful long-term health system integration.

Introduction
The World Health Organization has declared the reduction of neonatal mortality a global pri-

ority [1]. Each year, two and a half million infants die in their first month of life and the major-

ity of these deaths occur in low resource settings [2]. While considerable progress has been
made over the last few decades, respiratory distress syndrome (RDS) remains a leading cause
of neonatal mortality worldwide [1–4]. RDS usually develops in the first 24 hours after birth in
premature newborns due to a lack of surfactant within the lungs, and often requires positive
pressure ventilation for treatment [5]. Continuous positive airway pressure (CPAP) is consid-

ered to be the gold standard, treatment for preterm neonates experiencing RDS and is recom-

mended by WHO [6–9].

Forms of CPAP can vary across a number of factors including the patient interface, sophis-
tication, and how they generate pressure. Bubble continuous positive airway pressure
(bCPAP) is a common mode of CPAP delivery for newborns that uses a bubbler instead of a
ventilator to generate pressure [6–8]. Since bCPAP systems are considered at least as effica-
cious and are considerably lower cost than ventilator-derived CPAP devices, they may have
significant potential to improve access to non-invasive ventilation in low-resource regions
worldwide [7, 10, 11]. While reviews of all forms of CPAP [12, 13] have described the efficacy
of the treatment, there has been a specific focus on bCPAP therapies suggesting that bCPAP
may be safe and effective in low and middle income countries (LMICs) [14–16]. These reviews
called for further research on effectiveness and sustainability of bCPAP therapy in low-
resource settings [13–16]. A recent systematic review on barriers and facilitators to implemen-
tation of neonatal bCPAP among health facilities in sub-Saharan Africa found that staffing
ratios, provider knowledge, and device maintenance were crucial to the success of the inter-
vention [17]. However, more information is needed to understand optimization and guide fur-
ther implementation of all forms of CPAP, including bCPAP, across low-resource settings.
Consideration of implementation factors such as successful CPAP device attributes, provider
and parent acceptance, and systems uptake must be better understood. Additionally, a broader
picture that considers qualitative factors is needed to understand how to create lasting sustain-
able uptake of CPAP. To explore these factors the following research question was formulated:
What are identified barriers, facilitators, and priorities for future implementation of CPAP for
neonates and infants in low-resource settings? To answer this more qualitative and nuanced
question, a scoping review was chosen to broadly map knowledge gaps and evidence [18].
Methods

Search strategy

The scoping review framework was adopted in order to present an overview of all the evidence relating to experiences with CPAP implementation [19]. A scoping review protocol was developed according to the Joanna Briggs Reviewer’s manual [20] and this review is reported in compliance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses extension for Scoping Reviews (PRISMA-ScR) checklist (S1 File) [21]. The final protocol was registered on Open Science Framework (https://osf.io/qwvgs/). The search query (S2 File) was run on six databases (MEDLINE, Embase, Web of Science, CINAHL, Global Health, and the WHO Global Index Medicus) from database inception to March 6th, 2020.

Selection of studies

Search results were uploaded to an online program (Covidence, Veritas Health Information, Melbourne, Australia) to allow for collaborative screening by multiple authors. Four reviewers (SD, RS, HA, AS) independently screened a sample of ten titles and abstracts and agreed on criteria for inclusion and exclusion. Two blinded reviewers (SD, RS) independently screened all articles by title and abstract. Conflicts were resolved by an independent arbiter (RH). Two blinded reviewers (SD, RS) then screened articles by full text for potential eligibility. A final arbiter (RH) resolved conflicts of agreement on inclusion for the final dataset. Original peer-reviewed research articles of any study design on implementation of CPAP devices in low-resource settings as defined by the World Bank Classification at time of study, provider or caregiver perspectives and experiences with CPAP, and cost-benefit analyses or cost-effectiveness studies were included. Grey literature, reviews, and research articles that solely focused on safety and efficacy of CPAP were excluded.

Data extraction

Three reviewers (SD, HA, AS) independently extracted data from each study using the Covidence data extraction form. Extracted data included: study year; study type/method and setting; population; sample size and method; study objectives; characteristics of CPAP intervention or treatment; complications, barriers, and facilitators. Findings were coded into broad themes by two independent reviewers (SD, HA) using an inductive content analysis on NVivo 12 (QSR International, Melbourne, Australia). An inductive analysis was used in order to uncover patterns and themes in the experiences and perceptions of CPAP implementation [22, 23]. Once all studies were uploaded into NVivo, the two reviewers coded a sample of the studies until data saturation was reached. The individual codebooks were compared and discussed in order to create a final codebook which was then applied to the full dataset.

Synthesis of results

Studies were grouped by intervention. Broad categories were developed from extracted data related to experiences with implementation of CPAP treatments and results were synthesized across articles. Due to the high variation in study designs and in order to capture and present all of the existing data, studies were not excluded based on quality; and therefore, critical appraisals were not conducted.
Results

Overview of included studies

Of the 1385 identified studies, 54 were included in the final analysis (Fig 1—PRISMA chart) [24]. Included studies are summarized in Table 1. Reasons for exclusion during full-text screening were: incorrect population, unrelated intervention, inappropriate setting, not about experiences with implementation, not original research, unavailable or incorrect reference. No
### Table 1. Summary table of included studies.

| Study            | Country  | Specific Intervention | Design                        | Study participants | Number of participants | Facility Type                  |
|------------------|----------|-----------------------|-------------------------------|--------------------|------------------------|--------------------------------|
| Abdulkadir 2013  | Nigeria  | bCPAP                 | Case Study                    | Neonates           | 1                      | Teaching Hospital              |
| Abdulkadir 2015  | Nigeria  | Nasal bCPAP (Improvised) | Descriptive Observational     | Neonates           | 20                     | Teaching Hospital              |
| Al-Lawama 2019   | Jordan   | Nasal bCPAP (Fisher & Paykel) | Prospective Observational     | Neonates           | 143                    | Tertiary Care Hospital         |
| Amadi 2019       | Nigeria  | bCPAP (Improvised)    | Prospective Cohort            | Neonates           | 57                     | Tertiary Care Hospital         |
| Antunes 2010     | Brazil   | Questionnaire         | Descriptive Observational     | Nurses             | 11                     | Tertiary Care Hospital         |
| Atreya 2018      | India    | bCPAP (Fisher & Paykel) | Qualitative Interviews        | Healthcare providers | 14                    | Tertiary Care Hospital         |
| Audu 2014        | Nigeria  | bCPAP (Improvised)    | Descriptive Observational     | Neonates and infants | 48                    | Tertiary Care Hospital         |
| Bahman-Bijari 2011 | Iran   | bCPAP (Fisher & Paykel) vCPAP (Bear Medical Systems) | Randomized Controlled Trial  | Preterm neonates  | 50                     | Tertiary Care Hospital         |
| Bassiony 1994    | Oman     | Nasal bCPAP (Beneveniste’s pediatric gas jet) | Retrospective Descriptive | Neonates           | 44                     | Teaching Hospital              |
| Boo 2016         | Malaysia | EnCPAP EnCPAP         | Retrospective Cohort          | Hospital facilities | 34                     | Not Specified                  |
|                  |          |                       |                               |                    |                        |                                |
| Carns 2019       | Malawi   | CPAP (Pumani)         | Descriptive Observational     | Neonates           | 2850                   | District Hospital              |
| Chen 2014        | Malawi   | bCPAP (Pumani) Nasal oxygen | Cost-Effectiveness Analysis | Neonates           | 87                     | Not Specified                  |
| Crehan 2018      | Malawi   | bCPAP TRY algorithm (Pumani) Nasal oxygen | Descriptive Observational | Infants            | 57                     | District Hospital              |
| Daga 2014        | India    | nCPAP (Improvised)    | Retrospective Cohort          | Neonates           | 140                    | Teaching Hospital              |
| Dai 2020         | China    | nCPAP (CareFusion Infant Flow System) | Prospective Observational | Neonates           | 429                    | Tertiary Care Hospital         |
| deSiqueira 2014  | Brazil   | CPAP                  | Survey                        | Nurses             | 20                     | Teaching Hospital              |
| Dewez 2018       | India    | CPAP                  | Qualitative Interviews        | Healthcare providers | 69                    | District Hospitals and Medical Colleges |
| Dewez 2020       | India    | CPAP (Improvised) CPAP (Commercial) | Cross-sectional Cluster | Hospital facilities | 694                   | Government Hospital            |
| Garcia Reza 2018 | Mexico   | nCPAP                 | Descriptive Observational     | Nurses             | 25                     | Tertiary Care Hospital         |
| Ghorbani 2013    | Iran     | nCPAP                 | Cross-Over Cohort             | Preterm neonates  | 44                     | Teaching Hospital              |
| Gondwe 2017      | Malawi   | bCPAP (Pumani)        | Qualitative Interviews        | Caregivers         | 12                     | Tertiary Care Hospital         |
| Guedes 2019      | Brazil   | nCPAP                 | Qualitative Interviews        | Nurses             | 30                     | Teaching Hospital              |
| Hendriks 2014    | South Africa | nCPAP (Fisher & Paykel) | Retrospective Descriptive     | Neonates           | 128                    | Rural District Hospital        |
| Hundalani 2015   | Malawi   | bCPAP TRY algorithm (Pumani) bCPAP early algorithm (Pumani) Oxygen only | Prospective Cohort | Neonates           | 325                    | Tertiary Care Hospital         |
| Jardine 2015     | South Africa | bCPAP (Fisher & Paykel) | Retrospective Descriptive     | Neonates           | 711                    | Tertiary Care Hospital         |
| Khan 2017        | India    | CPAP (Fisher & Paykel) CPAP (Phoenix Medical) | Randomized Controlled Trial | Preterm neonates  | 170                    | Tertiary Care Hospital         |

(Continued)
| Study                          | Country | Specific Intervention                      | Design               | Study participants | Number of participants | Facility Type                      |
|-------------------------------|---------|-------------------------------------------|----------------------|--------------------|------------------------|-----------------------------------|
| Koyamaibole 2006 [35]         | Fiji    | bCPAP (Fisher & Paykel) Retrospective     | Neonates            | 1152               | Tertiary Care Hospital  |
| Myhre 2016 [69]               | Kenya   | bCPAP (Improvised) Retrospective          | Preterm neonates    | 118                | Rural Tertiary Care Hospital |
| Nahimana 2015 [70]            | Rwanda  | bCPAP (Pumani) Retrospective Cohort       | Preterm VLBW Neonates | 135              | Rural District Hospital  |
| Nyondo-Mipando 2020 [49]      | Malawi  | bCPAP Qualitative Interviews               | Healthcare providers | 46                | Secondary and Tertiary Care Hospitals |
| Okonkwo 2016 [71]             | Nigeria | bCPAP Survey Healthcare providers         | Preterm neonates    | 237                | Tertiary Care Hospital       |
| Osman 2014 [58]               | Egypt   | nCPAP Prospective Cohort                  | Preterm infants     | 60                 | Tertiary Care Hospital      |
| Sessions 2019 [33]            | Malawi  | bCPAP Observational: Time Motion Study    |                      | 12                 | Rural District Hospital    |
| Silva 2010 [37]               | Brazil  | Questionnaire Qualitative Interviews      | Nurses and nursing technicians | 30            | Tertiary Care Hospital      |
| Tagare 2010 [7]               | India   | bCPAP (Fisher & Paykel) Randomized        | Preterm neonates    | 30                 | Tertiary Care Hospital      |
| Van den Heuvel 2011 [41]      | Malawi  | bCPAP (Improvised) Prospective Cohort     | Neonates            | 5                  | Tertiary Care Hospital      |
| Nitigurirwa 2017 [67]         | Rwanda  | Neonatal training program (427 days)      | Retrospective       | Hospital facilities | Teaching and District Hospitals |
| Olayo 2019 [43]               | Kenya   | bCPAP training (2 days) Prospective       | Healthcare providers | 79                | Level 4 and Level 5 Hospitals |
| Chen 2017 [63]                | Taiwan  | Mobile Cart Training Pre-Post Intervention | Healthcare providers | 59           | Tertiary Care Hospital      |
| McAdams 2015 [36]             | Uganda  | RSS Scoring Training Descriptive          | Healthcare providers | 19                | Rural Tertiary Care Hospital |
|                               |         | bCPAP (Improvised)                        | Neonates            | 21                 |                        |
| Asibon 2019 [68]              | Malawi  | Peer mentorship and training program       | Pre-Post Intervention | Nurses            | Secondary and Tertiary Care Hospitals |
| Tiryaki 2016 [73]             | Turkey  | bCPAP Lecture Pre-Post Intervention       | Nurses              | 36                 | University, State and Private Hospitals |
| Wilson 2014 [32]              | Ghana   | 1st generation international trainers     | Descriptive         | Healthcare providers | District Hospital                  |
|                               |         | 2nd generation local trainers             | Observational       |                  |                        |
| Bashir 2019 [53]              | India   | CPAP nasal mask (Fisher & Paykel) Randomized Controlled Trial | Preterm neonates   | 175                | Tertiary Care Hospital       |
|                               |         | CPAP nasal prongs (Fisher & Paykel)       |                      |                    |                        |
|                               |         | CPAP rotating group—prongs and mask (Fisher & Paykel) |                      |                    |                        |
| Bonfim 2014 [48]              | Brazil  | New nasal prongs Prospective Cohort        | Infants with GA < 37 weeks | 70             | Tertiary Care Hospital       |
| Goel 2015 [52]                | India   | bCPAP prongs (Fisher & Paykel) Randomized Controlled Trial | Preterm neonates   | 118                | Tertiary Care Hospital       |
| Singh 2017 [46]               | India   | nCPAP nasal mask Randomized Controlled Trial | Neonates           | 75                 | Tertiary Care Hospital       |

(Continued)
studies were excluded based on language (six non-English papers were translated using Google Translate). Findings were coded into six main categories: device attributes, patient experiences, provider experiences, parent experiences, barriers, and facilitators (Inter-rater reliability kappa score 0.91).

Description of included studies

The 54 included studies were conducted in 19 countries over five regions: Africa (n = 23), Asia (n = 15), Central & South America (n = 9), Middle East (n = 6), and Oceania (n = 11). Studies ranged from analysis of CPAP treatments (n = 34), training processes (n = 7), patient interfaces (n = 5), nasal protection (n = 3), body positions (n = 2), pain relief (n = 1), and general knowledge or perception surveys (n = 2). Most included studies were randomized controlled trials (n = 10), followed by observational (n = 8) and prospective cohort (n = 6) studies. The most common study populations were term and preterm neonates (n = 18), followed by only preterm neonates (n = 11), and healthcare providers (n = 15). Four studies described their sample population with the general term “infants,” which refers to ages 1–12 months, so unless specifically mentioned, the following findings refer to preterm and term neonates, defined as under one month of age.

Device attributes

Fourteen different CPAP devices were described across the included studies, including Fisher & Paykel (n = 14), Pumani (n = 8) and locally-made or improvised devices (n = 9). CPAP devices varied in price, features, and patient interfaces.

Price was one of the most common themes overall. Five studies emphasized that affordability and cost-effectiveness of different CPAP devices encouraged implementation [25–29] while five studies cited that if a CPAP device was expensive, cost was a barrier to implementation [25–27, 30, 31]. Commercial CPAP devices were noted to have other challenges. For example,
one study reported that nurses found certain CPAP systems “cumbersome [to set up], particularly securing the tubing to the headdress” [32]. Sessions et al. measured the length of time healthcare providers (HCPs) spent initiating and monitoring treatment with Fisher & Paykel bCPAP devices and reported it took 12.45 additional minutes to set up and adjust bCPAP equipment compared to the application of standard nasal oxygen [33]. A major focus of most bCPAP devices is to blend pure oxygen with air in order to decrease risk of potential complications from high concentrations of oxygen such as retinopathy of prematurity. However, this complex process is not possible in improvised CPAP devices, and was reported as an important challenge [27].

Important characteristics of various CPAP devices described across the studies included ease of use [25–27, 29, 34, 35] and effectiveness [26, 28, 30, 32, 34, 35]. Ease of use referred to experiences around simple set ups or low maintenance CPAP devices, while effectiveness related to a device’s overall ability to provide quality care. Factors such as “simplicity” [27] of a CPAP device and “the feedback provided with use of bCPAP, in terms of bubbling of the water column and wiggling of the chest wall” [26] were cited examples of ease of use. An additional identified device benefit was the potential for certain CPAP devices to be transportable, which could enable use in critical pre-hospital and transit settings [25].

**Patient experience**

Twenty-seven studies examined CPAP-related complications and comfort. The most common reported complications were related to nasal irritation [36, 37], nasal lesions [38–40] and abrasions [41] as well as nasal trauma or injuries such as nasal bleeds or hyperemia [40, 42, 43], and nasal septal necrosis [37, 44–46]. Low patient birthweights, low gestational ages [46, 47], and longer treatment times [40, 48, 49] were associated with increased nasal trauma. A number of studies also reported on techniques to reduce nasal trauma through application of protective dressings and use of various patient-device interfaces. In two studies, hydrocolloid dressings, a soft gel-based dressing, effectively reduced nasal injuries [50, 51]. Two of the four studies that compared nasal prongs to nasal masks concluded nasal masks were associated with statistically significant lower incidences of nasal injuries [(36% vs 58%) [52] (33% vs 92%) [53]].

Seven studies described pain or discomfort experienced by a patient on CPAP treatment [37, 45, 54–58]. These studies noted different levels of reported pain (assessed using validated pain assessment tools) based on device type and patient position. Khan et al. found that neonates in a local low-cost CPAP (J-CPAP) group had significantly lower average Neonatal-Pain Agitation and Sedation Scores (N-PASS) than those in a Fisher & Paykel bCPAP group [45]. Osman et al. reported higher pain scores in an nCPAP group compared to high flow nasal cannula [58]. Jabraeli et al. compared pain scores across supine, prone, and facilitated tucking (fetal) positions with nCPAP and described that the lowest pain scores were recorded when the neonate was in a fetal position [56]. Two additional studies found that when neonates received CPAP in a prone position, heart rates and respiratory rates were lower [59], but there were higher rates of nasal prong displacement (56% required repositioning) [60].

**Parent experience**

Four studies reported on parents’ experience when their newborns underwent CPAP treatment [33, 49, 50, 61]. These studies emphasized that communication between HCPs and parents is important. Parents should be taught about CPAP and engaged in their neonate’s care [61]. Two studies described parents’ fears related to CPAP treatment [49, 61]. Nyondo-Mipando et al. stated: “Study participants reported that caregivers sometimes had fears that the many tubes interfered with breathing and that oxygen therapy was associated with death--a
perception that may have been influenced by the lack of clear, effective communication between providers and caregivers” [49]. These two studies also reported on parent interactions with their babies while on CPAP treatment. Participation in their infant’s care, such as checking for bubbling in the device, was associated with decreased anxiety and worry [49, 61].

Provider experience

Multiple studies discussed providers’ knowledge of CPAP, device assembly, and patient selection for CPAP treatment. HCPs were more confident in their ability to use CPAP when the devices were simple and accompanied by quality training [26, 32, 34]. Several studies described nurses’ perceptions with CPAP treatment [26, 34, 35, 41, 43, 62]. Dewez et al. highlighted “most nurses felt that trained nurses could initiate CPAP independently” [34] and Atreya et al. stated that a CPAP device provided “neonatal nurses with more autonomy” [26]. In settings with limited medical personnel, this allowed nurses to play an important role in patient care [34].

Six studies described providers’ experiences with setting up CPAP devices and initiation of CPAP treatment [33, 39, 63–66]. Nasal prong dislodgment and the need to re-adjust the patient-device interface were common technical challenges during treatment for neonates and infants [7, 45, 67]. Ntigurirwa et al. described these challenges were difficult to address, “when the nurse to patient ratio is so much lower” [67]. Additionally, Sessions et al. reported that health workers “spent an average of 34.71 min longer per patient, initiating bCPAP compared to low-flow oxygen . . . [and] performed, on average, 26.40 more unique tasks” [33]. Chen et al. addressed this issue by demonstrating that both preparation and application time decreased significantly after staff were trained on a specific CPAP set up protocol [63].

Barriers

The primary barriers to CPAP implementation were a lack of HCPs and insufficient facility resources. HCP turnover and scarcity were often cited as limitations to effective training and quality patient monitoring [26, 32, 34, 41, 42, 44, 49, 65, 67–70]. Nahimana et al. suggested that gaps in “correct identification and initiation of eligible infants . . . might be a result of turnover of nurses and doctors” [70]. A lack of knowledge on how and when to initiate CPAP treatment was another commonly described barrier [26, 34, 37, 41, 49, 63, 70]. One study reported that a lack of device familiarity led to hesitation in use [41]. A lack of familiarity with CPAP may be associated with insufficient staff training [32, 49, 63, 64, 68, 71]. Two studies reported on nurses’ hesitation because they were “afraid of harming neonates because of the need to reuse consumables” [34] or due to “fear that the clinician would question their decision” [49] to initiate CPAP treatment. Other barriers to use of CPAP included lack of institutional buy-in [34, 41] and low staff motivation [67].

Facility resource constraints included lack of uninterrupted electricity, compressed air, oxygen blenders, specific CPAP protocols [72], and computers for record keeping [65]. Reliable electricity was the most frequently described facility infrastructure barrier that affected both patient care [34, 42, 49] and training [68]. In some instances, facility backup generators were not reliable during power outages [49]. Equipment shortages at medical facilities and in supply chains were the most commonly noted of all physical barriers [27, 32, 34, 49, 71, 72]. Amadi et al. identified “the high cost of devices, consumables and maintenance as limitations to the use of commercial CPAP systems” [25]. Four studies described it is critical that CPAP replacement parts are available in local supply chains [25, 27, 32, 42]. One study reported that facilities lacked CPAP devices because there were “not enough machines or many machines were broken”
To address these challenges, Carns et al. described that "spare parts should be easily sourced, and consumables should not be costly" [42].

Facilitators

Quality training and mentorship were the most commonly described facilitators for successful CPAP implementation [32, 35, 36, 41–43, 49, 63, 67–71, 73]. Four papers reported that refresher trainings improve CPAP use [32, 49, 68, 70]. Carns et al. described that follow-up “mentoring visits have ensured continued use of CPAP” [42] and Ntigurirwa et al. stated, “through regular, short visits, intensive training can be delivered and problems dealt with . . . but avoids the potential risk of trainers taking over the clinical care of the babies from local staff” [67]. While some studies reported that CPAP training increases provider knowledge and awareness [42, 63, 73], the most effective approach to training that enables long-term CPAP implementation is not well understood. Wilson et al. implemented a train-the-trainer model where American providers trained Ghanaian nurses, who then trained their colleagues; the latter of whom scored significantly lower on both knowledge and skills testing [32].

Another facilitator described by six studies was the use of an algorithm to guide optimal selection and treatment of patients [36, 44, 49, 64, 66, 70]. Clinical decision algorithms, such as the TRY algorithm were described as easy to teach and integrate [36] to improve infant and neonate treatment [64, 66]. According to Crehan et al, “the TRY-CPAP algorithm was helpful in guiding healthcare workers in the safe and appropriate application of low-cost bubble CPAP in a district hospital setting where usually physicians are absent and care is nurse-led” [64]. Additionally, some studies reported on the need for training on bioengineering support for CPAP devices [36, 42]. Finally, two studies identified buy-in from Ministries of Health and policymakers as critical facilitators to successful implementation [26, 42].

Discussion

This scoping review examined the literature to identify challenges and priorities of CPAP implementation in low-resource settings. Potential priorities for successful CPAP implementation included ease of CPAP device operation [25–27, 29, 34, 35], low cost [25–27, 30, 31], and reliable supply chain for consumables [25, 27, 32, 42]. Common barriers of CPAP implementation included unreliable electricity [34, 42, 49, 68], insufficient CPAP devices and supporting equipment such as pulse oximeters [27, 32, 34, 49, 71, 72], and lack of bioengineering for CPAP device maintenance and repair [32, 34]. Quality training and mentorship that empowered providers facilitated successful CPAP implementation [32, 35, 36, 41–43, 49, 63, 67–71, 73].

A major finding from this review was that it is essential that CPAP devices are easy to assemble, use, maintain, and have simple bioengineering support [33, 39]. Evidence has shown how devices designed in high resource settings are not sustainable as once they break, there is no bioengineering support to fix them [74, 75]. While CPAP devices have traditionally been designed in high resource settings, the unique contexts of low resource regions need to be considered when implementing CPAP across these settings. For example, the polite bCPAP device was specifically designed after surveying Nigerian HCPs on their preferences. Affordability, transportability, and simplicity were the most essential characteristics [25]. The essential takeaway here is that a device’s success is dependent on the users and their settings and therefore it is imperative to involve the target audience in the design and implementation process. Such a human-centered design approach has a greater potential to create sustainable, context-based solutions [76]. Incorporating human-centered design facilitates local ownership of CPAP devices and programs by creating a system that may be more appropriate and sustainable [77].
In addition to engineering devices to match their settings, the sustainability of their consumables must also be considered [74]. It is well understood with any device that without available consumables devices will be unusable and only generate waste. That is why it is essential future interventions go beyond facility introduction of CPAP devices to comprehensive integration into health systems in order to ensure sustainability and scale. This includes engaging local manufactures and supply chains. Another solution includes understanding what components could be safely cleaned as reused. Two studies in this review did so for nasal prongs [48, 78], but there is a need to determine safe and standardized reprocessing procedures that are feasible across facilities with different levels of resources. These factors should also be considered in the initial design of devices as mentioned above [76].

Quality training and mentorship were identified as vital facilitators of successful CPAP implementation [17]. Providers must feel confident, empowered, and knowledgeable about CPAP to support and encourage long-term implementation. There is a need for more evidence on different models of training and mentorship, especially taking into account limitations on staff availability. The findings from this review suggest that training models should be integrated into the flow of work with interval in-service training and simulation. As with device design, the development and implementation of training materials should be co-created with local healthcare provider leaders in the settings where they will be used. This will not only foster engagement, but also further adapt education and use to the particular setting in which it will be used [79].

Limitations
A limitation of this review was the significant variation in study design across the included studies. By setting out to capture a wide range of experiences, we incorporated studies with varied interventions and outcomes. For example, the subset of papers on complications and interventions associated with nasal injury were challenging to compare with studies that reported on the effectiveness of different CPAP devices.

Conclusion
Inconsistent parameters and outcomes between studies to-date have prevented meta-analyses [13–16]. The study designs, interventions, and objectives in our included studies were also remarkably diverse. Each of the studies in this review addressed an aspect of CPAP implementation that is important to consider when planning for long-term integration of this treatment. While implementation factors are often addressed separately from efficacy and safety in high-resource settings [80], the breadth of experiences described in this review indicates how these measures must be considered concurrently in low-resource settings. Future effectiveness studies should consider not only the short and medium term population outcomes, but also factors that influence sustained integration of CPAP into health systems. A standardized set of implementation outcomes for future research—common barriers and facilitators to study—could allow for improved data synthesis and guidance on optimal care and future research questions.

Successful implementation and integration of CPAP devices across health systems in low-resource settings require appropriate devices, reliable supply chains to replace consumables, and innovative training models that engage users. Each of these elements have one key connection: they each require a deeper engagement of healthcare workers and health systems using these devices. From start to finish CPAP design and implementation should be driven by the final users and the system in which they operate. Combined, it is the hope that these efforts can empower and promote device use, rather than perpetuate potentially unsustainable implementation processes for CPAP use in low-resource settings.
Supporting information
S1 File. PRISMA-ScR checklist. (DOCX)
S2 File. Database search queries. (DOCX)

Acknowledgments
The authors would like to acknowledge Harvard Countway Library for the review services provided by Paul Bain in reviewing and running the search query across databases and importing the citations into Covidence.

Author Contributions
Conceptualization: Sara Dada.
Data curation: Sara Dada, Rupam Sharma.
Formal analysis: Sara Dada, Henry Ashworth, Alina Sobitschka.
Methodology: Sara Dada, Rebecca L. Hamilton.
Resources: Sara Dada.
Supervision: Thomas Burke.
Writing – original draft: Sara Dada, Henry Ashworth, Vanitha Raguveer.
Writing – review & editing: Sara Dada, Henry Ashworth, Alina Sobitschka, Vanitha Raguveer, Rebecca L. Hamilton, Thomas Burke.

References
1. Secretary-General U. Special Edition: Progress Towards the Sustainable Development Goals. Publication E/2019/68. United Nations Economic and Social Council; 2019.
2. Newborns: reducing mortality: World Health Organization; 2019 [updated 19 September 2019. https://www.who.int/news-room/fact-sheets/detail/newborns-reducing-mortality.
3. Hug L, Alexander M, You D, Alkema L. National, regional, and global levels and trends in neonatal mortality between 1990 and 2017, with scenario-based projections to 2030: a systematic analysis. The Lancet Global Health. 2019; 7(6):e710–e20. https://doi.org/10.1016/S2214-109X(19)30163-9 PMID: 31097275
4. Kamath BD, Macguire ER, McClure EM, Goldenberg RL, Jobe AH. Neonatal mortality from respiratory distress syndrome: lessons for low-resource countries. Pediatrics. 2011; 127(6):1139–46. https://doi.org/10.1542/peds.2010-3212 PMID: 21536613
5. Ainsworth SB. Pathophysiology of neonatal respiratory distress syndrome: implications for early treatment strategies. Treat Respir Med. 2005; 4(6):423–37. https://doi.org/10.2165/00151829-200504060-00006 PMID: 16336027
6. Abelenda VLB, Valente TCO, Marinho CL, Lopes AJ. Effects of underwater bubble CPAP on very-low-birth-weight preterm newborns in the delivery room and after transport to the neonatal intensive care unit. Journal of Child Health Care. 2018; 22(2):216–27. https://doi.org/10.1177/1367493517752500 PMID: 29335421
7. Tagare A, Kadam S, Vaidya U, Pandit A, Patole S. Bubble CPAP versus ventilator CPAP in preterm neonates with early onset respiratory distress—a randomized controlled trial. Journal of Tropical Pediatrics. 2013; 59(2):113–9. https://doi.org/10.1093/tropej/fms061 PMID: 23306407
8. Urs PS, Khan F, Maiya PP. Bubble CPAP—A primary respiratory support for respiratory distress syndrome in newborns. Indian Pediatrics. 2009; 46(5):409–11. PMID: 19179737
9. Organization WH. WHO recommendations on interventions to improve preterm birth outcomes. 2015.
Implementation of CPAP for neonates and infants in resource-poor settings: A scoping review

10. Won A, Suarez-Rebling D, Baker AL, Burke TF, Nelson BD. Bubble CPAP devices for infants and children in resource-limited settings: review of the literature. Paediatrics and International Child Health. 2019; 39(3):168–76. https://doi.org/10.1080/20469047.2018.1534389 PMID: 30375281

11. Duke T. CPAP: a guide for clinicians in developing countries. Paediatrics & International Child Health. 2014; 34(1):3–11. https://doi.org/10.1179/2046905513Y.0000000102 PMID: 24165032

12. Dewez JE, van den Broek N. Continuous positive airway pressure (CPAP) to treat respiratory distress in newborns in low- and middle-income countries. Tropical Doctor. 2016; 47(1):19–22. https://doi.org/10.1177/0049475516630210 PMID: 26864235

13. Martin S, Duke T, Davis P. Efficacy and safety of bubble CPAP in neonatal care in low and middle income countries: a systematic review. Archives of Disease in Childhood Fetal & Neonatal Edition. 2014; 99(6):F495–504. https://doi.org/10.1136/archdischild-2013-305519 PMID: 25085942

14. Norgaard M, Stagstrup C, Lund S, Poulsen A. To Bubble or Not? A Systematic Review of Bubble Continuous Positive Airway Pressure in Children in Low- and Middle-Income Countries. Journal of Tropical Pediatrics. 2019; 10:10.

15. Thukral A, Sankar MJ, Chandrasekaran A, Agarwal R, Paul VK. Efficacy and safety of CPAP in low- and middle-income countries. Journal of Perinatology. 2016; 36 Suppl 1:S21–8. https://doi.org/10.1038/jp.2016.29 PMID: 27109089

16. Ekhaguere OA, Mairami AB, Kirpalani H. Risk and benefits of Bubble Continuous Positive Airway Pressure for neonatal and childhood respiratory diseases in Low- and Middle-Income countries. Paediatric Respiratory Reviews. 2019; 31:36–1. https://doi.org/10.1016/j.prrv.2018.04.004 PMID: 29907334

17. Kinshella MW, Walker CR, Hiwa T, Vidler M, Nyondo-Mipando AL, Dube Q, et al. Barriers and facilitators to implementing bubble CPAP to improve neonatal health in sub-Saharan Africa: a systematic review. Public Health Rev. 2020; 41:6. https://doi.org/10.1186/s40985-020-00124-7 PMID: 32368359

18. PRISMA Extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation. Annals of internal medicine. 2018; 169(7):467–73. https://doi.org/10.7326/M18-0850 PMID: 30178033

19. Arksey H, O'Malley L. Scoping studies: towards a methodological framework. International journal of social research methodology. 2005; 8(1):19–32.

20. Peters M, Godfrey C, McNerney P, Munn Z, Tricco AC, Khalil H. Chapter 11: Scoping Reviews (2020 version). JBI Manual for Evidence Synthesis. Aromatari E, Munn Z, editors: JBI; 2020.

21. Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation. Annals of internal medicine. 2018; 169(7):467–73. https://doi.org/10.7326/M18-0850 PMID: 30178033

22. Kyngäs H. Inductive content analysis. The application of content analysis in nursing science research: Springer; 2020. p. 13–21.

23. Thomas DR. A general inductive approach for qualitative data analysis. 2003.

24. Moher D, Liberati A., Tetzlaff J., & Altman DG (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. BMJ.; 339:b2535. https:/ /doi.org/10.1136/bmj. b2535 PMID: 19622551

25. Dewez JE, van den Broek N. Continuous positive airway pressure (CPAP) to treat respiratory distress in newborns in low- and middle-income countries. Tropical Doctor. 2016; 47(1):19–22. https://doi.org/10.1177/0049475516630210 PMID: 26864235

26. Atreya MR, Lorenz JM, Narendran V. Provider Perceptions of Bubble Continuous Positive Airway Pressure and Barriers to Implementation in a Level III Neonatal Unit in South India. Advances in Neonatal Care. 2018; 18(6):500–6. https://doi.org/10.1097/ANC.0000000000000510 PMID: 29863501

27. Audu L, Otuneye A, Mairami A, Mukhtar M. Improvised bubble continuous positive airway pressure (BCPAP) device at the National Hospital Abuja gives immediate improvement in respiratory rate and oxygenation in neonates with respiratory distress. Nigerian Journal of Paediatrics. 2015; 42(1):12–6. https://doi.org/10.1097/TP.0b013e3182c69b0e PMID: 2622551

28. Amadi HO, Okonkwo IR, Abiyoue IO, Abubakar AL, Olateju EK, Adesina CT, et al. A new low-cost commercial bubble CPAP (bCPAP) machine compared with a traditional bCPAP device in Nigeria. Paediatric Respirator y Reviews. 2019; 29:31–6. https://doi.org/10.1016/j.prrv.2018.04.004 PMID: 29907334

29. Dewez JE, van den Broek N. Continuous positive airway pressure (CPAP) to treat respiratory distress in newborns in low- and middle-income countries. Tropical Doctor. 2016; 47(1):19–22. https://doi.org/10.1177/0049475516630210 PMID: 26864235

30. Bahman-Bijari B, Malekijany A, Niknafs P, Baneshi M-R. Bubble-CPAP vs. Ventilatory-CPAP in Preterm Infants with Respiratory Distress. Iranian Journal of Pediatrics. 2011; 21(2):151–8. PMID: 23056781
31. Hendriks H, Kirsten GF, Voss M, Conradie H. Is continuous positive airway pressure a feasible treatment modality for neonates with respiratory distress syndrome in a rural district hospital? Journal of Tropical Pediatrics. 2014; 60(5):348–51. https://doi.org/10.1093/tropej/fmu025 PMID: 24876302

32. Wilson PT, Brooks JC, Otpupiri E, Moresky RT, Morris MC. Aftermath of a clinical trial: evaluating the sustainability of a medical device intervention in Ghana. Journal of Tropical Pediatrics. 2014; 60(1):33–9. https://doi.org/10.1093/tropej/fmt074 PMID: 23980121

33. Sessions KL, Mvalo T, Kondowe D, Makonokaya D, Hosseininpour MC, Chalira A, et al. Bubble CPAP and oxygen for child pneumonia care in Malawi: a CPAP IMPACT time motion study. BMC Health Services Research. 2019; 19(1):533. https://doi.org/10.1186/s12913-019-4364-y PMID: 31366394

34. Dewez JE, Chellani H, Nangia S, Metsis K, Smith H, Mathai M, et al. Healthcare workers’ views on the use of continuous positive airway pressure (CPAP) in neonates: a qualitative study in Andhra Pradesh, India. BMC Pediatrics. 2018; 18(1):347. https://doi.org/10.1186/s12887-018-1311-8 PMID: 30400844

35. Koyamaibole L, Kado J, Qovu JD, Colquhoun S, Duke T. An evaluation of bubble-CPAP in a neonatal unit in a developing country: effective respiratory support that can be applied by nurses. Journal of Tropical Pediatrics. 2006; 52(4):249–53. https://doi.org/10.1093/tropej/fmi109 PMID: 16326752

36. McAdams RM, Hedstrom AB, DiBlasi RM, Mant JE, Nyonyintono J, Otai CD, et al. Implementation of Bubble CPAP in a Rural Ugandan Neonatal ICU. Respiratory Care. 2015; 60(3):437–45. https://doi.org/10.4187/respcare.03438 PMID: 25389349

37. Silva DMd Chaves EMC, Farias LM Lélis ALPdA. Use of continuous positive airway pressure in newborns: knowledge of the nursing team using at the hospital. Rev RENE. 2010; n(e:):195–203.

38. Dewez JE, Nangia S, Chellani H, White S, Mathai M, van den Broek N. Availability and use of continuous positive airway pressure (CPAP) for neonatal care in public health facilities in India: a cross-sectional cluster survey. BMJ Open. 2020; 10(2):e031128. https://doi.org/10.1136/bmjopen-2019-031128 PMID: 32114460

39. García Reza C, Mejía-Flores MA, Guadarrama Pérez L, Gómez Martínez V. Intervenciones de enfermería en neonatos con presión positiva continua. Investigacion en Enfermería: Imagen y Desarrollo. 2018; 20(1):10-N.PAG.

40. Yong SC, Chen SJ, Boo NY. Incidence of naso trauma associated with nasal prong versus nasal mask during continuous positive airway pressure treatment in very low birthweight infants: a randomised control study. Archives of Disease in Childhood Fetal Neonatal Edition. 2005; 90(6):F480–3. https://doi.org/10.1136/adc.2004.069351 PMID: 15941925

41. van den Heuvel M, Blencowe H, Mittermayer K, Rylance S, Couperus A, Heikens GT, et al. Introduction of bubble CPAP in a teaching hospital in Malawi. Annales of Tropical Paediatrics. 2011; 31(1):59–65. https://doi.org/10.1173/1465328110Y.00000000001 PMID: 21262111

42. Cars J, Kawaza K, Liaghati-Mobarhan S, Asibon A, Quinn MK, Chalira A, et al. Neonatal CPAP for Respiratory Distress Across Malawi and Mortality. Pediatrics. 2019; 144(4):10. https://doi.org/10.1542/peds.2019-0668 PMID: 31540968

43. Olayo B, Kirigia CK, Oliwa JN, Agai ON, Morris M, Benckert M, et al. Effective training-of-trainers model for the introduction of continuous positive airway pressure for neonatal and paediatric patients in Kenya. Paediatrics & international Child Health. 2019; 39(3):193–200. https://doi.org/10.1080/20469047.2019.1624007 PMID: 31190634

44. Jardine C, Ballot DE. The use of nasal CPAP at the charlotte maxeke johannesburg academic hospital. SAJCH South African Journal of Child Health. 2015; 9(2):45–8.

45. Khan J, Sundaram V, Murki S, Bhatti A, Saini SS, Kumar P. Nasal injury and comfort with jet versus bubble continuous positive airway pressure delivery systems in preterm infants with respiratory distress. Eur J Pediatr. 2017; 176(12):1629–35. https://doi.org/10.1007/s00431-017-3016-7 PMID: 28914355

46. Singh J, Bhardwaj V, Chitra D. To Compare the Efficacy and Complication of Nasal Prongs vs Nasal Mask CPAP in Neonates. 2017.

47. Bassiouney MR, Gupta A, el Buayy M. Nasal continuous positive airway pressure in the treatment of respiratory distress syndrome: an experience from a developing country. Journal of Tropical Pediatrics. 1994; 40(6):341–4. https://doi.org/10.1093/tropej/40.6.341 PMID: 7853438

48. Bonfil S, de Vasconcelos MGL, de Sousa NFC, da Silva DVC, Leal LP. Nasal septum injury in preterm infants using nasal prongs. Revista Latino-Americana De Enfermagem. 2014; 22(5):626–33. https://doi.org/10.1590/0104-1169.2014.2205298 PMID: 24593679

49. Nyondo-Mipando AL, Wco Kinshella ML, Bohne C, Suwedi-Kapesa LC, Salimu S, Banda M, et al. Barriers and enablers of implementing bubble Continuous Positive Airway Pressure (CPAP): Perspectives of health professionals in Malawi. PLoS ONE [Electronic Resource]. 2020; 15(2):e0228915. https://doi.org/10.1371/journal.pone.0228915 PMID: 32053649
50. Xiaoyan XU, Yuanxiang WEN, Chenghua Z. Application of hydrocolloid dressing in the treatment of N-CPAP. Modern Clinical Nursing. 2013(6):16–8.

51. Xie LH. Hydrocolloid dressing in preventing nasal trauma secondary to nasal continuous positive airway pressure in preterm infants. World Journal of Emergency Medicine. 2014; 5(3):203–8. https://doi.org/10.5847/wjem.j.issn.1920-8642.2014.03.008 PMID: 25225585

52. Goel S, Mondkar J, Panchal H, Hegde D, Utture A, Manerkar S. Nasal Mask Versus Nasal Prongs for Delivering Nasal Continuous Positive Airway Pressure in Preterm Infants with Respiratory Distress: A Randomized Controlled Trial. Indian Pediatr. 2015. https://doi.org/10.1007/s13312-015-0769-9 PMID: 26713987

53. Bashir T, Murki S, Kiran S, Reddy VK, Oleti TP. ‘Nasal mask’ in comparison with ‘nasal prongs’ or ‘rotation of nasal mask with nasal prongs’ reduce the incidence of nasal injury in preterm neonates supported on nasal continuous positive airway pressure (nCPAP): A randomized controlled trial. PLoS ONE [Electronic Resource]. 2019; 14(1):e0211476. https://doi.org/10.1371/journal.pone.0211476 PMID: 30703172

54. Antunes JCP, Nascimento MA dL. The non-nutritive sucking of premature newborn as a nursing technology. La succión no nutritiva de los recién nacidos prematuros como una tecnología de enfermería / A succão não nutritiva do recém-nascido prematuro como uma tecnologia de enfermagem. Rev bras enferm. 2013; 66(5):663–7. https://doi.org/10.1590/s0027-28172013000500004 PMID: 24217748

55. Antunes JCP, Nascimento MAL, Gomes AVO, Araujo MC. Installation CPAP nasal—identifying the pain of newborns as a nursing care [sic]. Journal of Nursing UFPE / Revista de Enfermagem UFPE. 2010; 4(1):137–44.

56. Jabræll M, Eskandari S, Hosseini MB, Rahmani P. The Effect of Body Position on Pain Due to Nasal Continuous Positive Airway Pressure (CPAP) in Premature Neonates: A Cross-Over Clinical Trial Study. International Journal of Pediatrics-Mashhad. 2018; 6(1):686–71.

57. Nunes CR, Castro SBd, Motta GdCPd, Silva AMd, Schardosim JM, Cunha MLCd. Prevention of nasal trauma due to CPAP in a preterm newborn: case report / Método de prevenção de lesão nasolacuada por CPAP em recém-nascido pré-termo: relato de caso. Rev HCPA & Fac Med Univ Fed Rio Gd do Sul. 2012; 32(4):480–4.

58. Osman M, Elsharkawy A, Abdel-Hady H. Assessment of pain during application of nasal-continuous positive airway pressure and heated, humidified high-flow nasal cannulae in preterm infants. J Perinatol. 2015; 35(4):263–7. https://doi.org/10.1038/jp.2014.206 PMID: 25429383

59. Ghorbani F, Valizadeh S, Asadollahi M. Comparison of Prone and Supine Positions on Oxygenation of Premature Infants with Respiratory Distress Syndrome Treated with CPAP in Tabriz Alzahra Hospital, 2010. Tabriz, Iran. Qom University of Medical Sciences Journal. 2013; 6(4):57–63.

60. Brunherotti MAA, Martinez FE. Influence of body position on the displacement of nasal prongs in preterm newborns receiving continuous positive airway pressure / Influência da posição corporal no deslocamento da pronga nasal em recém-nascido pré-termo em pressão positiva contínua em vias aéreas. Rev paul pediatr. 2015; 33(3):280–5.

61. Gondwe MJ, Gombachika B, Majamanda MD. Experiences of caregivers of infants who have been on bubble continuous positive airway pressure at Queen Elizabeth Central Hospital, Malawi: A descriptive qualitative study. Malawi Medical Journal. 2017; 29(1):10–5. PMID: 28567190

62. Al-Lawama M, Alkhathib H, Wakileh Z, Elqaisi R, AlMassad G, Badran E, et al. Bubble CPAP therapy for neonatal respiratory distress in level III neonatal unit in Amman, Jordan: a prospective observational study. International journal of general medicine. 2019; 12:25–30. https://doi.org/10.2147/IJGM.S185264 PMID: 30636889

63. Chen CY, Chou AK, Chen YL, Chou HC, Tsao PN, HsiehWS. Quality Improvement of Nasal Continuous Positive Airway Pressure Therapy in Neonatal Intensive Care Unit. Pediatrics & Neonatology. 2012; 53(4):137–44.

64. Crehan C, Colbourn T, Heys M, Holme N, Molyneux E. Evaluation of ‘TRY’: an algorithm for initiation of CPAP in neonates with respiratory distress in Malawi. Archives of Disease in Childhood Fetal & Neonatal Edition. 2015; 100(4):F332–6. https://doi.org/10.1136/archdischild-2014-308082 PMID: 25877290
67. Ntigurirwa P, Mellor K, Langer D, Evans M, Robertson E, Tuyisenge L, et al. A health partnership to reduce neonatal mortality in four hospitals in Rwanda. Global Health. 2017; 13(1):28. https://doi.org/10.1186/s12992-017-0252-6 PMID: 28569202

68. Asibon A, Lufesi N, Choudhury A, Olvera S, Molyneux E, Oden M, et al. Using a peer mentorship approach improved the use of neonatal continuous positive airway pressure and related outcomes in Malawi. Acta Paediatrica. 2019; 19:19. https://doi.org/10.1111/apa.15025 PMID: 31535392

69. Myhre J, Immaculate M, Okeyo B, Anand M, Omoding A, Myhre L, et al. Effect of treatment of preterm infants with respiratory distress using low-cost bubble CPAP in a rural African hospital. MIDIRS Midwifery Digest. 2017; 27(2):263-.

70. Nahimana E, Ngendahayo M, Maghe H, Odhiambo J, Amoroso CL, Muhirwa E, et al. Bubble CPAP to support preterm infants in rural Rwanda: a retrospective cohort study. BMC Pediatrics. 2015; 15:135. https://doi.org/10.1186/s12887-015-0449-x PMID: 26403679

71. Okonkwo I, Okolo A. Bubble CPAP in Nigerian tertiary hospitals; Patented and improvised. Nigerian Journal of Paediatrics. 2016; 43(4):286–90.

72. Boo NY, Cheah IG, Neoh SH, Chee SC, Malaysian National Neonatal R. Impact and Challenges of Early Continuous Positive Airway Pressure Therapy for Very Low Birth Weight Neonates in a Developing Country. Neonatology. 2016; 110(2):116–24. https://doi.org/10.1159/000444316 PMID: 27074004

73. Tiryaki Ö, Cinar N. Manejo de la presión positiva continua en las vías respiratorias en el recién nacido: el impacto de talleres interactivos basados en conferencias sobre la formación de las enfermeras de cuidados intensivos neonatales Manejo da pressão positiva continua nas vias respiratorias no recém-nascido: o impacto de oficinas interativas baseadas em conferências sobre a formação das enfermeiras de cuidados intensivos neonatais / Management of Continuous Positive Airway Pressure in the Newborn: Impact of Lecture-based Interactive Workshops on Training for Neonatal Intensive Care Nurses. Aquichan. 2016; 16(2):159–68.

74. Compton B, Barash DM, Farrington J, Hall C, Herzog D, Meka V, et al. Access to medical devices in low-income countries: addressing sustainability challenges in medical device donations. NAM Perspectives. 2018.

75. Perry L, Malkin R. Effectiveness of medical equipment donations to improve health systems: how much medical equipment is broken in the developing world? Medical & Biological Engineering & Computing. 2011; 49(7):719–22. https://doi.org/10.1007/s11517-011-0786-3 PMID: 21597999

76. Demiril HO, Duffy VG, editors. A Sustainable Human Centered Design Framework Based on Human Factors 2013; Berlin, Heidelberg: Springer Berlin Heidelberg.

77. Organization WH. Human resources for medical devices, the role of biomedical engineers: World Health Organization; 2017.

78. do Nascimento RM, Ferreira AL, Coutinho AC, Santos Veríssimo RC. The frequency of nasal injury in newborns due to the use of continuous positive airway pressure with prongs. Rev Lat Am Enfermagem. 2009; 17(4):489–94. https://doi.org/10.1590/s0104-11692009000400009 PMID: 19820885

79. DasGupta S, Fornari A, Geer K, Hahn L, Kumar V, Lee HJ, et al. Medical education for social justice: Paulo Freire revisited. J Med Humaniit. 2006; 27(4):245–51. https://doi.org/10.1007/s10912-006-9021-x PMID: 17001528

80. Peters DH, Tran NT, Adam T. Implementation research in health: a practical guide: World Health Organization; 2013.

81. Abdulkadir I, Abdullahi F. The Use of bubble nasal CPAP in the management of IRDS-A Case report and literature review. Nigerian Journal of Paediatrics. 2013; 40(3):303–6.

82. Abdulkadir I, Hassan L, Abdullahi F, Purdue S, Ogala WN. Nasal Bubble CPAP: One Year Experience in a Neonatal Unit of a Tertiary Health Facility in Northwestern Nigeria. Nigerian Postgraduate Medical Journal. 2015; 22(1):21–4.

83. Dai T, Lv L, Liu X, Chen J, Ye Y, Xu L. Nasal Pressure Injuries Due to Nasal Continuous Positive Airway Pressure Treatment in Newborns: A Prospective Observational Study. Journal of Wound, Ostomy, & Continence Nursing. 2020; 47(1):26–31. https://doi.org/10.1097/WON.0000000000000604 PMID: 31929441

84. de Siqueira VSA, Alves VH, de Souza Rosa Barbosa MT, Rodrigues DP, Vieira BDG, da Silva. QUALITY INDICATORS IN VENTILATORY ASSISTANCE IN A UNIVERSITY HOSPITAL: DO KNOW IN NURSING. Journal of Nursing UFPE / Revista de Enfermagem UFPE. 2014; 8(4):797–807.