Bubble CPAP splitting: innovative strategy in resource-limited settings

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ABSTRACT

Background Non-invasive respiratory support for neonates using bubble continuous positive airway pressure (bCPAP) delivery systems is now widespread owing to its safety, cost effectiveness and easy applicability. Many innovative solutions have been suggested to deal with the possible shortage in desperate situations like disasters, pandemics and resource-limited settings. Although splitting of invasive ventilation has been reported previously, no attempts to split non-invasive respiratory support have been reported.

Objective The primary objective was to test the feasibility of splitting the bCPAP assembly using a T-piece splitter in a simulation model.

Methods A pilot simulation-based study was done to split a single bCPAP assembly using a T-piece. Other materials consisted of a heated humidification system, an air oxygen blender, corrugated inspiratory and expiratory tubing, nasal interfaces and two intercostal chest tube drainage bags. Two pressure manometers were used simultaneously to measure delivered pressures at different levels of set bCPAPs at the expiratory limb of nasal interfaces.

Results Pressures measured at the expiratory end of two nasal interfaces were 5.1 and 5.2 cm H_2O, respectively, at a flow of 6 L/min and a water level of 5 cm H_2O in both chest bags. When tested across different levels of set continuous positive airway pressure (3–8 cmH_2O) and fractional inspired oxygen concentration (0.30–1.0), measured parameters corresponded to set parameters.

Conclusion bCPAP splitting using a T-piece splitter is a technically simple, feasible and reliable strategy tested in a simulation model. Further testing is needed in a simulated lung model.

INTRODUCTION

Globally, more than 80% of childhood mortality under 5 years of age occur in low-income and middle-income countries with over 15 million babies being born preterm every year.[1 2] Complications of preterm birth leading to respiratory complications have been one of the top three leading causes of death in these children.[1] Use of continuous positive airway pressure (CPAP) is one of the recommended interventions to reduce mortality and morbidity in preterm infants.[3] Two recently published randomised controlled trials from Bangladesh and Ghana showed physiological and mortality benefits with the use of bubble continuous positive airway pressure (bCPAP) in select paediatric populations below 5 years of age.[4 5]

bCPAP is a form of non-invasive respiratory support which is a gentle, simple, safe and effective way of respiratory support especially used in infants and children. It acts as a bridge between oxygen therapy and invasive ventilation. The feasibility and widespread use of such set-up in resource-limited countries is further supported by its perceived safety, reduced invasiveness and less demanding technical skill requirement.

In the last few years, several new devices with alterations in the original design have been described for more widespread use of CPAP in resource-limited settings. However, many such designs use a high-resistance interface and narrow expiratory tubing, and this can significantly affect CPAP delivery and imposed work of breathing.[6] There is anticipated to be a surge in the number of preterm births in India due to rising maternal infection with the novel coronavirus infection and a parallel dwindling of availability of medical supplies, ventilators and CPAP machines because of demands in adult intensive care units and wards. Therefore, preterm and high-risk infants with respiratory distress may miss out on this therapy.

The idea of splitting ventilator using air tube splitters to ventilate multiple patients simultaneously has been tried in countries where there is acute shortage of ventilators especially in the current COVID-19 pandemic.[7] However, this was

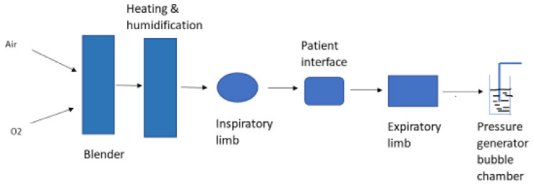

Figure 1 Typical bubble continuous positive airway pressure set-up for a single patient.

Figure 2 T-piece splitter.

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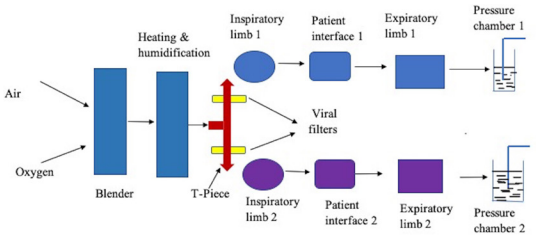

Figure 3 Split continuous positive airway pressure with T-piece with proposed position of viral/bacterial filters.

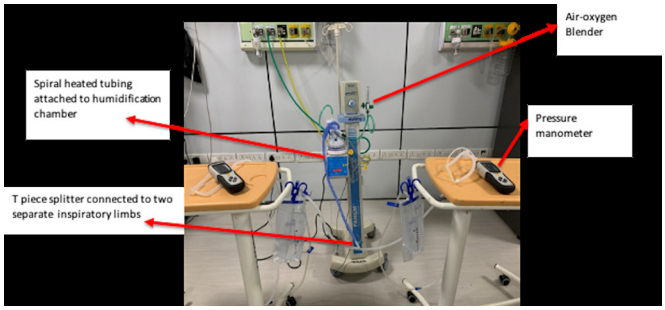

Figure 4 Split continuous positive airway pressure assembly using a single T-piece splitter.

in adults, and no studies have addressed the issue of applying the same principles to non-invasive ventilation. Hence, we aimed to test a practical solution whereby a T-piece connector and dual microbial filter was used to split the bCPAP assembly into two users using a single humidifier and air–oxygen blender. The assembly was tested in a simulation model.

MATERIAL AND METHODS

A pilot simulation-based study was conducted in the neonatology unit of a tertiary care academic institute in northern India. Materials which are locally available in our unit were used for the experimental set-up. The basic assembly of a bCPAP system consists of an air–oxygen blender, humidifier, bubble generator jar, circuits and interface (figure 1). An air–oxygen blender (Make Biomed Devices, USA) and a heated humidifier system (Make Flexicare Medical India Pvt, India branch) was used as a common unit for the two CPAPs. Other materials used were chest tube drainage bags filled with water (Make Romsons Scientific & Surgical Industries Pvt, India), corrugated tubing as inspiratory and expiratory limbs, each with a length of 1.2 m and an internal diameter of 10 mm. The central supply wall-mounted ports provided air and oxygen to the blender, and after adjusting the flow in the flow meters, the humidification chamber was attached. A spiral heated tubing with a length of 1.1 m and an internal diameter of 15 mm was connected to the respiratory humidifier, and a T-piece splitter (figure 2) was used at the end of tubing for splitting the single set-up into two systems (figure 3). The ends of the T-piece splitter were then connected to two corrugated tubings, which acted as inspiratory limbs. Two Hudson nasal prongs (size 2) were used as patient interfaces. The other ends of interfaces are attached to two corrugated expiratory tubings, which were then joined to two chest drainage bags filled with water. To measure the water level accurately, 1 cm graduated markings from 0 to 10 cm were made. The level of the water column could be adjusted according to the desired CPAP requirement (figure 4). Two pressure manometers (Make HTC Instruments PM 6205, India) were used simultaneously to measure pressure at the expiratory end of both the nasal interfaces. Delivered fractional inspired oxygen concentration (FiO_2) was measured using an oxygen analyser (Make Teledyne Analytical Instruments, USA). Using two or more T-piece splitters for delivery to multiple patients or use of simple oxygen tubing in place of corrugated heated tubing in resource-limited settings is also configurable; however, this would require separate assessment under experimental settings.

The literature search was done using various data sources like PubMed, Google Scholar, screening of cross references and grey literature using search words “spilt ventilation”, “co-ventilation” and “split non-invasive ventilation”.

RESULTS

Pressures measured at the expiratory end of two nasal interfaces were 5.1 and 5.2 cm H_2O, after occluding the nasal prongs and at a flow of 6 L/min and water level of 5 cm in both chest tube drainage bags. When measured across set levels of CPAP (3–8 cmH_2O), delivered pressures were comparable to set levels of CPAP. Similarly, delivered FiO_2 closely approximated to set FiO_2 on oxygen blender (table 1).

DISCUSSION

The technique of splitting ventilation for providing respiratory support to multiple patients was attempted in four simulated test

Table 1 Set and measured parameters at two circuits of the split CPAP system

	Circuit 1			Circuit 2		
Set FiO_2 on oxygen blender	Measured FiO_2	Set CPAP (cm H_2O)	Measured CPAP (cm H_2O)	Measured FiO_2	Set CPAP (cm H_2O)	Measured CPAP (cm H_2O)
0.30	0.28	3	3.6	0.29	3	3.3
0.40	0.41	4	4.1	0.40	4	4.0
0.45	0.44	4	4.1	0.43	5	4.6
0.50	0.48	4	4.2	0.49	6	5.9
0.50	0.50	5	5.1	0.51	5	5.2
0.60	0.60	6	5.9	0.60	5	5.1
0.70	0.72	6	6.2	0.69	6	6.0
0.80	0.80	6	6.1	0.78	8	7.9
0.80	0.81	7	6.9	0.78	6	6.1
0.90	0.88	7	7.1	0.89	7	6.8
1	0.99	8	8.1	0.99	8	7.8

CPAP, continuous positive airway pressure; FiO_2, fractional inspired oxygen concentration.

Table 2 Review of literature on prior attempts on splitting of ventilation for multiple patient use

Author, year	Subjects	Strategy	Conclusions
Clark *et al*, 2020[13]	Simulation model	Two test lungs of different compliance tested with single ventilator	Demonstrated capacity to simultaneously ventilate two test lungs of different compliance
Raredon *et al*, 2020[14]	Simulation model	Pressure-regulated ventilator splitting Yale University protocol—used customised circuits with inspiratory pressure gated valves with ins that can support two test lungs with individualised peak-inspiratory and end-expiratory pressures	Tailoring of ventilator pressures for each patient, and the ability to titrate those pressures over time, may provide a more useful means of stretching ventilator resource.
Tornstad and Olsen, 2020[15]	Simulation model	Technical assessment using test lungs of different compliance and resistance	Discrepancies in delivered tidal volume in paired lungs, not able to identify reliable settings
Vries *et al*, 2020[16]	Descriptive	Technical description	Described methods for set up and monitoring
Branson *et al*, 2012[9]	Simulation model	Four test lungs with different combination of compliance and resistance	Evenly distributed ventilation in equal lungs but large differences in ventilation in lungs with different compliance
Smith and Brown, 2009[17]	Two healthy human volunteers	Single ventilator used in two healthy human volunteers	Accepted CO_2 levels after 10 min of ventilation
Paladino *et al*, 2008[18]	Four adult human-sized sheep	Single ventilator with modified circuits ventilated for 12 hours	Sufficient ventilation, oxygenation and haemodynamic stability throughout experiment
Neyman and Irvin, 2006[8]	Simulation model	Four equal test lungs ventilated for 6 hours	Evenly distributed ventilation among all test lungs

lungs by Neyman and Irvin in 2006.[8] The authors concluded that a single ventilator may be quickly modified to ventilate four simulated adults for a limited time. A similar study by Branson *et al* found that large and uncontrollable variation in individual tidal volume occurred when connected lungs have different compliance and resistance.[9] Similar attempts at ventilating multiple patients using a single ventilator have been tried with variable success in animal, human and simulation models (table 2). However, none have reported splitting of non-invasive ventilation. The use of a T-piece splitter to split bCPAP for multiple patient is an option until definitive arrangement for respiratory support is made, especially in resource-limited settings.

The practice of splitting ventilation is largely unregulated, experimental and untested. However, emergency situations like the COVID-19 pandemic has prompted its use in intensive care units to meet overwhelming demand for ventilators.[10] Many regulatory bodies across the globe have conflicting views on use of splitting the ventilation as a possible crisis management strategy.[11 12] Concerns include patient safety, logistical and technical challenges and ethical concerns. Triage and ventilator prioritisation to patients most likely to benefit from mechanical support and to recover from the disease still remains the recommended option in crisis.

This is the first study reporting a splitting technique for bCPAP which demonstrated reliable pressure delivery in both circuits in an experimental set-up. Advantages of the technique include the following: it is simple; it is made from available hospital materials; and it can deliver individualised CPAP levels to two patients simultaneously by adjusting the level of the water chamber.

A recent study of effect of alterations in the original CPAP system design in a mechanical lung model concluded that high-resistance interfaces (like RAM cannula and modified nasal oxygen cannula) and narrow expiratory tubing (with internal diameters less than 8 mm) in bCPAP systems can significantly affect CPAP delivery and can result in increased work of breathing.[6] Use of standard low-resistance Hudson nasal prongs and corrugated tubing (with an internal diameter of 10 mm) in our study prevents such limitations in CPAP delivery.

Limitations include the inability to adjust FiO_2 for different patients and risk of cross infections, which can be minimised using bacterial/viral filters and standard infection control procedures. The problem of rebreathing due to dead space ventilation may occur due to length of tubing and needs testing further on simulated lung models followed by animal and human studies. The clinical use of any bCPAP system needs appropriate training of health workers and mechanisms for patient monitoring and safety, and this type of innovative solution to a resource problem should not be used outside these parameters and considerations.

CONCLUSION

bCPAP splitting using a T-piece splitter is a technically simple, feasible and reliable strategy tested in a simulation model. It may provide a means to provide bCPAP care for multiple infants simultaneously using a single common unit in resource-limited settings and to overcome crises of device shortages in emergency situations. The technique needs further testing in a simulated lung model prior to animal and human studies.

Contributors GG conceptualised the idea. KMN, AV and RJ performed the practical assembly and testing of the methodology. AV and KMN wrote the manuscript. AS and GG performed the critical appraisal.

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