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Editorial

‘Led by the science’, evidence gaps, and the risks of aerosol transmission of SARS-COV-2

Respiratory infections are transmitted by direct or indirect contact with infectious material, droplet spread, or via airborne aerosol particles. The latter, due to small size and mass, remain airborne and can be inhaled into the lungs, whereas droplets of greater mass are assumed to travel less than 2 m from source, and land in the vicinity of the patient. Infection control measures are therefore designed to minimise spread by direct or indirect contact, dissemination by droplets, and transmission by airborne material. Some medical interventions are more likely to generate aerosol. These aerosol generating procedures (AGPs) as currently defined by Public Health England, are listed in Fig. 1. The categorisation of AGPs dates back to the Severe Acute Respiratory Syndrome (SARS) outbreak in 2003, and subsequent H1N1 influenza epidemic in 2009.

There has recently been a debate on whether manoeuvres used in resuscitation should be added to the list of aerosol-generating procedures – WHO Infection control guidance[1] classifies cardiopulmonary resuscitation (including chest compression, defibrillation and airway manoeuvres) as an AGP, whereas Public Health England (PHE) has not included chest compression as an AGP in Infection Control and Prevention guidance.[2] This discrepancy highlights problems in understanding how respiratory aerosols are generated, and has important relevance to the risk management in those attending infected patients, including the use of personal protective equipment (PPE). Full enhanced PPE (FFP3 mask, eye shield, gown and gloves) is recommended when managing patients using AGPs, whereas if the main source of transmission is thought to be droplets and/or direct/indirect contact when working within 2 m of the patient, the PPE recommended consists of surgical mask, eye protection, gloves and plastic apron.

A recent systematic review[3] has examined the link between resuscitation manoeuvres during cardiac arrest in patients in the SARS-COV-1 and influenza epidemics, and subsequent infection in resuscitation teams. The review found no evidence to support risk to teams from aerosolised particles during chest compression, but equally it was not possible to exclude a level of risk. Separating cardiopulmonary resuscitation (CPR) into components, the risk from defibrillation is likely to be less than chest compression, but chest wall recoil and air shifts during chest compression could plausibly cause propulsive exhalation from the nose and mouth of aerosol and droplets, therefore it is an area recommended for further research. In the meantime a further review of evidence by the New Emerging Respiratory Virus Threats Advisory Group (NERVTAG), UK has not concluded that chest compression should be classified as aerosol-generating as published in PHE guidance April 27 2020.[2]

To investigate the effects of chest wall compression further, Ott et al.[4] in this edition of Resuscitation have examined possible emission of particles using 2 models – one a simulator manikin and the other a cadaver model. In the simulator model detergent detectable by ultraviolet light was nebulised into the manikin at an airflow rate of 8 l/min, and chest compression performed. For the cadaver model the airways and lungs were insufflated with the same ultraviolet sensitive detergent using an ambu bag via a shortened endotracheal tube. The endotracheal tube was then removed and chest compression was applied, with visualisation of the emitted material as in the simulator model.

Chest compression in both models produced a plume of exhalate. The spread of this was influenced by the use of a facemask which deflected flow towards the model's forehead, and an oxygen mask which produced diffuse dissemination from the periphery of the mask around the model. Following placement of a laryngeal airway with expiratory filter, almost no plume was visible. This finding has useful practical relevance.

These are interesting results, adding to argument that chest wall compression may be an AGP but the study raises further questions. It is clear that a plume of material was produced from both models, but particle size was not measured. It is likely than some aerosol generated was that from nebuliser in the simulator model. As a consequence it is difficult to know to what extent the simulator and even cadaver model reproduces chest wall recoil in patients, and the shifts in airflow associated with this. Moreover, droplets and aerosol from a human airway will behave physically in accordance with changes in temperature on exhalation, and other variables, which are quite different to the behaviour of particles in the simulator model or cadaver.

Ott et al.'s models[4] therefore cannot demonstrate conclusively whether chest compression during cardiopulmonary resuscitation yields droplets or aerosol in real life scenarios in humans, nor whether the plume of material represents an infection risk. However they do clearly show that the plume is mitigated by placement of a laryngeal airway. In clinical practice and especially in patients with severe SARS-COV-2 chest wall compression is likely to accompanied by the need for intubation and ventilation–the latter being recognised as aerosol-generating, and therefore requiring use of enhanced PPE. For policy decisions on the use of enhanced PPE during a cardiac arrest it is a matter of balancing the risks of delaying the intervention in order to

- Intubation, extubation and related procedures, for example, manual ventilation and open suctioning of the respiratory tract (including the upper respiratory tract)
- Tracheostomy or tracheostomy procedures (insertion or open suctioning or removal)
- Bronchoscopy and upper ENT airway procedures that involve suctioning
- Upper gastro-intestinal endoscopy where there is open suctioning of the upper respiratory tract
- Surgery and post mortem procedures involving high-speed devices
- Some dental procedures (for example, high-speed drilling)
- Non-invasive ventilation (NIV); Bi-level Positive Airway Pressure Ventilation (BiPAP) and Continuous Positive Airway Pressure Ventilation (CPAP)
- High Frequency Oscillatory Ventilation (HFOV)
- Induction of sputum
- High flow nasal oxygen (HFNO)

Fig. 1 – Procedures considered to be potentially infectious AGPs for COVID-19 (COVID-19: Infection Prevention and Control (IPC) Public Health England May 3, 2020.

don PPE, versus the risk to the rescuer from not using that level of infection control.[3] For isolated defibrillation for an arrhythmia, as may be seen in a patients with covid-19 myocarditis, the fact that defibrillation can be activated at a distance of more than 2 metres after electrode placement, means that the risk of aerosol contamination to the operator is relatively low. For chest wall compression, despite the fact that NERVTAG do not rate this an AGP, the proximity of the operator performing chest compressions, and likelihood of emissions from the patient (whether droplets or aerosol) would suggest that enhanced PPE use is advisable, especially in the high risk situation of Covid-19, and this is the recommendation of the European Resuscitation Council COVID-19 Guidelines.[5]

This mismatch between some guidance and experience on the frontline raises wider issues on infection control, aerosol generation and PPE guidance. 'Science led' policies will always be based on evidence from previous outbreaks, combined with evolving knowledge from current pandemic experience. While the case definitions of SARS, influenza and covid-19 include fever, cough and breathlessness, a cardinal and particular feature of covid-19 affecting up to 70% of patients, is new and continuous cough, indicating upper airway inflammation. Spasmodic and forceful cough may occur spontaneously when examining a patient with suspected or confirmed covid-19, or be triggered by upper airway interventions, such as taking a nasopharyngeal or oral swab sample, performing spirometry, or ear nose and throat (ENT) examination.

Infection control precautions are predicated on a conventional categorisation that recognises droplets as greater than 5 μm in size, and 'larger droplets' more than 10 μm, whereas an aerosol is defined by particles of less than 5 μm. However this simple division into particles above and below 5 μm, is entirely arbitrary. Recent analysis has shown that respiratory emissions from human coughs and sneezes constitute a mixture of mucosalivary droplets and a multiphase gas cloud or plume of matter which behaves in a dynamic manner.[6,7] Larger droplets settle out in the vicinity of the individual, contaminating the environment and acting as a direct and indirect contact risk. Smaller droplets evaporate as they move away from the warm moist airway, and become droplet nuclei or aerosol. Within the atmosphere of gas cloud aerosol may persist for much longer periods than isolated droplets. The trajectory of the cloud is influenced by evaporation rates (in turn affected by environmental humidity and temperature), and the speed and force of the cough or sneeze. Cough peak flow in normal adults is in excess of 400 l/min. Droplet nuclei may stay suspended in the air for hours depending on ambient conditions such ventilation, or air changes in the room.[6] The presence of viral antigen within these droplets, and the infectivity of the material are further important variables. The exposure 'dose' from a cough, sneeze or exhalation is likely to vary according to the proximity of the healthcare worker (HCW) to the patient's airway, the patient's viral load, and the use and type of PPE protection. It is also plausible that underlying conditions such as asthma, bronchiectasis, and COPD may not only increase propensity to cough or wheeze, but may produce secretions with different muco-elastic properties, which affect particle size and behaviour. A study[8] of droplet dispersion during a physiotherapy session designed to clear airway secretions in a group of patients with purulent sputum due mainly cystic fibrosis and bronchiectasis, produced droplets of 10 μm and above, and no detectable aerosol. Sputum produced in this group is observably different to the clearer more mucoid secretions found in those with viral infection and without pre-existing airway disease.

In a study of cough aerosol production in healthy normal subjects without infection, Zayas et al.[9] showed a huge variation if droplet size varying from 0.1 to 900 μm, with 97% droplets less than 1 micron in size. Lindsley et al.[10] measured the presence of influenza virus in aerosol particles from coughs in infected individuals and found that much of the viral RNA was contained in particles in the respirable range – 35% in particles less than 4 microns, 23% in particles of 1 –4 μm and 42% in particles less than 1 μm. While the presence of viral RNA cannot be equated with infectivity, this work does suggest that influenza, at any rate, can be spread by the airborne route, rather than by droplets and contact alone. The same research group has also examined the efficacy of face shields against cough aerosol and droplets generated by a cough simulator.[11] They found that face shields can very significantly protect from short term exposure to large droplets, but that smaller aerosol particles remain airborne for longer and may disperse around the facial shield and be respired[11] indicating the need for greater protection.

Overall these findings suggest that the risk of *aerosol transmission* of SARS-COV-2 should be considered even in the absence of use of typical AGPs, and this alters considerations about PPE use in hospital and community settings.[12] How should we use this information? While full enhanced PPE is indicated for aerosol generating procedures, the above work suggests that some patients themselves are aerosol generators, and this is a particular risk in COVID-19. Persistent cough in an individual with high viral load may conceivably put those in the vicinity at as much risk as if, say, continuous positive airway pressure or non-invasive ventilation is applied. Distancing of more than 2 m may also be insufficient in those with a paroxysmal, propulsive cough. This may also explain the increased occupational risk to members of the public such as taxi and bus drivers in an enclosed environment, in the vicinity an infected passenger. Clearly mitigating the effects of the cough with the patient using a surgical mask is useful, but not always possible e.g. in a child. Those with pre-existing respiratory disorders may also find face coverings difficult to tolerate. Undoubtedly this creates a dilemma, as it is not feasible to use enhanced PPE, in particular FFP3 or N95 masks during all patient contacts. However, it remains the case that clinical situations should be judged and managed according to risk, and PHE recognise that '*provision of healthcare is dynamic and in a single care episode more than one context may be encountered, PPE should be changed (upgraded) as appropriate*'.[2]

It is of concern that infection of health and social care workers in the covid-19 pandemic has been significant. This has generally not occurred in areas such as Critical Care units where use of enhanced PPE is near universal as most patients are intubated and receiving a range of AGPs. These new considerations on aerosol generation are relevant to those examining and assessing patients in Accident and Emergency or ENT departments, and to care workers in the community, where PPE for droplet and direct contact infection control may not suffice, and suboptimal protection may contribute to increased infection risk. This concern is over and above the reported lack of supply of adequate PPE to staff.

We should be led by the science and evidence base, but this should be updated and revised according to new analyses, and frontline experience with SARS-COV-2. While infection control guidance based on AGP/airborne versus droplet precautions is a useful and pragmatic concept leading directly to PPE choices, risk management in real life is likely to be more complicated, involving host factors in the patient, the technical procedures employed, and clinical context.

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