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# Should chest compressions be considered an aerosol-generating procedure? A literature review in response to recent guidelines on personal protective equipment for patients with suspected COVID-19

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ABSTRACT

**There is disagreement between international guidelines on the level of personal protective equipment (PPE) required for chest compressions for patients with suspected COVID-19. This discrepancy centres on whether they are considered to be an aerosol-generating procedure (AGP), thus requiring airborne protection to prevent transmission to healthcare workers (HCWs). The need to don higher-level PPE has to be weighed against the resulting delay to emergency treatment.**

**We performed a literature search on this topic which found eight relevant studies. All were observational with low patient numbers and multiple confounding factors, but describe cases of acute respiratory infection transmission during chest compressions. One systematic review concluded that chest compressions were not an AGP. Two simulated studies (released as preprints) potentially demonstrate aerosol generation. Given that there is evidence for infection transmission during chest compressions, we conclude that a precautionary approach with appropriate PPE is necessary to protect HCW from contracting a potentially fatal infection.**

**KEYWORDS:** Aerosol generating procedures, cardiopulmonary resuscitation, chest compressions, COVID-19, personal protective equipment

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## Introduction

The most recent Public Health England (PHE) and Health Protection Scotland (HPS) guidelines (7 April 2020)[1,2] on COVID-19 personal protective equipment (PPE) state that 'chest compressions [and defibrillation] are not considered AGPs (aerosol-generating procedures)'. This was reiterated in a later statement (27 April 2020) following a review by the New and Emerging Virus Threats Advisory Group (NERVTAG).[3,4] This guidance contradicts the positions of the Resuscitation Council UK (RCUK)[5] and the World Health Organization (WHO)[6] and has created concern among medical professionals.[7,8] AGPs require enhanced PPE, potentially delaying resuscitation. This must be balanced against the risk of transmission to the healthcare worker (HCW). This review seeks to examine the reasons for the guideline discrepancy and the available evidence to guide practice.

## Background

### Levels of personal protective equipment

The level of PPE recommended for a clinical encounter reflects the perceived risk of infection transmission via droplet, contact or airborne spread. For contact and droplet precautions during direct care of possible or confirmed inpatient cases, 'level two' PPE is recommended by PHE,[9] consisting of a disposable apron and gloves, fluid-resistant surgical mask and eye or full face protection. For the extra precautions against airborne transmission required during AGPs, 'level three' PPE is recommended, which includes the addition of a filtering facepiece respirator (FFP mask) and disposable fluid-resistant gown.

### What is an aerosol-generating procedure?

Aerosols are particles containing pathogens suspended in air which can transmit infection.[2,10] AGPs are procedures which mechanically create aerosols, or induce the patient to create aerosols.[10] This allows airborne spread of infections normally transmitted via droplet or contact transmission.[1,11]

There is disagreement about whether coughing can be considered aerosol-generating; 'induction of sputum' is included in the PHE list of AGP,[1] whereas the NERVTAG review states that 'an expiration breath, much like a cough, is not currently recognised as a high-risk event or an AGP'.[4] This is pertinent as the mechanism of chest compressions has been described as similar to exhaling or coughing.[4,10]

### Chest compressions versus cardiopulmonary resuscitation

Some discrepancy across guidelines can be attributed to differing terminology between 'cardiopulmonary resuscitation' (CPR) and

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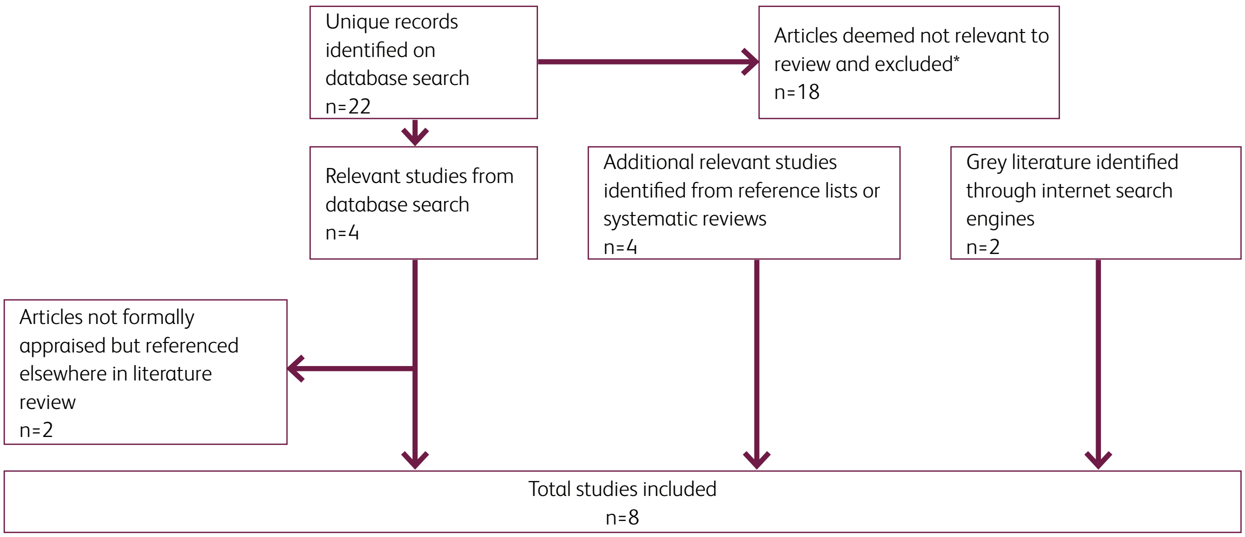


*Excluded through manual review of article abstracts

**Fig 1. Literature inclusion methodology.**

'chest compressions', which may not be used interchangeably in the literature. CPR may involve additional procedures to chest compressions, such as assisted ventilation, intubation or defibrillation, some of which may be AGPs.[1,2,12] This review aims to look specifically at chest compressions, although in practice it is difficult to distinguish risk from chest compressions alone as this is only one link in the chain of survival.

## Current guidelines on PPE and chest compressions

PHE and HPS guidance[1,2] advises that, for suspected COVID-19 patients, chest compressions and defibrillation can be commenced with level two PPE. Once any form of airway intervention or other AGP is required, level three PPE should be worn. PHE reference WHO guidelines from 2014,[11] and one systematic review,[13] both discussed below, to support these recommendations.

The WHO guidelines[11] do not specify whether chest compressions alone are considered an AGP, but do advise that there is a risk of infection transmission related to CPR involving intubation. Updated guidance specific to COVID-19[6] includes CPR as an AGP; however, this is without breakdown of individual procedures and again without specific mention of chest compressions.

In contrast, the RCUK position is that level three PPE should be worn for chest compressions and CPR.[5,14,15] HCWs can apply defibrillator pads and treat a shockable rhythm if present with level two PPE, as this can be done at a distance. However, they advise that all members of the resuscitation team wear level three PPE before entering the room or performing chest compressions, as they class this as AGP. This guidance is reflected in the modified Advanced Life Support algorithm,[16] with acknowledgement of potential treatment delay. In the community, the advice to the public is to deliver compression-only CPR and cover the patient's mouth and nose with a cloth if infection is suspected.[17]

The Royal College of Physicians (RCP) has likewise supported the requirement for level three PPE for chest compressions and CPR.[18] The Northern Ireland guidelines from the Health Protection Surveillance Centre (HPSC)[19] include CPR as being 'consistently recognised' as an AGP with an increased risk of pathogen transmission. Similarly, the American Heart Association (AHA)[20] and American College of Chest Physicians (CHEST)[21] have also made the recommendation for wearing full AGP PPE throughout resuscitation.

In summary, PHE advice that chest compressions are not an AGP stands in stark contrast to that of the RCUK, RCP, HPSC, AHA, CHEST and WHO.

## Methodology

A database search was performed on 22 April 2020 and included Medline, EMBASE, CINAHL, BNI, HMIC and PubMed. It included the following queries: aerosol generating procedures and cardiopulmonary resuscitation or chest compressions. 22 unique articles were found and articles deemed not to be relevant were manually excluded based on their title and abstract (Fig 1). The search strategy was performed by a librarian and full details of the search terms can be found in the supplementary material (S1). A summary of the papers included is found in Table 1.

## Studies included in literature review

### AGPs and risk of transmission of acute respiratory infections to healthcare workers: A systematic review (Tran *et al*, 2012)[13]

This systematic review, referenced by PHE,[1,2] WHO[11] and HPSC[19] guidelines, identified five case-control and five retrospective cohort studies which evaluated transmission of SARS (SARS-CoV-2) to HCWs. Of these studies, three involved chest compressions: one case-control study[22] and two cohort studies.[23,24] This review did not consider chest compressions or defibrillation to increase the risk of transmission, although it did not specifically address whether these procedures are aerosol-generating. All studies were classed as 'very low' quality by the GRADE system; the equivalent of stating that the true effect is probably markedly different from the estimated effect.

**Table 1. Studies included in literature review**

| Study | Study design | Overview | Population | Summary |
|---|---|---|---|---|
| Tran *et al*, 2012, Canada[13] | Systematic review | Transmission of SARS-CoV to healthcare workers | 5 case-control studies, 5 cohort studies | Chest compressions are not considered to increase the rate of transmission of acute respiratory infections |
| Liu *et al*, 2009, China[22] | Case-control study | Possible risk factors of SARS transmission | 477; 51 infected | Chest compressions were associated with a 33% risk of contracting SARS, compared with 11% that did not contract SARS |
| Raboud *et al*, 2010, Canada[23] | Retrospective cohort study | SARS transmission in cohort with close contact to airway of SARS patient and failure of infection control practices | 697; 26 infected | Out of 26 infected HCWs, one was involved in chest compressions. Eight of the control group performed chest compressions and did not contract SARS |
| Loeb *et al*, 2004, Canada[24] | Retrospective cohort study | Risk of SARS infection in critical care nurses | 32 nurses; 8 infected | Three nurses were involved in chest compressions and none contracted SARS |
| Christian *et al*, 2004, Canada[26] | Cross-sectional study | Possible cluster of SARS-CoV infections in HCWs during CPR | 9; 3 symptomatic, 1 confirmed infection | Risk of transmission through chest compressions difficult to establish due to multiple confounding factors, refusal of serological testing and small sample size |
| Nam *et al*, 2015, Korea[25] | Case study | MERS infection of 1 HCWs contracted while performing CPR | 1 | Identified three possible routes of infection transmission during CPR in this case, including the generation of aerosols |
| Ott *et al*, 2020, Germany[27,28] | Simulation (Two studies) | Aerosol spread during chest compressions in dummy and cadaver models | – | Limited applicability as not yet peer-reviewed. Suggested that aerosols may be generated in the direction of the provider during chest compressions |

HCWs = healthcare workers.

### Risk factors for SARS infection among hospital healthcare workers in Beijing: a case control study (Liu *et al*, 2009)[22]

Liu *et al* conducted a retrospective case control study to evaluate possible risk factors for SARS infection among HCWs in a Beijing hospital. The case group comprised 51 infected HCWs, and the control group 426 non-infected HCWs.

The authors found that seven risk factors were associated with a significantly increased odds ratio of SARS infection: emergency care (21.1% in case group versus 8.4% in control group, $p=0.001$), chest compressions (33.3% versus 11.1%, $p=0.02$), intubation ($p<0.001$), contact with respiratory secretions ($p=0.004$) or sputum ($p=0.004$), contact with pathological specimens ($p=0.04$) or the deceased ($p=0.04$). 15 HCWs in total delivered chest compressions, of whom five contracted SARS. On multivariate analysis, chest compressions were found to be an important predictor of infection transmission with an odds ratio of 4.52 ($p=0.031$), but given that there was a high correlation between HCWs who performed intubation and chest compressions, the relative risk of either procedure in isolation could not be distinguished.

### Risk factors for SARS transmission from patients requiring intubation: A multi-centre investigation in Toronto, Canada (Raboud *et al*, 2010)[23]

This retrospective cohort study examined routes of SARS transmission to 26 infected HCWs out of 697 involved in care of SARS patients, and concluded transmission was attributable to close airway contact and failure of infection control practices. A total of nine HCWs performed chest compressions, of whom one became infected; four HCWs performed defibrillation, with one contracting SARS. It is unclear whether the same affected HCW involved in defibrillation also participated in chest compressions, and whether they had also been involved in other procedures.

This study is included in the review by Tran *et al*,[13] where it was noted that there was a higher odds ratio for risk of SARS transmission to HCWs who performed chest compressions and defibrillation: 3.0 and 7.9 respectively.

### SARS among critical care nurses, Toronto (Loeb *et al*, 2000)[24]

Another retrospective cohort study reviewed the risk of SARS infection in HCWs in critical care. Eight out of 32 nurses who entered a SARS patient's room were infected during the study period (eleven days). Of the three nurses who performed chest compressions, and the two who performed defibrillation, none contracted SARS. It is not clear whether the same nurses involved in defibrillation also performed chest compressions, nor what PPE was worn.

This study was reported in the review by Tran *et al*[13] as having low odds ratio for the risk of SARS transmission to HCWs for both chest compressions and defibrillation: 0.4 and 0.5 respectively.

### Healthcare worker infected with Middle East Respiratory Syndrome during cardiopulmonary resuscitation in Korea (Nam *et al*, 2015)[25]

This case study referenced in the latest guidance from HPS[2] describes one HCW who became infected while performing CPR on a patient with confirmed MERS in an isolation room wearing equivalent level three PPE. It was thought likely that this HCW was infected via bodily fluids which splashed onto their mask and face during CPR. The authors theorise that there were three possible routes of infection transmission during CPR: generated aerosols inhaled through a gap between face and mask, mucosal exposure to contaminated sweat, and/or contamination during PPE doffing.

It should be noted that this case study states that aerosols can be generated during CPR, referencing the systematic review by Tran *et al*[13] despite the opposite conclusion being cited from this review elsewhere.

### Possible SARS coronavirus transmission during cardiopulmonary resuscitation (Christian *et al*, 2004)[26]

This cross-sectional study investigated a cluster of SARS-CoV infections in HCWs performing CPR on a SARS patient. The arrest was attended by nine HCWs. Six wore the US equivalent of UK level three PPE, with the remainder wearing more advanced 'level four' PPE. All wore N95 respirators (equivalent to FFP2 masks) but were not fit-tested.

There were two team members whose only role in the arrest was performing chest compressions. One wore the level four PPE, and they were asymptomatic and refused testing. The other wore level three PPE and developed symptoms typical of SARS three days later, but their serological results were indeterminate.

It is difficult to interpret these results due to the small sample size and multiple confounding factors, such as the differing levels of PPE, the possibility of contact with other SARS patients, and absence of serological results.

### CPR and COVID-19: Aerosol-spread during chest compressions (Ott *et al*, 2020)[27]; Aerosol-spread during chest compressions in a cadaver model (Ott *et al*, 2020)[28]

In these two non-peer-reviewed papers, Ott *et al* carry out two simulations examining whether chest compressions generate aerosols. The first study[27] involved a modified CPR dummy with a nebuliser containing disinfectant solution visible under ultraviolet light attached to the dummy's lungs. Photographs were taken in a dark room while participants performed chest compressions, allowing the luminescent aerosols to be visualised. The simulation was repeated to compare aerosolisation during chest compressions alone, with a surgical face mask, oxygen mask and laryngeal airway in situ.

The simulation was replicated[28] using three human cadaveric models with the same solution instilled into the lungs. The methodology is unclear as the paper initially reports that the solution was instilled via endotracheal tube, then later that the solution was administered via nebuliser set and self-inflating bag. The same procedures as for the CPR dummy were repeated and photographed.

Both studies found that aerosols could be visualised during chest compressions, with the most visible spread during compressions alone with no face covering, when aerosols could be seen to spread in the direction of the HCW. The use of an oxygen mask created diffuse aerosol spread, whereas the face mask redirected the aerosol spread to the patient's forehead. Insertion of a laryngeal tube with airway filter created almost no aerosol spread.

These experiments attempt to address an unanswered question about the generation of aerosols during chest compressions, but the model used is somewhat flawed. The methodology in the cadaver experiment is unclear, and when using the CPR dummy it would appear that the nebuliser was continuously running which calls into question whether the aerosols were truly generated by the compressions alone.

The most relevant points are the potential generation of aerosols towards the HCW during chest compressions, putting them at risk. Additionally, the efficacy of a face mask in redirecting aerosols away from the provider may support the RCUK's guidance for chest compressions in the community.[17]

## Discussion

Our literature review has highlighted the paucity of evidence regarding whether chest compressions are aerosol-generating, and therefore carry a risk of transmitting acute respiratory infections. This has led to the discrepancies across international guidelines for appropriate PPE.

Two recent studies[27,28] by the same authors, albeit not peer-reviewed, potentially demonstrate aerosolisation of fluid within the lungs during chest compressions, and that these aerosols spread in the direction of the healthcare provider. The physiology of chest compressions is such that there is increased intrathoracic and airway pressure with each compression.[29] This pressure has been shown in pig models to force respiratory gases from lungs[30] and, while the pressure is not enough to ventilate, it could potentially aerosolise viral particles.

It is not possible to state definitively whether chest compressions are aerosol-generating. This is currently undergoing systematic review by the International Liaison Committee on Resuscitation.[31] The relevant clinical question must be whether there is a risk of transmission of infection to the HCW.

The available evidence for risk of infection transmission in practice is solely from small observational studies. PHE, WHO and HPSC guidelines,[2,11,19] as well as one case study,[25] all reference the one available systematic review[13] but draw different conclusions as to whether chest compressions are aerosol-generating.

The three studies included in the systematic review by Tran *et al*[13] relevant to chest compressions all have small patient numbers and are of low quality. Liu *et al*[22] report five out of fifteen HCWs who performed chest compressions contracted SARS, giving an odds ratio of 4.5. Raboud *et al*[23] reported that one out of nine HCWs who delivered chest compressions contracted SARS, with an odds ratio of 3.0. Loeb *et al*[24] reported that three HCWs delivered chest compressions to SARS patients and none contracted the disease, giving an odds ratio of 0.4. Across the three studies only 27 HCWs in total delivered chest compressions, of whom six became infected. After weighting, the systematic review created a pooled estimate from the two cohort studies[23,24] which decreased the OR to 1.4. The authors concluded that there was not a significant risk of infection transmission from chest compressions, but to determine this on the basis of these small numbers seems falsely reassuring.

An additional case study[25] provides limited evidence for transmission via aerosol-generation during chest compressions. Another cross-sectional study[26] has multiple confounding factors limiting any practical application.

Most studies have involved SARS or MERS patients, but so far there have been no studies specifically looking at SARS-CoV-2 transmission during chest compressions. A Canadian review[32] recommended the equivalent of UK level three PPE with a fit-tested N95 mask for all contact with critically ill patients with suspected or confirmed COVID-19. The authors classed resuscitation procedures as 'higher' or 'lower' risk, with chest compressions falling into the lower risk category. For higher risk procedures, such as intubation, they suggest that use of powered air purifying respirators (PAPRs) should be 'strongly considered'.

There are inherent challenges in investigating this topic. Often HCWs are involved in many potentially AGPs during multiple patient encounters, making the isolated exposure risk from each procedure very difficult to assess. During CPR, assisted ventilation can generate aerosols, making this exposure difficult to separate from chest compressions. There are other confounding factors including the level of PPE worn, and the frequency of patient contact, which are either not reported or not possible to standardise. There are also small sample sizes which makes generalisation difficult. WHO guidelines acknowledge this complexity when stating that chest compressions with intubation are classified as AGPs, highlighting the complex dynamic nature of resuscitation, but not offering reassurance that chest compressions alone are risk-free.

There is ultimately an ethical angle to this discussion. The requirement for PPE has the potential to cause delay to life-saving treatment, but this must be balanced against the potential for infection transmission to HCWs. Ensuring scene safety is the first priority in all life support guidance.[16,17,20,21] The principle of 'do no harm' in the context of a highly contagious pathogen should also be extended to the HCW. Applying the principles of utilitarianism, the safety of HCWs is paramount to the healthcare service as a whole. Furthermore, steps can be taken to minimise delay including familiarity with equipment,[14,16] simulations to practice donning PPE, and pre-prepared PPE packs on resuscitation trolleys.

Chest compressions and defibrillation are the only interventions in cardiac arrest which have been shown to improve survival.[12,33] The RCUK guidelines suggest that in the immediate assessment of a patient in cardiac arrest, a HCW wearing level two PPE can apply defibrillation pads and defibrillate a shockable rhythm prior to chest compressions,[16] while waiting for the rest of the resuscitation team to arrive and don appropriate PPE. Indeed, it is likely that cardiac arrest in COVID-19 patients would likely be due to either an arrhythmia or hypoxaemia. An arrhythmia is best treated with early defibrillation, and in the event of hypoxaemia, the crucial intervention will be ventilation which requires level three PPE.[34]

## Conclusion

The available evidence for whether chest compressions are an AGP with a risk of transmission of acute respiratory infection to the healthcare provider is very limited, of low quality and purely observational. There is a role for better experimental studies to further illuminate this issue. Nevertheless, there is evidence that transmission may have occurred during chest compressions, hence a precautionary approach would seem appropriate.

In clinical practice the burden of proof is placed on demonstrating safety rather than the absence of danger. We would recommend that the safety of healthcare providers remains paramount where there is any risk of contracting a potentially fatal infection. ■

**Key practice implications**

> There is insufficient evidence to suggest that chest compressions are not aerosol-generating procedures with a risk of transmission of infection; therefore we conclude that level three PPE should be worn.

## Supplementary material

Additional supplementary material may be found in the online version of this article at www.rcpjournals.org/clinmedicine:
S1– Full search strategy for this literature review.

## Acknowledgements

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