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Editorial

Are tracheal intubation and extubation aerosol-generating procedures?

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"a wise man proportions his belief to the evidence"

David Hume (Scottish Enlightenment Philosopher, 1711–1776)

The COVID-19 pandemic has significantly impacted peri-operative care due to staff redeployment and a reduction in elective surgery secondary to depletion of resources and a requirement for increased infection control procedures in order to protect healthcare staff. As well as patients with severe COVID-19 infection who require tracheal intubation, patients may be relatively asymptomatic and present for surgery. COVID-19 is highly infectious and may be transmitted through small droplets and/or aerosols [1]. There is evidence that airway management may be a source of transmission of infection as these are potential aerosol-generating procedures and, therefore, use of full airborne personal protective equipment (PPE) has become standard practice in all patients. This has important implications as PPE shortages in some countries has impacted on the provision of elective surgery. The latest experiments for respiratory emissions indicate that a high concentration of droplets/aerosols (virus hosts) appears in the breathing zone (Fig. 1) [2]. Recommendations are revised periodically and, given the rapid escalation of the pandemic, often have little evidence base, thereby adding to the cognitive load and anxiety of frontline healthcare workers. Experience from severe acute respiratory syndrome (SARS) and other infectious disease epidemics has been the main reason for adoption of airborne protective measures for aerosol-generating procedures, but there is a paucity of clinical data supporting this approach. Current infection control guidelines are based more on a precautionary than evidential approach [3]. Even the use of facemasks by the general public has been an area of much controversy and confusion.

Aerosol generation has been a major focus of guidelines underpinning the required level of PPE. It is imperative to recognise that many daily activities generate aerosols, but these do not necessitate staff to don the same high level of PPE [4]. Whether or not these pose a clinically significant risk depends on the number, size and concentration of infectious aerosols [5]. In this issue of *Anaesthesia*, there are two papers using robust scientific approaches to evaluate aerosol generation during tracheal intubation and extubation to address this gap in evidence [6, 7]. From these two studies, it can be confirmed that tracheal intubation and extubation does produce a certain number of aerosols which can remain suspended and spread in the operation room air; but does this research

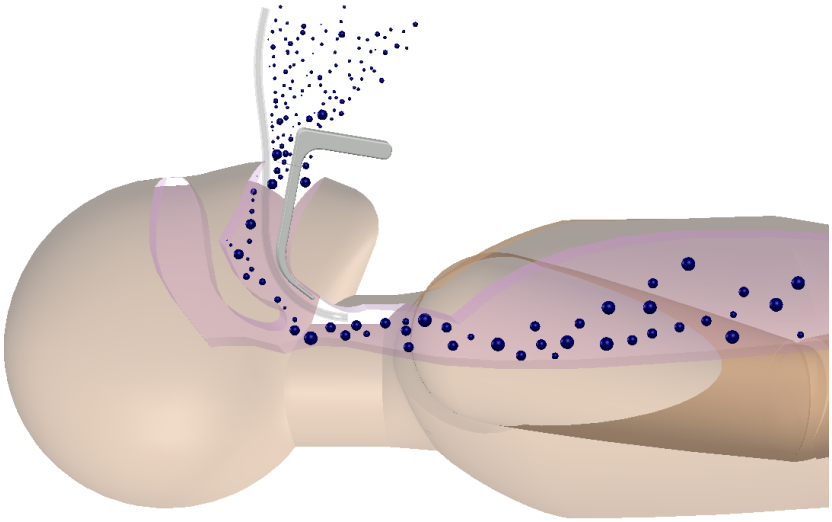

Figure 1 Tracheal intubation produces airborne particles of various sizes.

provide any reassurance as to whether what we are currently doing is safe or appropriate?

Dhillon et al. [6] report their findings in cm^{-3} and, for the purpose of this editorial, we have converted their data to l^{-1} to allow direct comparison with Brown et al. [7]. Both groups recorded baseline aerosol concentration, but in order to assess infection transmission risk, the absolute number of aerosols generated is more significant than an increase from baseline. Brown et al. measured aerosol particle baseline concentration in an empty (0.4 particles.l^{-1}) and occupied (3.4 particles.l^{-1}) ultra-clean laminar flow operation theatre during non-aerosol-generating procedures. Baseline concentration of aerosol particles in the study by Dhillon et al., taken before anaesthesia induction, showed 27 particles.l^{-1}. These low background concentration levels facilitated the detection of changes that occurred during typical airway management.

In the study by Brown et al. the tracheal intubation sequence over a 5-min period generated seven particles, on average, from a baseline of 2 in an empty theatre. In the absence of the ultra-clean laminar flow ventilation system, a similar particle count was observed, implying that these results are transferable to other settings and not attributable to the rapid removal of aerosols from the environment. This finding is not replicated in the study by Dhillon et al., as the aerosol concentration increased 12-fold to 324 particles.l^{-1} during the process of tracheal intubation. Of note, however, the range of aerosol concentration seen during tracheal tube insertion was very broad (337–3506 particles.l^{-1}).

During the tracheal extubation sequence, both studies also identified a rise in aerosol production: Brown et al. showed the detection of 100 particles.l^{-1} on average over a 5-min period, and Dhillon et al. showed an increase to 319 particles.l^{-1}. Brown et al. demonstrated that, in a non-ultra-clean laminar flow environment, baseline air particle concentrations are significantly higher which precludes detecting these modest increases. They also demonstrated that a single volitional cough produced 732 particles.l^{-1}, which is in excess of the average amount of aerosol generated by airway management in either study. Violent expiratory events, such as a cough, produce a mixture of droplets and aerosols that range from 0.5 μm to 20 μm in size [8, 9]. In both studies, spikes can be seen in aerosol generation during cough episodes in the tracheal extubation sequence. The substantial differences in the aerosol concentrations of these two studies at baseline and following tracheal intubation/extubation could be attributed to:

1 The difference in the background ventilation systems (26 vs. 500–650 volume air exchanges.h^{-1}): the degree of ventilation that influences underlying airflow could alter droplet/aerosol pathways as well as particle concentrations at the sampling points.
2 The difference in particle counters that were used: Brown et al. used an optical particle sizer that detects particles in a narrower size range of 0.3–10 μm, while Dhillon et al. made use of several sizers that allowed them to measure a wider range of aerosols sized from 0.01 to 35 μm. To date, an agreed definition of the distribution of aerosol during tracheal intubation is unavailable, and there could be some smaller aerosols

that Brown et al. could not detect using the optical particle sizer.

3 The difference in sampling locations between these two studies: we still have a poor understanding of the temporal and spatial dispersion of aerosols from tracheal intubation and aerosol measurement results are likely to be time- and location-dependent based on these two studies. Different sampling locations and underlying aerodynamic conditions could lead to variation in measured particle concentrations.

There is some contention over how to define aerosol-generating procedures, the classification of aerosols into droplets and what is airborne. Small particles with diameters <5 μm can be considered aerosols, which can remain suspended in air for many hours, while droplets with diameters >5 μm will undergo gravitational settling in a short time [8]. It is known that <5% of all human aerosols are >5 μm [9]. Brown et al. define aerosol-generating procedures as procedures with a greater likelihood of producing aerosols than coughing, and this aligns with UK NHS guidance [10]. This bar is significantly higher than other institutions that also include activities such as talking and breathing in their definition [11]. Aerosols can be produced during a procedure without classifying the intervention as high-risk. A volitional cough produced 732 particles.l^{-1} in the study by Brown et al. and, using this as a reference point, neither the sequence of tracheal intubation nor extubation reached this level in either study. Coughing and sneezing produce more aerosols [12] than those generated from airway manoeuvres, but infection control guidelines do not mandate healthcare workers to don airborne precaution PPE for asymptomatic untested patients. Furthermore, a study during the H1N1 pandemic in the UK found that aerosol-generating procedures did not significantly increase the probability of sampling an H1N1-positive aerosol in the vicinity of an H1N1-positive patient [13].

Aerosols

Recent stability tests confirm that aerosol and fomite transmission of COVID-19 is evident because the virus can remain viable and infectious in small droplets for several hours [14]. The overall risk of transmission (airborne, droplet, fomite) is distinct from the risk from aerosol-generating procedures. A crucial confounding variable is the physiological state of the patient. During SARS, transmission rates increased with higher acute physiology and chronic health evaluation-2 (APACHE-2) scores [15]. Healthcare staff performing non-aerosol-generating procedures were also at risk of contracting the disease simply by spending extended periods of time in close proximity to patients who were critically ill [16], perhaps because of higher patient viral loads. Around 1 in 10 healthcare workers involved in tracheal intubation of patients with suspected or confirmed COVID-19 subsequently reported infection [17]. If sicker patients pose a higher transmission risk, is a healthcare worker performing tracheal intubation contracting COVID-19 highly likely? It is impossible to assign disease transmission to a specific healthcare intervention when so many confounding variables are unaccounted for. Brown et al. acknowledge in their discussion that *"it is equally plausible that other transmission mechanisms such as direct exposure to respiratory secretions or fomites or association between those who undertook tracheal intubation and performance of other high risk activities could have contributed to the spread of SARS*."

'Super-spreaders' produce many more aerosol particles that other persons. The 80:20 rule is often cited by infectious disease specialists: 20% of infected individuals are responsible for 80% of further infections [18]. This principle was strengthened by mathematical and statistical analyses of the SARS outbreaks in Hong Kong and Singapore, which found that over 70% of infections were attributable to super-spreader events. The number of aerosols produced also varies between individuals, with some producing far in excess of others. In one study, 99% of the bioaerosols produced came from 6 out of 11 patients investigated [19]. Rhinorrhoea, an unusual symptom of SARS, was also linked to super-spreading events [20]. Whether increased secretions or co-infection correspond to increased bioaerosol production needs to be investigated further.

Airborne transmission

Airborne transmission has been a global concern during this pandemic as this was seen in SARS where, for example, airborne spread was responsible for a large community outbreak in an apartment block in Hong Kong. A recurring argument against the use of airborne precautions for all tracheal intubations is based on the principle that airflow is required to generate aerosols. However, a patient who has received a neuromuscular blocking agent to facilitate a tracheal tube should not produce aerosols. This is supported by Brown et al., as no increase in aerosolised particles was detected above the patients' faces, but is at odds with the findings of Dhillon et al. The wide ranges in aerosol concentrations reported by Dhillon et al. may indicate varying techniques and timings in the conduct of tracheal intubation. The induction drugs are stated in the

Table 1 Suggested personal protective equipment (PPE) for airway management based on risk stratification determined by TOCC (Travel, Occupation, Contact, Cluster) history, symptoms and test results.

Risk stratification	LOW TOCC negative and asymptomatic or COVID-19 test negative	HIGH TOCC positive or symptomatic or COVID-19 test positive
Suggested PPE	• Theatre cap • Surgical facemask (ASTM level 2) • Eye protection • Gown (AAMI level 1) • Gloves	• Theatre cap • N95 mask or higher-level respirator • Face shield • Gown (AAMI level 3 or 4) • Gloves

Recommendations for ASTM (American Society for Testing and Materials) level masks or N95, mucosal membrane protection, AAMI (Association for the Advancement of Medical Instrumentation) level gowns and gloves.

methods but whether doses were standardised or effective is unclear. Tracheal intubation took place at the point of apnoea which may not correlate with full neuromuscular block. Quantitative, objective measurement of neuromuscular function is a more accurate endpoint [21] and this should be routine if trying to reduce aerosol-generating procedures. Likewise, it would seem prudent to make the process as easy as possible with routine use of videolaryngoscopy. This simplistic view does not consider the other steps in the process, such as positive pressure ventilation, use of suction, and cuff inflation which can also create aerosol. We can mitigate risk by avoiding positive pressure ventilation and suctioning only where necessary. Full denitrogenation of the lungs should be routine and, if facemask ventilation is required, efforts should be made to optimise mask seal to the face and minimise oxygen flow to reduce leak. Interestingly, there has been some debate over the use of supraglottic airways as some organisations have suggested their use is aerosol generating [22]. However, there is a lack of evidence to support decreased safety of supraglottic airways over tracheal tubes or vice versa and more pragmatic advice from the Difficult Airway Society, the Association of Anaesthetists and the Royal College of Anaesthetists suggests they are a reasonable option with the caveats of preferential use of second-generation devices and scrupulous attention to ensuring a leak-free seal [23]. This is an area worthy of further study given that placement and extraction are generally less likely to induce cough than an endotracheal tube. The airway seal may not be as good if positive pressure ventilation is used but it is unknown whether this creates aerosol.

Some attention may need to be directed to tracheal extubation since the risk of aerosol generation seems higher. We use a low-dose remifentanil infusion during extubation, titrated to maintain satisfactory ventilation while attenuating airway reflexes and having an antitussive effect which then rapidly dissipates on cessation. Dexmedetomidine may also be a useful adjunct as it will reduce airway secretions and smooth the extubation process. Selective use of throat packs can lessen the need for pharyngeal suctioning and be less likely to generate aerosol. A clear plastic bag can be placed over the face and front of the head and the airway device removed into the bag which can then be sealed and carefully discarded.

The findings of Brown et al., while encouraging, need to be interpreted as intended. A major limitation stated by the authors is that their data includes *"no measurements from subjects known to have COVID-19 or other inter-current respiratory comorbidity"*. The results from the study by Dhillon et al. are based on only three patients and show higher aerosol generation but still less than that produced by a volitional cough. Further studies are necessary to look at the spatial particle distribution during airway management in a real-time basis and perhaps evaluate some of the suggestions we have described above.

What about PPE?

"It's not what you do it's the way that you do it. . .". The major question that now arises is whether these results suggest that use of airborne PPE is necessary for airway management in the elective setting during a pandemic. There is almost certainly a risk of transmission of infection to healthcare workers during airway procedures but it seems that the generation of aerosols, as a mode of transmission, can be almost eliminated by careful attention to technique and, therefore, use of an ordinary facemask, gloves and goggles should suffice. Risk stratification and the PPE level required can be determined based on TOCC (Travel, Occupation, Contact, Cluster) history, whether patients are symptomatic of infection and test results, as we suggest in Table 1. As the studies were conducted in operating theatres where rate of air change is high and the environment is relatively controlled and stable, the results will not necessarily apply to other less optimal settings such

as the ward or emergency department. In addition, tracheal intubation in these areas is usually time-critical, meaning comprehensive risk stratification may be difficult to complete. It is probably prudent, therefore, to consider all patients requiring tracheal intubation in the ward or emergency department as high risk of being infectious during a pandemic. COVID-19 is set to continue to disrupt our daily lives for the foreseeable future. To inform decisions regarding infected cases, we need a much better understanding of aerosol evaporation and diffusion and how this is affected by air flow in these other settings.

Whether or not we need to continue using full airborne precaution PPE for airway management in the elective setting is bound to be contentious but the evidence presented here is reassuring and suggests that, with careful attention to technique and appropriate pharmacotherapy, this may not be necessary in patients at low risk of being infectious, that is, those who are TOCC negative and asymptomatic or COVID-19 test negative (Table 1). Although such patients may still be infectious, the viral load is likely to be low and aerosol generation negligible.

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