Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

ventilation grills to filter the air passing to recovery was the best solution for our case. We designed a housing for the filters to ensure a good seal.

After installation, theatre ventilation function testing was repeated. In view of the increased resistance to air flow created by the filter, we assessed for a potential air leak, which was found to be significant. The smoke seal on the theatre doors was refitted. Further testing showed that the theatre air changes remained above the recommended minimum 25 per hour with negligible leak and contamination of adjacent areas.

It is important to highlight that in a modified airborne infection isolation room such as this, the mechanical elements degenerate over time, rendering them inefficient and placing staff and patients at risk. They therefore require regular testing and maintenance to ensure they are operating effectively, the frequency of which should be guided by the manufacturer. Usual precautions required in respiratory isolation, such as keeping doors closed and using appropriate protective equipment, must also be adhered to.

As our obstetric theatre setup is not unusual, we considered that we may not be alone in facing this infection control challenge. With the COVID-19 crisis potentially continuing for some time, we wished to share our experience in the hope that this will prove useful to colleagues in other hospitals and trusts.

Authors' contributions

Engineering and technical aspects: LMD
Infection control and prevention consulting: IH
Clinical aspects and research and drafting manuscript: SY
Manuscript proof reading and editing: all authors

Declarations of interest

The authors declare that they have no conflicts of interest.

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Use of a high-flow extractor to reduce aerosol exposure in tracheal intubation

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Keywords: aerosol-generating procedure; COVID-19; HEPA; high flow extractor; SARS-CoV-2; simulation; tracheal intubation

Editor—Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) transmission is thought to be through fomites, droplets, and droplet nuclei (aerosols).[1] Aerosol-generating medical procedures are commonly performed and are associated with increased risk of infection of healthcare workers.[2] Some clinicians are using barriers such as transparent plastics and Plexiglas boxes to reduce aerosol spread.[3–7] However, these barriers may limit access to the patient and mobility of the clinician.[8] An alternative to barriers that may reduce aerosol spread is directed *high flow air extraction*. A high flow air extractor combines high flow suction and a high-efficiency particulate (HEPA) filter. We conducted a study to determine if high flow air extraction reduces aerosol exposure of clinicians. We designed an experimental model that determined the efficacy of removal of particles similar in size to human aerosols. We used two particles to simulate aerosols, essential oil particles ranging in size from 1 nm to 1 μm, and ISO 12103-1 A1 Ultrafine test dust (Powder Technologies Inc., Arden Hills, MN, USA) ranging in size from 1 to 20 μm. We simulated human breathing using an essential oil diffuser as a continuous aerosol source.

Human cough aerosols range in size from 0.58 to 5.42 μm with 80% in the 0.74–2.12 μm range.[9] For coughing experiments, a manikin (Electripod ET/J10 Tracheal Intubation model; TUQI, Shanghai, China) was used (Supplementary 1a, b). We applied 500 mg of A1 Ultrafine test dust to the oropharynx and distal trachea of the manikin and simulated a cough using a medical air gun connected to the distal trachea and fired for 0.4 s. The researchers placed their hand 2–3 cm from the mouth of the manikin to simulate a covered cough. The high-flow air extractor Epurair HA-500 (Industrie Orkan Inc., Montreal, Quebec, Canada) was placed 25–30 cm above the manikin's head.

We quantified aerosols with the following sensors (Supplementary 1a, b). Two dust aerosol calibrated DustTrak DRX (TSI, Shoreview, MN, USA) units using four chambers placed near the source and the clinician's head. Two wide-range aerosol spectrometers, miniWRAS 1371 (Grimm Aerosol Technik, Ainring, Germany) each with 41 bins and calibrated to an oil aerosol were similarly placed. To determine the vertical and horizontal variation in concentrations, 10 DC1700 optical particle monitors (Dylos, Riverside, CA, USA) were placed at predetermined positions (Supplementary 1a, b). To eliminate inter-monitor variation, monitors were co-located for 10 min after the experiments and reported concentrations corrected by the deviation from the mean concentration of each monitor. The high-flow air extractor is a portable high efficiency filtration unit allowing up to 235 L s^{-1} (500 ft^3 min^{-1}) that can be used to transform a regular room into a negative pressure room. It contains a HEPA filter that removes 99.97% of all airborne pathogens of 0.3 μm or greater. The filtered air can be adapted to an existing exhaust system or vented outside. We operated the device with a calibrated booster fan to maintain a continuously measured flow of 142 L min^{-1} for the experiments (Supplementary 2). Each experiment was completed in triplicate, and mean concentration values were used for analysis.

Our primary outcome was to determine the reduction of aerosols at the source. A 99% reduction in the aerosol concentration near the source would be consistent with the Centre for Disease Prevention and Control's (CDC) requirements for air exchanges between patient encounters.[10] Secondary outcomes included reduction of aerosol concentrations at the level of the clinician's head with the high-flow air extractor 'on' during a cough and an obstructed cough. The effectiveness, *H*, was calculated by subtracting the ratio of 'high-flow air extractor on' to 'high-flow air extractor off' mean particle concentration measured by each aerosol quantification device from unity.

The high-flow extractor device was 99% effective at removing aerosols near the source, resulting in no levels detected at the clinician's head (Fig. 1a and Supplementary 3 online video). During an uncovered cough, the high-flow extractor had a 97% effectiveness in reducing the aerosols detected near the clinician's head (Fig. 1b). In these first two scenarios, aerosols were effectively removed at source and did not contaminate the room or reach the clinician's head. However, when the cough was covered by the provider's hand there was only a 52% reduction in aerosols detected at the clinician's head; the absolute concentration was very low because of less aerosols reaching the clinician's head as a result of covering the cough (Fig. 1c). The covered cough resulted in a higher concentration of aerosols at sensors placed lateral to the patient (Supplementary 4). This was likely because aerosols were diverted away from the device's intake but subsequently reached the clinician's head. The effectiveness of the high-flow air extractor was high for larger particles (>1 μm) emitted from the simulated cough, and generally low for small particles (<1 μm) (Supplementary 5a, b).

Supplementary video related to this article can be found at https://doi.org/10.1016/j.bja.2020.07.014

Our study shows that a high-air flow extractor is effective in removing aerosols during simulated continuous breathing and a simulated cough. However, simply covering a cough with a gloved hand resulted in the escape of aerosols and subsequent detection at the clinician's head.

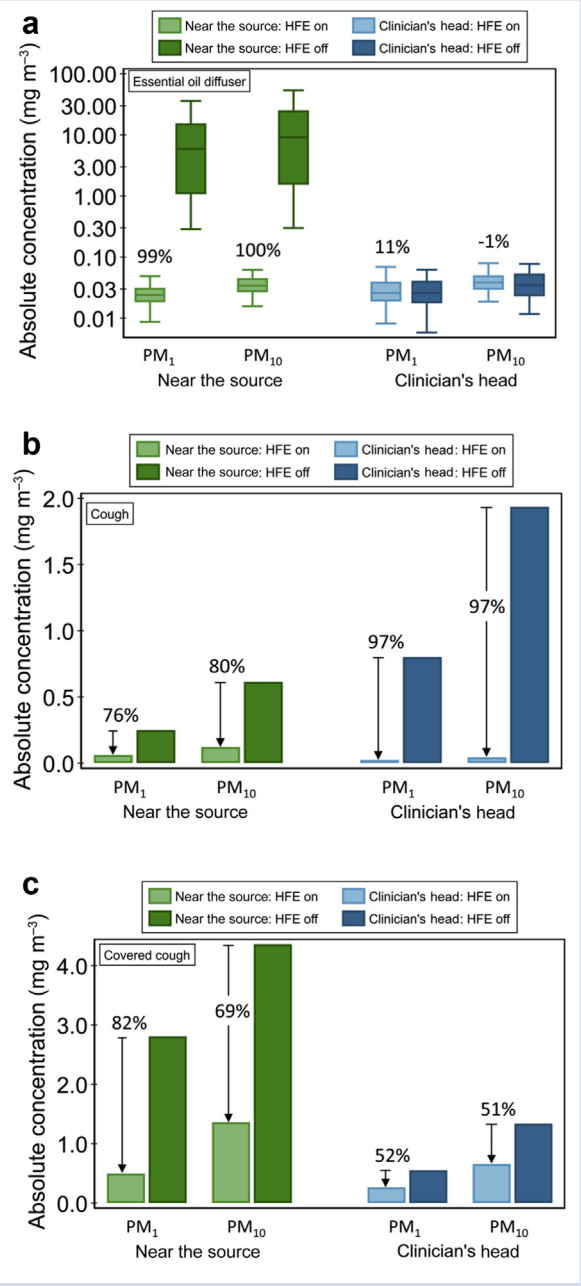

Fig 1. Particle concentration measurements from the two DustTrak DRX units near the source (NS) and clinician's head (HH) with the high flow extractor (HFE) turned on and off. Calculated HFE effectiveness is labelled on top of each pair of boxes/bars during (a) essential oil diffuser test; (b) simulated cough test; (c) simulated covered cough test. In (a), the boxes represent the first and third quartiles, the line in the boxes represents the median, the whiskers represent 1.5 times the inter-quartile range. Concentrations outside of the whiskers are excluded for visual clarity. In (b) and (c), the bars represent the mean concentrations during the tests.

Removal of aerosols may enhance the safety of healthcare workers and improve operational efficiencies. Currently, a minimal air exchange rate of 15–20 h^{-1} is recommended for operating room air decontamination. At this rate 18–28 min is required to reduce airborne contaminants by 99%.[10] This delay causes workflow inefficiencies and the extractor can be used to accelerate air decontamination.

A limitation of this study is the difference between airflows in the test environment and actual operating rooms. Compared with the test environment, operating rooms have higher air exchange rates (15–20 *vs* 0.75 h^{-1}), which may cause turbulence, interfere with the extractor exhaust plume, and decrease capture efficiency. We have shown that the high-flow air extractor is highly effective at reducing aerosol concentrations at the source. This has potentially large-scale implications for clinical practice and warrants translation into high-risk clinical areas in order to minimise clinician exposure. Furthermore, this technique is consistent with current recommendations from the CDC to augment room air exchanges.

Authors' contributions

Conceptualisation: CM, TE, VC, PF, JF
Methodology: CM, TE, VC, PF, JS, SD
Visualisation: CM, TE, VC, PF, JS, TL, BD
Software: PF, JS, TL, BD
Analysis: PF, JS, TL, BD
Original draft preparation: CM, TE, VC, PF, JS, SD, TL, BD
Review and editing of the manuscript: CM, TE, VC, PF, JS, SD, TL, BD, JF

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Declarations of interest

The authors declare no that they have no conflicts of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.bja.2020.07.014.

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Regulating inspiratory pressure to individualise tidal volumes in a simulated two-patient, one-ventilator system

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Keywords: ARDS; COVID-19; critical care; inspiratory pressure; mechanical ventilation; split ventilation

Editor—The mainstay of treatment for severe bilateral pneumonia and acute respiratory distress syndrome (ARDS) caused by coronavirus disease 2019 (COVID-19) is positive-pressure mechanical ventilator support.[1] However, ventilator shortages have occurred owing to overwhelming patient volumes coupled with prolonged durations of ventilator dependence.[2–4] Potential solutions include bag-valve-mask ventilators and supporting two or more patients per ventilator (ventilator splitting).

The proof of concept of ventilator splitting was first demonstrated in 2006 by Neyman and Irvin[5] as a method of ventilating multiple simulated lungs with a single ventilator. Subsequently, this strategy was validated on four sheep in 2008 for 12 h, and on two awake humans for 10 min.[6,7] However, prolonged support of multiple patients per ventilator is challenging because of the inability to compensate for variability in patient size and pulmonary compliance, which can also vary over the course of the disease.[8]

COVID-19 patients typically require 10 days of mechanical ventilatory support, and the inability to individualise tidal volume during this time could lead to hyper- or hypoventilation. Therefore, numerous national societies have warned against splitting ventilators to support multiple patients.[9] In order to safely ventilate multiple patients, systems must allow individualised control of patients' tidal volumes and ensure changes in one patient do not affect the other. We present a solution affording patient-specific peak inspiratory pressure (PIP) adjustment for multiple patients using a single ventilator. During the preparation of this manuscript, we became aware of the Pressure-Regulated Ventilator Splitting (PReVentS) group solution,[10] which tackles some of these issues; similarities and differences are discussed.

In our design, an adjustable fixed-pressure regulator was added at the inspiratory limb of each simulated patient's breathing circuit. Critically, the regulators have adjustable diaphragms set relative to atmospheric pressure such that the pressure for each patient is fixed; adjustments to inspiratory pressure on the ventilator do not affect delivered PIP. Thus, airway pressures (and consequently tidal volumes) are modulated for each patient independently of one another. Both Dräger Apollo (Draeger Medical Inc., Telford, PA, USA) and Medtronic Puritan-Bennett 840 (Minneapolis, MN, United States) ventilators were used for testing; the data presented are from a Dräger Apollo (Draeger Medical Inc.).

The ventilators were separately attached to two lung simulators using Y-pieces to split standard 60-inch ventilator circuits into parallel inspiratory configurations (Fig. 1a). The PIP of each simulated lung was controlled by a 4116ANNKE Pneumatic Precision Low Pressure Regulator (Fairchild Industrial Products Company,Winston-Salem, NC, USA), and a pressure gauge was attached to the end of each inspiratory limb upstream of each simulated patient. This pressure regulator has a sensitivity of 0.127 cm H_2O control. Connectors to the pressure regulator (at the inlet and outlet) were 3D-