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.

Declarations of interest

The authors declare that they have no conflict of interests. The views expressed in this publication are those of the author(s) and not necessarily those of the NHS, the National Institute for Health Research, or the Department of Health and Social Care.

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Effect of entraining oxygen at different locations in a noninvasive ventilator

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Editor—Guidance on using noninvasive ventilation produced by NHS England,[1] and the Association for Respiratory Technology and Physiology (ARTP) COVID Group[2] suggests that oxygen can be entrained into the breathing system at the patient end, directly into the heat and moisture exchange (HME) filter or through an oxygen entrainer. This is contrary to manufacturer guidance (for the Breas Vivo 2, the system in use at the Nightingale Hospital), which recommends entraining the oxygen into the dedicated port at the back of the machine.

The aim of this study was to determine whether entraining oxygen at the patient end or machine end of the breathing system caused a difference in delivered fractional oxygen (FiO_2) or pressure to the patient. This was done using continuous positive airway pressure (CPAP) and bi-level positive airway pressure (BiPAP) modes to also assess if this was dependent on ventilation mode.

The following experiments took place in the Nightingale Hospital (London, UK) in an unused ward adjacent to the patient ward. The named experimenters were assisting clinical staff in a technical support role. Experiments were conducted largely at night when the ward activity was at its quietest. Consequently, the experimenters wore full personal protective equipment (PPE). They had limited access to measurement instrumentation that they may have used in a more standard setting.

The Vivo 2 (Breas, Sweden) Noninvasive Ventilator was set up as if it were being used on a patient, including a heat and moisture exchange (HME) filter. In addition, a second filter (high-efficiency particulate air [HEPA] filter) was placed in series with the usual filter. The extra filter was added so that FiO_2 could be measured via a sampling line using a Penlon 465 anaesthetic machine (Penlon Ltd, Oxfordshire, UK). A test lung (Drager Ltd, Lubeck, Germany) was attached in place of a patient.

Initially, oxygen was entrained through the dedicated port on the Vivo 2. Using the CPAP mode, pressure was set sequentially to 5, 10, and 15 cm H_2O. For each CPAP pressure setting, oxygen flow rate was incrementally increased from 0 to 15 L min^{-1} (via a flow regulator attached to the piped oxygen supply), and FiO_2 was recorded. The whole process was then repeated with oxygen entrained directly into the HME filter. The experiment was then repeated with one

experimenter depressing the test lung once every 4 s to simulate patient breathing.

The Vivo 2 was then set to BiPAP mode, and the above procedure repeated. (Inspired positive airway pressure [IPAP] of 12–14 cm H_2O, expired PAP [EPAP] of 8 cm H_2O, ventilatory frequency of 16 bpm, Tinsp set to 1.5 s, and volume target set to 480 ml.) Two different FiO_2 recordings were made as the readings fluctuated with each 'breath'. A high reading and a low reading were taken once these stabilised (after about 2 min).

Finally, to investigate the effect on pressure, the patient breathing system was attached to the Penlon anaesthetic machine. The Noninvasive Ventilator was used to provide expiratory air in a CPAP mode. CPAP pressure was gradually increased, and the Penlon machine was used to measure the pressure in the breathing system in real time.

Using the CPAP mode and with oxygen entrained in the back of the machine, FiO_2 linearly increased with flow rate. At 5 cm H_2O, FiO_2 plateaued at a flow rate of 4 L min^{-1}. The plateau occurred later with increasing CPAP pressure. When the oxygen was entrained directly into the HME filter at the patient end, FiO_2 increased to a maximum level (~95%) as soon as flow rate was initiated (0.5 L min^{-1}) and plateaued at this point (Fig. 1). The same result was achieved for all CPAP pressure levels.

When the test lung was compressed to simulate breathing, the results fluctuated significantly with each simulated 'breath', but the same pattern was observed with a much earlier plateau in FiO_2 when oxygen was entrained at the patient end compared with the Noninvasive Ventilator port.

When the Noninvasive Ventilator was set to BiPAP mode, the pattern was similar to CPAP. When 2 L min^{-1} of oxygen was entrained at the filter, FiO_2 plateaued at its maximum level. There was a linear response with increasing flow rate when oxygen was entrained at the back of the machine, with a plateau at around 10 L min^{-1}. When measuring the effect on delivered pressure, entraining oxygen at the filter had minimal impact (1–2 cm H_2O) compared with the machine end, even at flow rates of 15 L min^{-1}.

These results indicate that entraining oxygen via the dedicated port on the Noninvasive Ventilator facilitates more controlled titration of delivered FiO_2. This allows modification of FiO_2 depending on patient needs and thus potentially improves patient management. These results are in line with a previous study conducted on patients with chronic obstructive pulmonary disease.[3]

The linear range was larger for CPAP pressures of 10 and 15 cm H_2O. We believe that this is because to increase pressure (when oxygen flow rate is constant), more air is suctioned by the Noninvasive Ventilator. Therefore the relative percentage of oxygen is lower. This is important for clinicians to note as FiO_2 should be adjusted accordingly. These results are in line with findings from the ARTP COVID group[2]; however, it should be noted that the FiO_2 values we achieved were significantly higher at comparable oxygen flow rates than the ones reported by ARTP.

When the test lung was compressed to simulate breathing, FiO_2 fluctuated significantly if oxygen was delivered directly to the filter. In contrast, FiO_2 remained stable and predictable if oxygen was delivered to the port in the Noninvasive Ventilator. This suggests that FiO_2 is highly dependent on patient-specific respiratory parameters when oxygen is delivered to the filter. The clinician has little control over this and cannot guarantee the FiO_2 being delivered. For this reason, delivering the FiO_2 via the port in the Noninvasive Ventilator seems preferable.

There was minimal change in pressure to the patient when delivering oxygen directly to the filter compared with the Noninvasive Ventilator port. This suggests that there is an internal safety value within the Vivo2 Noninvasive Ventilator which ensures that pressures are limited within the closed breathing system.

A limitation to this study is that we were unable to measure the results with the breathing system attached to a patient to comply with infection prevention measures. The actual FiO_2 delivered to the patient may vary because of the leakage of flow around the mask.

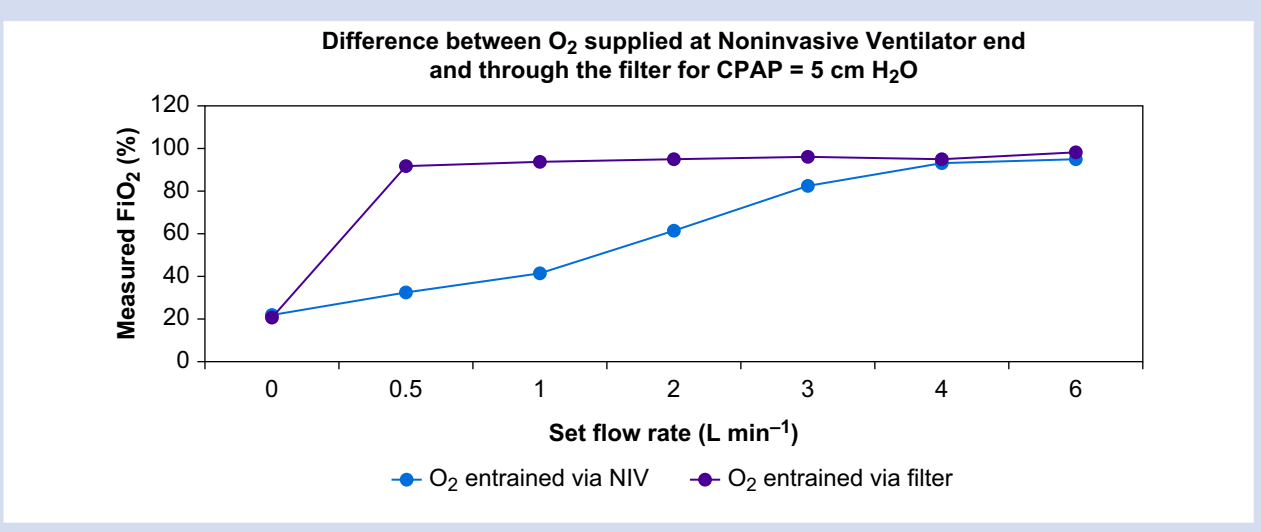

Fig 1. Difference in FiO_2 when oxygen is entrained at the patient end (filter) compared with the Noninvasive Ventilator. CPAP, continuous positive airway pressure.

These results suggest that oxygen should preferentially be entrained via the dedicated port in the Noninvasive Ventilator, as this allows greater control of delivered FiO_2. It is difficult to deliver an FiO_2 <90% when entraining via the filter, which may be too high for some patients. In addition, patient-specific breathing mechanics make predicting FiO_2 uncertain when delivered via the filter. Our results given here can be used to estimate FiO_2 with a given CPAP, oxygen flow rate, and mode of ventilation. However, different Noninvasive Ventilator machines and patient settings may result in different relationships, so we suggest creation of a look-up table for each set up to allow clinicians to set an estimated FiO_2 using a given flow rate and CPAP. This will only work however, when oxygen is supplied via the Noninvasive Ventilator port.

Declarations of interest

The authors declare that they have no conflicts of interest.

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Are aerosol-generating procedures safer in an airborne infection isolation room or operating room?

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Keywords: aerosol-generating procedure; COVID-19; isolation room; operating room; safety; tracheal intubation

Editor—One of the most important considerations for healthcare workers in the midst of the coronavirus disease 2019 (COVID-19) pandemic is the location in which aerosol-generating procedures are performed for patients with suspected or known COVID-19. Aerosol-generating procedures include ventilation through a facemask, tracheal intubation, and tracheal extubation. For non-surgical patients, a negative-pressure airborne infection isolation room is the preferred location for performing aerosol-generating procedures, because the negative pressure reduces droplet and aerosol transmission from within the isolation room to the environment outside.[1] For surgical patients with suspected or known COVID-19, the ASA[1] also recommends 'perform [ing] procedures in an airborne infection isolation room rather than in an operating room.' Some readers may interpret the ASA recommendation to imply increased safety when performing aerosol-generating procedures in an airborne infection isolation room compared with an operating room. However, there is limited evidence regarding the safety of healthcare workers within these two locations in terms of aerosol exposure and exposure time. Using an airway manikin model setup,[2] we compared aerosol exposure and time by measuring particle concentrations during and after saline nebulisation in a positive pressure operating room and a negative pressure airborne infection isolation room.

We simulated aerosol exposure during intubation using a nebuliser (Airlife Misty Max 10 Disposable Nebulizer, CareFusion, San Diego, CA, USA) to nebulise saline into aerosol droplets with a median size of 1.6 μm into the trachea of an airway manikin placed in the centre of a room.[2] The aerosolised droplets generated are comparable in diameter to aerosolised COVID-19 droplets (which have two size ranges: 0.25–1 μm and >2.5 μm).[3] Using a particle counter (Digital PM2.5 Air Quality detector, Geekcreit, Banggood, Guangzhou, China), particle concentrations (μg m^{-3}) of particulate matter with diameter <1 μm (PM_1), <2.5 μm ($PM_{2.5}$), and <10 μm (PM_{10}) were measured. One particle counter was placed 30 cm directly above the manikin to simulate the proceduralist's location and exposure during tracheal intubation with direct laryngoscopy,[2] and the other particle counter was placed immediately outside the closed door to detect aerosol leakage outside the room. During pilot experiments, particle concentrations returned to baseline (0 μg m^{-3}) within ~10 min in both rooms upon discontinuation of the nebuliser. Thus, we decided to measure particle concentrations every second for