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REVIEW

An anaesthetic and intensive care perspective on infection control measures for the prevention of airborne transmission of SARS-CoV-2

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Abstract

Guidance regarding appropriate use of personal protective equipment in hospitals is in constant flux as research into SARS-COV-2 transmission continues to develop our understanding of the virus. The risk associated with procedures classed as 'aerosol generating' is under constant debate. Current guidance is largely based on pragmatic and cautious logic, as there is little scientific evidence of aerosolization and transmission of respiratory viruses associated with procedures. The physical properties of aerosol particles which may contain viable virus have implications for the safe use of personal protective equipment and infection control protocols. As elective work in the NHS is reinstated, it is important that the implications of the possibility of airborne transmission of the virus in hospitals are more widely understood. This will facilitate appropriate use of personal protective equipment and help direct further research into the true risks of aerosolization during these procedures to allow safe streamlining of services for staff and patients.

Key words: Aerosol; Aerosol-generating procedures; COVID-19; Personal protective equipment; SARS-CoV-2

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Introduction

The prevalence of SARS-CoV-2 continues to require consideration of heightened infection control precautions for all healthcare workers. Personal protective equipment has been written about extensively in the media and medical journals. In particular, the concept of aerosol-generating procedures and appropriate measures required to minimise associated transmission are points of regular debate.

As elective work is reinstated, risk management and appropriate strategies for use of personal protective equipment require careful scrutiny. In addition, extrapolation from epidemiological modelling regarding a second spike in infection rates (Xu and Li, 2020) means that the workforce needs to be prepared for another period of redeployment and high volume contact with patients with confirmed or suspected SARS-CoV-2 infection. It is important to have clear, effective strategies for infection control and use of personal protective equipment. However, as understanding of the virus develops, the guidance regarding infection control practice is in a constant state of flux. For this reason, it is also imperative that the rationale behind practices is understood.

Aerosol-generating procedures and airborne transmission

Transmission of SARS-CoV-2 occurs mainly via the droplet or contact route. Generation of aerosols creates the possibility of airborne transmission. The World Health Organization (2014) defines an aerosol-generating procedure as 'any medical and patient care procedure that results in the production of airborne particles (aerosols)'. However, breathing, speaking and coughing can generate aerosols from the respiratory tract (Yang et al, 2007; Anfinrud et al, 2020). Aerosolised particulates containing SARS-CoV-2 RNA have been detected in hospital areas where no aerosol-generating procedures take place (Liu et al, 2020), leading to speculation that airborne transmission may be possible outside hospital settings. The risk

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of airborne transmission may be increased significantly during the performance of ‘high risk aerosol-generating procedures’, namely ‘medical procedures that have been reported to be aerosol-generating and consistently associated with an increased risk of pathogen transmission’ (World Health Organization, 2014). A more helpful definition of an aerosol-generating procedure might be a procedure which is ‘more likely to generate higher concentrations of infectious respiratory aerosols than coughing, sneezing, talking, or breathing’ and ‘potentially put healthcare personnel and others at an increased risk for pathogen exposure and infection’, offered by the Centers for Disease Control and Prevention (2020) in the United States of America.

Aerosols are generated by movement of air across the surface of a liquid. Increased force of air currents decreases the size of particles generated (World Health Organization, 2014). Procedures which result in high velocity airflow at the interface between air and the respiratory mucosa of infected patients, beyond that of a cough or sneeze, likely fulfil these criteria. This is particularly relevant to SARS-CoV-2 transmission, as infected individuals accumulate high viral loads in upper airway secretions (To et al, 2020).

The risk associated with aerosol-generating procedures rests on the behaviour of aerosolised particulates. An aerosol is a particle suspended in a gas that is small enough to remain airborne for long periods of time. By convention a cut off of 5 μm is often used, with particles of this diameter or smaller classed as aerosols (Tellier, 2006). In contrast, droplets are particles of a critical size at or above which they settle on surfaces quickly. Particles of 10 μm diameter or more generally fall into this category. Between 5 and 10 μm, particles behave as either aerosols or droplets depending on environmental factors (Kohanski et al, 2020). The presence of infective aerosols increases the radius of air and surfaces around patients that should be considered contaminated. In an indoor environment, a 10 μm diameter particle will descend with gravity (or settle) 1 m in 5.6 minutes, whereas a particle of 1 μm diameter settles 1 m in 9.3 hours (Kohanski et al, 2020). The longer a particle remains airborne, the further it may travel from its origin. Particles behaving as droplets tend to settle within 1.5–2 m of their origin, hence droplet precautions are required within 2 m of patients (Tran et al, 2012). The length of time before settling determines how long air remains contaminated, although this will be impacted by local ventilation and air currents.

Particle size also affects the deposition site within the respiratory tract. Particles of 5 μm or below generally deposit in the lower airways. Droplets larger than 10 μm are more likely to deposit in the upper airways (Tellier, 2006). The impact of the anatomical point of deposition is not known. Theoretically, deposition lower in the respiratory tract could affect the type and severity of symptoms experienced.

Which procedures are aerosol generating?

Table 1 lists the procedures which are currently classed by Public Health England (2020b) as ‘aerosol-generating procedures’. The absence of chest compressions during cardiopulmonary resuscitation from this list diverges from guidance issued by the Resuscitation Council UK, which classes this as an aerosol-generating procedure (Wyllie, 2020). Data surrounding transmission risks associated with cardiopulmonary resuscitation are rife with confounding factors. It is not possible to separate the risks of different procedures performed during cardiopulmonary resuscitation, including tracheal intubation and manual ventilation, so guidance must be based on pragmatism and logic. The UK’s New and Emerging Respiratory Virus Threats Advisory Group argues that, during chest compressions, airflow through the patient’s respiratory tract will be akin to that of breathing, therefore should not be treated as an aerosol-generating procedure (Public Health England, 2020a). In fact, all procedures in **Table 1** have varying, generally weak levels of evidence supporting their designation as aerosol generating. As such, advisory bodies must take a pragmatic and cautious approach.

Intubation and/or extubation

One study investigating particle sizes containing H1N1 RNA, before and after intubation of infected patients, found increased particles of diameters that would be considered aerosols after intubation, although this was not statistically significant (Thompson et al, 2013). Several small studies investigating transmission of SARS and other respiratory viruses to healthcare workers found a weak association with performance of intubation and infection. All studies

Table 1. Procedures classed as aerosol generating as per Public Health England guidance August 2020
Respiratory tract suctioning
Bronchoscopy
Manual ventilation
Tracheal intubation and extubation
Tracheotomy or tracheostomy procedures (insertion or removal)
Upper ear nose and throat airway procedures that involve suctioning
Upper gastrointestinal endoscopy where there is open suctioning of the upper respiratory tract
High-speed cutting in surgery or postmortem procedures if this involves the respiratory tract or paranasal sinuses
Dental procedures using high-speed devices such as ultrasonic scalers and high-speed drills
Non-invasive ventilation, bi-level positive airway pressure ventilation and continuous positive airway pressure ventilation
High-frequency oscillatory ventilation
Induction of sputum using nebulised saline
High-flow nasal oxygen

From Public Health England (2020b)

point to confounding factors, including difficulty in confirming use of droplet personal protective equipment and contact precautions (National Services Scotland, 2020). During the SARS epidemic, a small study found higher rates of infection in healthcare workers involved in intubation compared to controls (Fowler et al, 2004). Nurses involved in patient care during the peri-intubation period were at highest risk, raising the possibility that the risk to healthcare workers is increased by exposure to the critically ill patient and surroundings before intubation. This raises questions about the risk of intubation in asymptomatic, swab negative patients, requiring further investigation. Recent data suggest a low rate of infection with SARS-CoV-2 in intensivists and anaesthetists undertaking endotracheal intubation (Cook, 2020). It is not possible to conclude whether this reflects adequate use of personal protective equipment during intubation, or that the risk during intubation has been overstated.

Logically it is difficult to ascertain a mechanism of aerosol formation during tracheal intubation. There is little to no airflow in the respiratory tract of patients who have received neuromuscular blocking agents during the act of tube insertion. There may be increased risk associated with leaks during face mask ventilation. It is very difficult, and not of particular use, to separate the risk associated with these procedures, as it is rare to perform one without the other, especially in the critically ill patient. Interestingly, little to no literature exists about risk during extubation, which logically presents more opportunity for aerosolization. Extubation, like deep respiratory suction, can instigate forceful coughing. The removal of the endotracheal tube if high flows continue through the circuit will allow aerosolization of secretions deposited on the tube.

Tracheostomy

Insertion of tracheostomy during the SARS epidemic showed increased transmission risk to healthcare workers involved compared to controls (Tran et al, 2012). There is no evidence specifically pertaining to the generation of aerosols during this procedure, but the process will often involve bronchoscopy guidance creating a profound leak from the ventilation circuit distal to microbial filters. This would most likely be the source of aerosol generation. Disconnection while moving from endotracheal tube to tracheostomy also provides an opportunity for aerosol generation. Tracheostomy change or removal in unparalysed patients usually involves suctioning and will cause forceful coughing which may generate aerosolised particles from upper airways and the tracheostomy site.

Bronchoscopy

There are few weak and contradictory air sampling studies investigating aerosolization during bronchoscopy (National Services Scotland, 2020). One study concluded that bronchoscopy without delivery of nebulised medication did not generate more aerosols (O'Neil et al, 2017). However, a study of bronchoscopy focusing on influenza RNA detected increased RNA containing aerosols, although this was underpowered (Thompson et al, 2013). In the absence of conclusive evidence, treating bronchoscopy as an aerosol-generating procedure remains a sensible precaution.

Non-invasive ventilation

Both continuous positive airway pressure and bilevel positive airway pressure use high-flow gas to apply positive pressure via a tight-fitting mask or hood. Air inevitably leaks around the mask, especially when ill fitting, providing opportunity for aerosol dispersion. Evidence surrounding the use of bilevel positive airway pressure during the SARS epidemic shows a weak association with infection in healthcare workers (National Services Scotland, 2020), although a particle sampling study concluded that there was no increase in aerosolisation when using bilevel positive airway pressure (Simonds et al, 2010). Other studies concur that delivery of bilevel positive airway pressure increases the radius of exhaled air dispersion, with higher inspiratory pressures further increasing the dispersion radius to up to 1 m (Hui et al, 2006, 2014). These studies did not investigate particle size or number, so can only conclude that the aerosols generated by normal exhalation are spread over a wider area, not that there is increased aerosol generation. No studies specific to the delivery of continuous positive airway pressure were found on a literature search.

High flow nasal oxygen

Delivery of flows of up to 60 litres per minute can be achieved using high flow nasal oxygen devices. Mouth opening allows flow from this to be diverted out of the oral cavity, creating a mechanism for aerosol generation from the nasal passages and upper airways (Kotoda et al, 2020). Evidence of aerosol generation by high flow nasal oxygen is mainly based on in vitro studies (Roberts et al, 2015; Kotoda et al, 2020). One in vivo study in patients with bacterial pneumonia concluded that high flow nasal oxygen did not create greater airborne contamination than conventional oxygen therapy (Leung et al, 2019). However, bacterial and viral contamination are not directly comparable, and this study was performed in an environment with six air changes per hour, making the results difficult to apply to ward environments.

A recent review concluded that evidence of smoke particle dispersion at high-flow nasal oxygen of 60 litres per minute was comparable to that of the use of oxygen masks at 15 litres per minute (Li et al, 2020). This only investigated particles <1 μm in diameter so again is not conclusive evidence of safety. However, it was noted that the patient donning a surgical face mask in conjunction with high flow nasal oxygen can significantly reduce dispersion of bioaerosols and is worth considering as a risk reduction strategy.

High-speed cutting devices (postmortem, surgery, dental)

Multiple studies have concluded that high-speed cutting devices used in surgery and postmortems generate aerosols. Dental procedures using ultrasonic and sonic drilling also generate aerosols (National Services Scotland, 2020). If the aerosol source is the respiratory tract or upper airways, personal protective equipment to protect against airborne transmission should be worn (see below). There are concerns regarding the possibility of infectivity of smoke plumes and gas released after laparoscopy (Royal College of Surgeons of England, 2020) but there is currently no evidence to support this.

Airway suctioning

The evidence base for risk associated with airway suctioning comes from healthcare worker infection rates during the SARS epidemic (National Services Scotland, 2020). These data pertain to the suctioning of intubated patients, and involve disconnection of the ventilator circuit, which is the logical source of aerosolization.

Induction of sputum and nebulisation

Multiple studies have concluded that chest physiotherapy is associated with neither an increased transmission of SARS nor increased aerosol particle detection (National Services Scotland, 2020). There is evidence that, although nebulisation increases aerosol particle detection, these particles are generated from the nebuliser, not the patient, so would not pose an infection risk. Despite this, induction of sputum with nebulised saline is still classified as an aerosol-generating procedure. Forceful and prolonged coughing will generate aerosols, although increased risk of transmission has not been demonstrated. Governing bodies have issued precautionary guidance surrounding procedures that involve proximity to the airway of patients undergoing procedures that induce this. The Association of Surgeons of Great Britain and Ireland (2020) stated that nasogastric tube insertion, which often causes forceful coughing, should be considered an aerosol-generating procedure. Furthermore, the Royal College of Speech and Language Therapists asserts that procedures such as swallow assessment inducing forceful coughing pose similar infection risks to induction of sputum using nebulised saline (Bolton et al, 2020).

Personal protective equipment

Current guidance for use of personal protective equipment falls into two categories: droplet precautions (required within 2 m of patients), and airborne precautions (required where aerosol-generating procedures are performed).

Droplet precautions

Droplet precautions include sessional use of fluid-resistant surgical masks and eye protection, single-use gloves and plastic aprons. Patients should also wear a fluid-resistant surgical mask, as the mechanism of risk reduction is mainly via reduction of droplet dispersal from the mask wearer (Rodriguez-Palacios et al, 2020).

Airborne precautions

Recommended personal protective equipment for environments with risk of aerosolisation include single use of filtering face piece respirator 3 (FFP3) masks (which should filter aerosolised particles at >99% efficiency), eye protection, long-sleeved fluid-resistant gown, and gloves. Long-sleeved gowns are required as bioaerosols may contaminate larger surface areas of clothing. Transmission occurs when a healthcare worker touches contaminated clothing then touches their mouth, nose or eyes. The gown reduces this risk by removing contamination once contact with the high-risk environment is terminated. Public Health England guidance makes no mention of hair coverings; they are unlikely to afford extra protection in aerosolised environments as the microbiome on human hair should rapidly destroy viral particles settling on hair (Infection Prevention Society, 2020).

High-risk areas

One important consideration regarding the use of personal protective equipment is identifying areas that are high risk and for how long these areas should be treated as containing aerosols, therefore requiring airborne personal protective equipment precautions, after an aerosol-generating procedure has been performed. Current guidance regarding timing of aerosol clearance after an aerosol-generating procedure is based on the number of air changes in the room. Five air changes are sufficient to remove >99% of airborne contaminants (Cook et al, 2020). This guidance is simple to follow in controlled environments such as operating theatres or negative pressure rooms, where air exchange rates are controlled. Most operating theatres undergo five air change within 15 minutes after an aerosol-generating procedure, rendering the room safe for healthcare workers to enter in droplet precaution personal protective equipment. However, there is little information in the literature about remote areas where aerosol-generating procedures are performed less frequently. During surges, areas such as resuscitation bays in the emergency department can be cohorted with healthcare workers consistently wearing airborne precautions in these areas. As admissions for SARS-CoV-2 infections decrease it is not viable to continue this practice. This creates issues when an aerosol-generating procedure must be performed in an area such as this, or a ward area, where ventilation rates are unknown. How long these areas are contaminated with aerosols, and the radius and timing of surface decontamination optimal for risk reduction, must be elucidated.

Bearing this in mind, in the intensive care unit healthcare workers are required to wear airborne precaution personal protective equipment for all contact with potentially infected ventilated patients. This is presumably to ensure that, in the event of accidental ventilator disconnection distal to the microbial filter, healthcare workers are still protected. Of note, similar precautions are not required in operating theatres where patients are also on closed circuit ventilation.

Problems posed by personal protective equipment and infection prevention and control strategies for anaesthesia and intensive care

As specialties used to dealing with emergencies, intensivists and anaesthetists understand the importance of communication. One of the biggest challenges during the pandemic has been difficulties faced by healthcare workers in communicating while wearing personal protective equipment for aerosol-generating procedures. Deciphering facial expressions and lip reading is impossible while speech is muffled by tight-fitting masks and visors. The extra strain on mental capacity created by fear of breaching personal protective equipment guidance, accompanied by discomfort and increased heat, makes normal working more physically and mentally demanding. This becomes compounded in emergency situations. Any safe reduction in requirements for personal protective equipment could therefore be of benefit to patients and staff.

Theatre turnover

As elective surgical work is reintroduced, waiting lists are longer than ever, and increasing list turnover in theatres will be paramount in tackling the backlog. This may be hampered by infection prevention control measures, including the donning and doffing of personal protective equipment and the need for delays after each aerosol-generating procedure before healthcare workers can enter to commence surgery or decontaminate the area. This delay can be mitigated by staff wearing airborne precaution personal protective equipment for the entire theatre session, but the aforementioned disadvantages of this in team environments must be weighed against the time savings that could be made.

Consensus guidance from the Royal colleges and Public Health England on 20 August 2020 stated that operating theatres should no longer be considered a ‘high risk hotspot’. This means that currently in operating theatres, airborne precaution personal protective equipment and delays for air changes are not required for aerosol-generating procedures in asymptomatic patients with a negative swab within 72 hours of surgery (Public Health England, 2020b). However, it is not always possible to fulfil these guidelines, and if background rates of infection increase, precautions may be reinstated. Guidance suggests that the responsibility for this decision be left to individual hospitals (Cook et al, 2020). It will be difficult for hospitals to make defensible decisions without increased mass testing to provide robust data about local SARS-CoV-2 prevalence.

Intensive care

As intensive care units stop providing care for SARS-CoV-2 positive patients in cohorted areas, issues associated with isolation rooms requiring airborne precaution personal protective equipment are highlighted. These patients may be reviewed in person and examined less often, both by intensive care physicians and other specialties, to try and reduce the use of personal protective equipment and minimise staff exposure. Meticulous communication between staff inside and outside of the room is required, and careful evaluation of the need for patient examination must be weighed against the risks of contamination and excessive use of personal protective equipment.

Conclusions and further research

This analysis of the risks surrounding aerosol generation in hospitals highlights the paucity of evidence on which experts can base guidance. As services that were paused

Key points

- Aerosols are particles that are smaller than droplets and remain airborne for longer periods of time.
- If aerosols contain viable virus, prolonged suspension will mean that the environment in which they were generated carries a risk of airborne transmission for an unknown length of time, and allows deposition of the virus over a larger radius.
- The definition of an aerosol-generating procedure is a procedure that generates aerosols over and above those generated during normal speech, coughing and sneezing, and is associated with increased risk of pathogen transmission to healthcare workers.
- The evidence pertaining to the risk of aerosol generation, and transmission of viruses as a result of procedures that are classed as aerosol generating is scarce, therefore guidance is largely based on pragmatic and cautious logic.
- Use of personal protective equipment and infection control measures, especially for prevention of airborne transmission, can create delays and barriers to care.
- More research into risks of procedures currently classified as aerosol-generating procedures, especially in asymptomatic patients may help streamline future services.

during the height of the first wave of SARS-CoV-2 infection are reinstated, the safety of healthcare workers and patients is paramount. These considerations are sometimes at odds with each other, as use of personal protective equipment creates issues regarding patient care and dealing with important backlogs in surgical work which, if left unchecked, could risk lives. It is important that, while patient pathways are redesigned, robust data are collected investigating the risks surrounding procedures which are believed to be aerosol generating.

Tracking infection rates among healthcare professionals, and correlating this with use of personal protective equipment, will identify inadequate personal protective equipment use and guidelines that are insufficient for healthcare worker protection. However, tracking healthcare worker infection rates will only identify areas where increased use of personal protective equipment is required for protection. If there are areas where airborne precaution personal protective equipment use or theatre delays are being unnecessarily employed, and therefore impacting negatively on patient care with no benefit to healthcare workers, other forms of evidence must be collected to prove this is the case. To be able to downgrade use of personal protective equipment in elective settings, two important areas of research are required. Robust evidence of ongoing SARS-CoV-2 prevalence in local populations must be gathered using mass testing. In addition, air sampling studies in theatres, to understand the true risk of aerosolization during performance of procedures classed as aerosol generating, especially in asymptomatic patients, may help elucidate appropriate infection prevention strategies.

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Conflicts of interest

Hazel R O'Mahony: none; Daniel S Martin has received lecture consultancy fees from Siemens Healthineers and Edwards Lifesciences.

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