Paediatric headbox as aerosol and droplet barrier

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ABSTRACT

Background High-flow nasal oxygen (HFNO) is frequently used in hospitals, producing droplets and aerosols that could transmit SARS-CoV-2.

Aim To determine if a headbox could reduce droplet and aerosol transmission from patients requiring HFNO.

Methods The size and dispersion of propylene glycol (model for patient-derived infectious particles) was measured using a spectrometer and an infant mannequin receiving 10–50 L/min of HFNO using (1) no headbox, (2) open headbox, (3) headbox-blanket or (4) headbox with a high-efficiency particulate (HEP) filter covering the neck opening.

Results All headbox set-ups reduced the dispersal of droplets and aerosols compared with no headbox. The headbox-blanket system increased aerosol dispersal compared with the open headbox. The fraction of aerosols retained in the headbox for HFNO of 10 and 50 L/min was, respectively, as follows: (1) open headbox: 82.4% and 42.2%; (2) headbox-blanket: 56.8% and 39.5%; (3) headbox-HEP filter: 99.9% and 99.9%.

Conclusion A HEP-filter modified headbox may serve as an effective droplet and aerosol barrier adjunct for the protection of staff caring for children receiving HFNO.

INTRODUCTION

The emergence of COVID-19, caused by highly infectious SARS-CoV-2, has affected the health of individuals and healthcare systems across the globe, creating a public health emergency. While SARS-CoV-2 is predominantly transmitted through exposure to respiratory droplets and fomites carrying the infectious virus, aerosol transmission has also been established.[1] Aerosols are defined as particles of less than 5 µm in diameter, while droplets are more than 5 µm in diameter, according to the World Health Organization and the Centres for Disease Control and Prevention.[2 3] Droplets and aerosols form part of a continuous spectrum of different sized particles generated by respiratory activity and reducing the spread of both is essential in the healthcare setting.

Healthcare workers are at increased risk of COVID-19 through exposure to patients undergoing aerosol-generating procedures (AGPs).[4] AGPs produce airborne particles or aerosols that may facilitate airborne transmission of a microorganism, such as SARS-CoV-2. High-flow nasal oxygen (HFNO) is a commonly used AGP for paediatric inpatients.[5] Infection prevention and control strategies are crucial to assist in minimising transmission of SARS-CoV-2 in healthcare settings. The placement of a paediatric headbox may provide an additional level of protection, as an engineering control, for healthcare workers caring for children receiving HFNO.

The aim of this study was to determine if the placement of a paediatric headbox could serve as an engineering control using a mannequin model to reduce both droplet and aerosol transmission from children requiring HFNO therapy.

METHOD

As a model for patient-derived infectious particles, an aerosol nebuliser (ATM220, Topas, Dresden, Germany) supplied propylene glycol aerosols and oxygen to an infant model mannequin (SimBaby, Laerdal Medical, Stavanger, Norway) at a rate of 2.5 L/min which exited from the mannequin's nasopharynx. Propylene glycol has similar physical properties compared with nasal/respiratory mucous that form the bulk of cough aerosols, with a density of 1.036 g/mL vs 1.02 g/mL, and viscosity of 0.045 Pa·s vs 0.04–10 Pa·s, respectively.[6–8] Propylene glycol aerosols were supplied to the mannequin's lungs at a flow rate of 2.5 L/min, through a nebuliser outlet attached to a plastic conduit inserted into the base of the mannequin's left lung, as based on the estimated expired volume of a 6-month-old male infant, weighing 8 kg, with a respiratory rate of 45 breaths/min and a tidal volume of 7 mL/kg. The size and concentration of propylene glycol particles escaping the mannequin's nasopharynx was measured using an optical spectrometer (Welas Promo 2300, Palas, Karlsruhe, Germany). The optical device counts and sizes all particles sampled at a rate of 5 L/min, in 128 size classes (groupings), logarithmically spaced between 0.1 and 10 µm in diameter, reported at an average of 1 s. HFNO was then applied to the infant mannequin at an increasing rate (10–50 L/min), and the size and concentration of propylene glycol particles escaping the box were measured

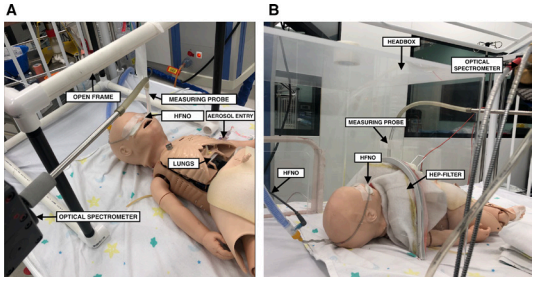

Figure 1 Infant mannequin in (A) no headbox (open frame), (B) headbox with a HEP-filter attachment at the neck opening. The filter was removed in the open headbox setup, and a blanket was used at the opening for the headbox-blanket setup. HEP-filter, high-efficiency particulate filter; HFNO, high-flow nasal oxygen.

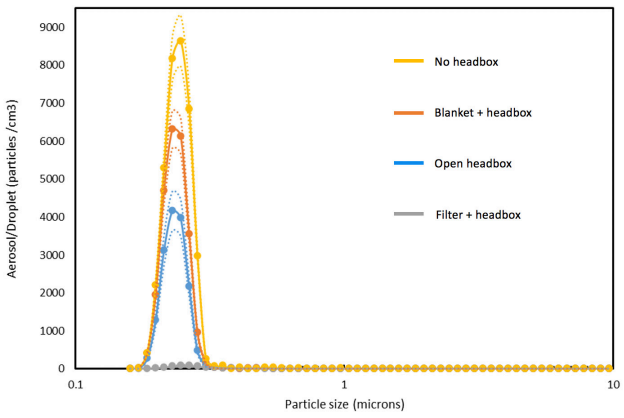

Figure 2 Mean combined aerosol and droplet dispersion across all high-flow nasal oxygen rates (10–50 L/min), measured immediately external to the headbox opening or frame. The 95% CI for each treatment group is illustrated (corresponding dotted line).

approximately 15 cm from the mannequin's mouth, near the box opening or attached to an open frame (figure 1). The measurement duration was 300 s (5 min) at each HFNO rate, which represents 300×128 (38 400) measurements across the particle size range of interest and the time interval. The HFNO rate was increased by 10 L/min to a maximum of 50 L/min every 5 min and then back down again for repeat measurements to evaluate the effect of increasing flow rates on aerosol dispersion. A clean air pause was not undertaken between measurements; however, the first 10 s of each measurement was excluded from analysis to allow particle concentrations to stabilise. The concentration of aerosols was measured with HFNO rates from 10 to 50 L/min using (1) no headbox, (2) open headbox, (3) headbox with blanket blocking the opening between the mannequin's neck and headbox, and (4) headbox with a high-efficiency particulate (HEP) filter attachment covering the opening. Ambient temperature (22°C) and humidity (42%) remained constant. The study was undertaken in a hospital clinical operating theatre specification room, with HEPA filtration and downdraft ventilation. The effect of cough on aerosol dispersion was simulated using validated computational fluid dynamic models and a cough peak flow rate of 50 L/min, with a volume of 285 mL over 0.1 s, extrapolated from a standardised paediatric cough peak flow rate curve in children.[9–11]

RESULTS

All headbox set-ups reduced the dispersal of droplets and aerosols compared with no headbox (figure 2). The open headbox significantly reduced the dispersal of droplet particles compared with no headbox (figure 2). The headbox-blanket combination increased aerosol dispersal compared with the open headbox system (figure 2). The headbox-filter combination significantly reduced droplet and aerosol dispersion (figure 2). The fraction of aerosols prevented from escaping the headbox for each set-up compared with no headbox for HFNO of 10 and 50 L/min was, respectively, as follows: (1) open headbox: 0.824 (95% CI±0.022) and 0.422 (95% CI±0.074); (2) headbox-blanket: 0.568 (95% CI±0.060) and 0.395 (95% CI±0.083); (3) headbox-HEP filter: 0.999 (95% CI±6.54×10^{-6}) and 0.999 (95% CI±9.81×10^{-6}) (table 1). The fraction of particles escaping the headbox increased with the application of higher HFNO flow rates. The mean fraction of particles prevented from escaping the headbox measured across all flow rates (10–50 L/min of HFNO) compared with no headbox was as follows: (1) open headbox 0.638 (95% CI±0.046); (2) headbox-blanket 0.388 (95% CI±0.084); (3) headbox-HEP filter 0.999 (95% CI±7.2×10^{-6}). Simulated cough, calculated using validated computational fluid dynamic models, did not appear to influence the fraction of particles escaping the headbox (table 1).[9–11]

DISCUSSION

The paediatric headbox has been used for decades as a safe, affordable, well-tolerated oxygen delivery system for infants. While its use has decreased in the last decade with increased use of HFNO, we present evidence that a paediatric headbox with a HEP filter may serve as an adjunct engineering control, a component of the hierarchy of controls, for reducing droplet and aerosol transmission in children who require HFNO therapy.[12] Several innovative protective measures have already been developed to reduce SARS-CoV-2 transmission, including an aerosol box[13] for tracheal intubation and a novel personal ventilation hood with a HEP filter.[14]

Table 1 (A) Fraction of particles escaping the headbox relative to open frame (no headbox) measurements, and 95% CI at 10, 20, 30, 40 and 50 L/min of HFNO and (B) estimated fraction of particles escaping the box calculated using a computational fluid dynamic model and the estimated effect of cough

(A) Measured experimental data (to four decimal places)						
Flow rate	**Open headbox**		**Headbox+Blanket**		**Headbox+Filter**	
	Mean	**CI (95%±)**	**Mean**	**CI (95%±)**	**Mean**	**CI (95%±)**
10	0.1757	0.0224	0.4321	0.0596	0.0002	6.54E-06
20	0.1552	0.0198	0.7571	0.1044	0.0002	6.54E-06
30	0.2991	0.0382	0.6894	0.0951	0.0002	6.54E-06
40	0.6015	0.0768	0.5779	0.0797	0.0002	6.54E-06
50	0.5774	0.0737	0.6051	0.0834	0.0003	9.81E-06
Mean	0.3618	0.0462	0.6123	0.0844	0.0002	7.20E-06
(B) Computer simulated data and effect of cough (to three decimal places)						
	Open headbox		**Headbox+Blanket**		**Headbox+Filter**	
Computer simulation data (average of 10 and 50 L/min)	0.451		0.211		0.017	
Experimental data (average of 10 and 50 L/min)	0.376		0.519		0	
Error between experiment and simulation	0.075		–0.308		0.017	
Simulated cough	0.469		0.15		0.01	

In this study, the headbox-blanket system reduced droplet and aerosol particle dispersion compared with no headbox during HFNO therapy; however, it unexpectedly increased aerosol dispersal compared with an open headbox system. This may have occurred due to the proximity of the measuring probe to a gap between the blanket and headbox, resulting in a jet effect that may be subject to experimental variability based on how the blanket was folded. This finding highlights the importance of further research, such as a pilot study in children, as an active moving child may produce different results compared with a stationary mannequin. The dramatic reduction in droplet and aerosol dispersal demonstrated by the headbox-HEP-filter system used in this study provides groundwork for further evaluation in the clinical setting and translation to potentially significant improvements in clinical practice.

The value of using a paediatric headbox with HEP filter to assist in reducing the burden of occupational health exposure of clinical staff caring for children with SARS-CoV-2, as well as other common viral infections, such as respiratory syncytial virus and influenza, when children require escalation of care to HFNO, warrants further consideration.

CONCLUSION

The application of a modified headbox, together with standard personal protective equipment practices, may allow for safer delivery of HFNO therapy. This concept could be applied to other AGPs as a simple, cost-effective adjunct for reducing respiratory virus transmission, including SARS-CoV-2. Further evaluation of its efficacy, safety and tolerability in clinical practice is required.

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