Reducing aerosol infection risk in hospital patient care

Our research programme

IOSH, the Chartered body for health and safety professionals, is committed to evidence-based practice in workplace health and safety. We maintain a Research Fund to support research and inspire innovation as part of our work as a thought-leader in health and safety. This work was funded by IOSH through its Research Fund, **www.iosh.com/researchfund**.

In this document, you'll find a summary of the independent study we commissioned from Turku University of Applied Sciences and University of Turku, Finland and University Hospitals of Leicester NHS Trust and University of Leicester, Leicester, UK: *Assessing hospital-acquired infection risk of healthcare workers from patients infected with aerosol-transmitted pathogens.*

www.iosh.com/getfunding

Reducing aerosol infection risk in hospital patient care

What's the problem?

Since the severe acute respiratory syndrome (SARS) outbreak in 2003, healthcare workers (HCWs) caring for patients infected with various emerging and re-emerging viruses[1] have become acutely aware of the potential risks they face, particularly through aerosol transmission.

If enhanced protection can be achieved by using more informed and evidence-based environmental control methods, this will potentially benefit all HCWs encountering these patients. In fact, this level of 'engineering control' is already well-established in existing infection control protocols (Figure 1), and is considered more effective than either administrative controls or personal protective equipment (PPE).

Figure 1 Hierarchy of infection control (modified from US CDC: **www.cdc.gov/niosh/topics/hierarchy/default.html**)

IOSH commissioned a research team at Turku University of Applied Sciences (TUAS) and University of Turku (UTU) in Finland and University Hospitals of Leicester NHS Trust in the UK to investigate the risk of potential aerosol transmission of infectious agents between patients and their HCWs in hospital isolation rooms. The aim was to see how an engineering control approach of optimising ventilation methods can reduce these risks.

The specific objectives were to assess how various factors affected HCW exposure to patient-exhaled aerosols:

- air distribution mode
- ventilation rate
- exhaust position
- distance between patient and HCW
- use of face masks.

The team also assessed the potential risks to HCWs posed by patients using medical nebulisers.

The study was carried out in a controlled environment in a full-scale isolation room model at TUAS, using smoke, gas, vaccine virus tracers and computational fluid dynamics (CFD) modelling.[2]

[1] MERS, avian and pandemic influenzas, Ebola and, most recently, SARS-CoV-2 causing Coronavirus Disease 2019 – Covid-19)

[2] Computational fluid dynamics "involves the solution of equations to predict velocity, pressure and temperature." Jones P and Whittle G, Computational fluid dynamics for building air flow prediction—current status and capabilities. *Building and Environment* 1992; 27(3) 321–338.

What did our researchers do?

The researchers examined the effects of three air supply distributions on the HCW exposure to the patient-exhaled air:

i baseline overhead mixing ventilation (MV);
ii local downward ventilation (LDV) over the patient's bed with background mixing ventilation; and
iii zonal downward ventilation (ZDV), which was studied by computer simulation only.

With local and zonal downward ventilation, the aim was to mix and dilute possible high contaminant concentrations around the patient's bed (that is, close to the source). The research team simulated the HCW with a breathing thermal manikin and the patient with a heated dummy. Both the manikin and the dummy had artificial lungs to simulate tidal breathing.

The main focus of the study was to find out which type of air supply distribution and exhaust vent placement in a single-bedded isolation room would offer the most protection to a HCW attending to a patient reclining in a bed – for example, during routine ward rounds, while taking a routine history, performing clinical examinations and recording daily observations like blood pressure, pulse and respiratory rate.

For each type of ventilation, the researchers used smoke visualisations to assess the airflow patterns and the dispersal of the patient's exhaled breath. They also carried out computer simulations to analyse the flow of contaminants and supply air in the room.

The research team carried out tracer gas measurements[3] to assess the effect of different factors on the spread of the patient-exhaled contaminants. They measured air velocities near the patient under different air distribution modes and studied the effect of air distribution on the patient's thermal comfort.

The study used a licensed live cold-attenuated influenza vaccine virus tracer (LAIV)[4] to assess the potential aerosol hazard produced when using a home nebuliser, which is not currently considered by most national and international infection control guidelines to be an aerosol-generating procedure (AGP) for either influenza or Covid-19.

[3] Tracer gases are substances used experimentally to measure ventilation (i.e. air flow) in various built environments. In this study, tracing the gas in the isolation room provided the research team with a measurement of patient-exhaled contaminants.

[4] LAIV are weakened forms of disease-causing germs. In this study, the research team used Fluenz Tetra.

What did our researchers find out?

The main findings of the study are demonstrated in Figures 2–5 below.

Smoke visualisations show that, with standard mixing ventilation, the patient's exhaled air is directed towards the HCW's breathing zone (Figure 2). On the other hand, local downward ventilation above the patient's bed is effective in reducing the HCW's exposure close to the patient: the exhaled air is effectively flushed downwards.

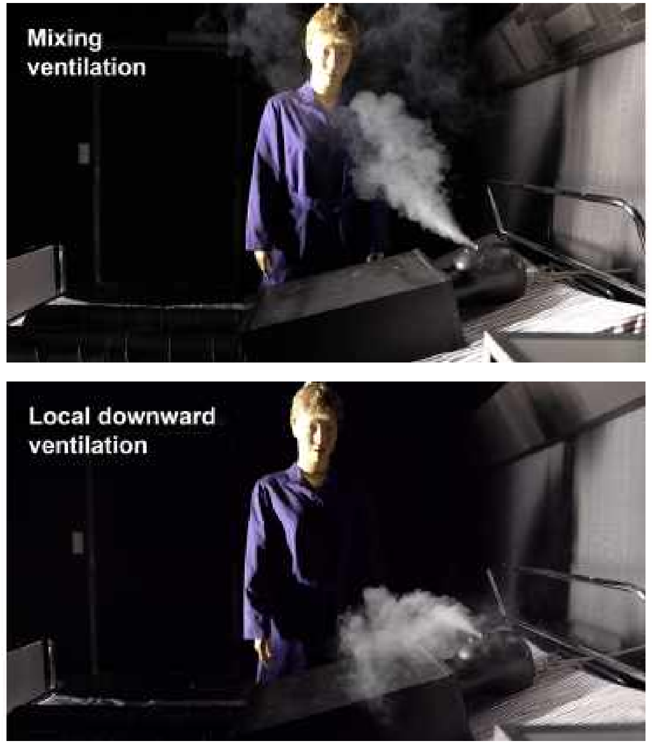

Figure 2 Smoke visualisations of effect of ventilation on aerosol exposure near patient.

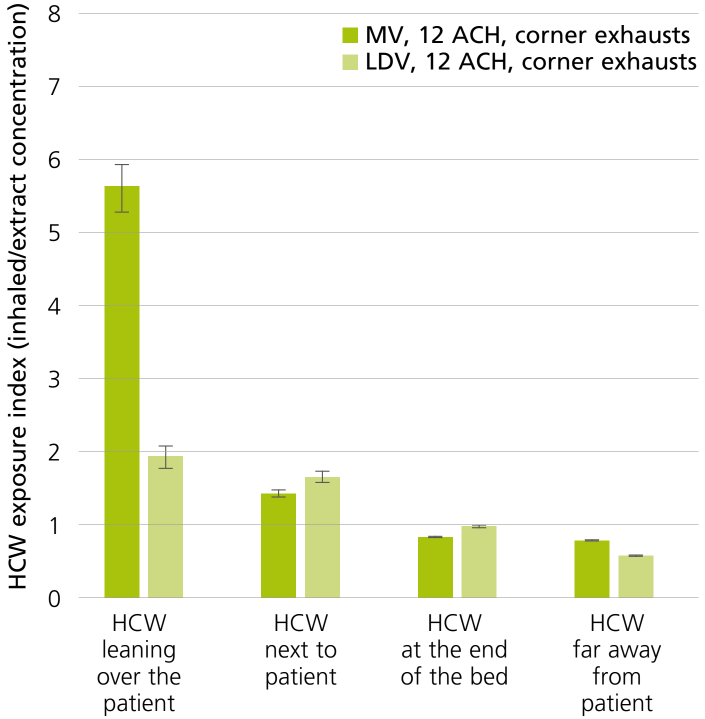

Figure 3 HCW exposure to patient's exhalation, by position and ventilation type. (Black whiskers represent standard error of the average exposure.)

The results of the tracer gas experiment (Figure 3) show that the HCW is exposed to much higher concentrations of exhaled air when leaning over the patient (when examining the patient or inserting an intravenous drip, for example). With mixing ventilation, the average inhaled concentration is five to six times higher than when the HCW is standing at the end of the bed. Local downward air supply over the bed lowers the concentration of exhaled air towards the room average.

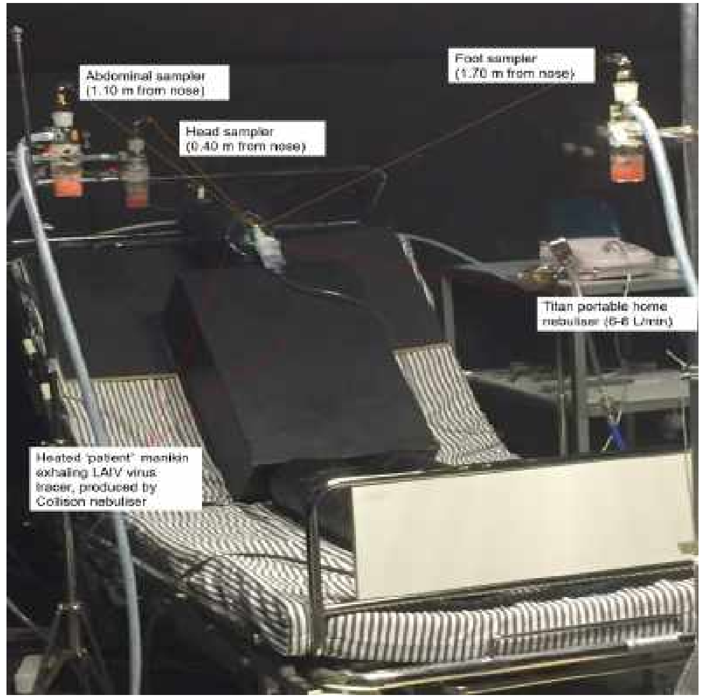

Figure 4 The experimental set-up to simulate HCW exposure to aerosol transmission when a patient is using a nebuliser mask.

There are noticeably higher concentrations of contaminant near a patient's head than at their side or the foot of the bed when they use a nebuliser (Figure 5). This implies that the potential for nebulisers to generate aerosols should be considered when planning the control of airborne contaminants.

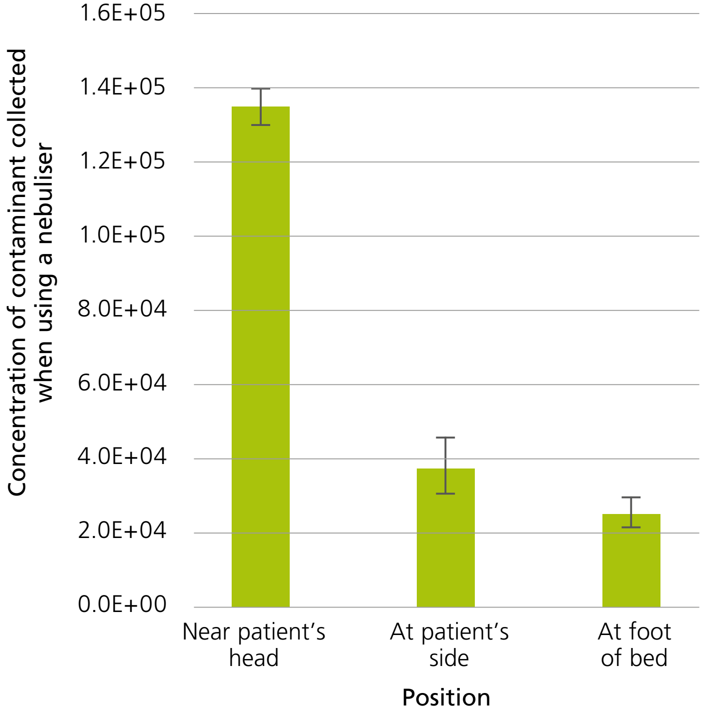

Figure 5 Concentration of contaminant in different positions when using a nebuliser mask.

The following results were obtained

Air distribution mode and ventilation rate

- Local downward ventilation (LDV) flushed the breathing zone of the patient, reducing the HCW exposure to about only 30 per cent of the exposure with MV when in the most critical leaning position.
- However, LDV causes more air movement over the patient's bed, which may be uncomfortable to the patient. The air distribution must be designed carefully with the understanding that minimising this draught to achieve acceptable patient thermal comfort will compromise HCW protection.
- The potential patient thermal discomfort caused by the higher airflow velocities with LDV may be mitigated if it is turned on only during nursing periods, with MV being used the rest of the time.
- According to the CFD simulation, zonal downward ventilation (ZDV) was even more effective than LDV for protecting the HCW. However, these results require further rigorous experimental validation.
- A higher ventilation rate decreases the average room concentration and increases the air mixing and dilution. It is effective in lowering the HCW aerosol exposure near the patient, at least up to 12 air changes per hour (ACH), provided that the air distribution can mix the air above the patient's bed.

Exhaust position

- In addition to supply air distribution, the location of the exhaust vent plays a role in HCW protection. Although exhausts can capture air only from a short distance and cannot control the room airflows generally, placing an exhaust close to high-concentration areas can lower the room concentrations notably.
- In this study, the most effective exhaust positions were in the wall behind the patient's bed or in the lighting panel (above and behind the patient) when the supply air was flushing the exhaled air in that direction.

Distance between patient and HCW

- When in a typical reclining position, the patient's exhaled air flowed directly towards the HCW breathing zone.
- Both the gas tracer and the live cold-attenuated influenza virus vaccine (LAIV) tracer tests showed that the highest exposure of the HCW to the patient's exhaled air occurred when they were leaning over the patient (e.g. when examining the patient or inserting an intravenous drip). In this situation and with mixing ventilation (MV), the inhaled concentration was typically five to six times the average room concentration.

Masks and nebulisers

- Masking the patient with an FFP2 or N95 mask was found to be an effective method in suppressing the penetration of a patient's exhalation jet into the room. However, wearing a mask may be uncomfortable for some patients if maintained for long periods.
- Finally, the research demonstrated that using a home nebuliser can spread exhaled virus-laden aerosols, mostly from the nebuliser mask side vents, which can infect carers and others nearby. Substantial viral loads were detected, which could be sufficient to cause infection if such personnel are present for the duration of the nebulisation session.

What does the research mean?

To optimise the protection of HCWs from their patients' exhaled breath, which could potentially be carrying airborne pathogens, the researchers recommend that isolation room designs should take the following factors into account:

- It is important to create and maintain sufficient air movement in the patient's bed area to dilute and flush away the patient's potentially pathogen-laden exhaled air (red in Figure 6) and distribute clean supply air (blue or green) into the HCW's breathing zone. However, thermal comfort must also be taken into account.

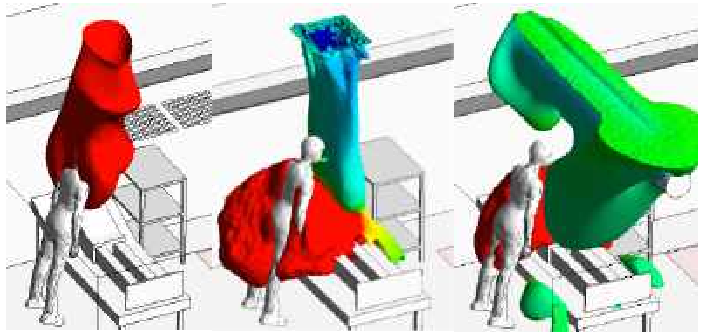

Figure 6 CFD simulation showing HCW exposure to patient's exhalation with mixing (left), local downward (centre) and zonal downward (right) ventilation. Exhaled air is show as envelopes of constant concentration (red) and the flow of supply air as envelopes of constant velocity color-coded with concentration (blue and green represent low concentrations).

- The supply air distribution and exhaust location can direct the patient exhalation away from the HCW breathing zone. This can be achieved partly by placing the exhaust vent where concentration of the patient's exhaled air is highest – for example, in the wall just above and behind the patient's head while he/she is lying or reclining in bed.
- Masking the patient is an effective method of containing the patient's exhaled breath, but as this may be uncomfortable if maintained for long periods it is an insufficient method of controlling the risk.
- As higher ventilation rates have been demonstrated to be effective in diluting and removing contaminated air in an isolation room at least up to 12 ACH, the care regime should incorporate this, provided that the air distribution is able to mix and dilute the air above the patient's bed.
- The use of nebulisers and oxygen masks with side vents may pose additional risks (as potential AGPs) to HCWs. Ideally, HCWs should not enter the room while such therapy is taking place for a patient with a confirmed respiratory infection – except to turn on or turn off such treatment. If HCWs do have to enter the room during such treatment, they should regard this as an exposure to a potential AGP and wear an FFP2 or FFP3 mask.

Don't forget…

This study found that local downward ventilation is more effective than standard mixing air distribution, from the point of view of contaminant control. However, it is not necessarily an optimal solution. There are many other possibilities for isolation room air distribution and these should be examined in future studies.

Ideally, more smoke visualisation and tracer experiments using both gas and LAIV (Fluenz Tetra) could help in the investigation of additional ventilation supply and exhaust vent set-ups. This could have included those that were computer-simulated but not validated further by experiments, and different mask types (including surgical and other home-made masks). The research team was unable to explore further the risks of nebulisation and oxygen mask use as AGPs under different ventilation rates (0, 6 ACH) using the LAIV, due to limitations in the amount of LAIV available and time.

Our summary gives you all the major findings of the independent project report by the Turku University of Applied Sciences and University of Turku, Finland and University Hospitals of Leicester NHS Trust, Leicester: *Assessing hospital-acquired infection risk of healthcare workers from patients infected with aerosol-transmitted pathogens*.

If you want to read about the study in more depth, you can download the full report from **www.iosh.com/reducing-hospital-infections**.

IOSH
The Grange
Highfield Drive
Wigston
Leicestershire
LE18 1NN
UK

+44 (0)116 257 3100
www.iosh.com

twitter.com/IOSH_tweets
facebook.com/IOSHofficial
tinyurl.com/IOSH-linkedin
youtube.com/IOSHchannel
instagram.com/ioshofficial

IOSH is the Chartered body for health and safety professionals. With over 48,000 members in more than 135 countries, we're the world's largest professional health and safety organisation.

We set standards, and support, develop and connect our members with resources, guidance, events and training. We're the voice of the profession, and campaign on issues that affect millions of working people.

IOSH was founded in 1945 and is a registered charity with international NGO status.

Institution of Occupational Safety and Health
Founded 1945
Incorporated by Royal Charter 2003
Registered charity in England and Wales No. 1096790
Registered charity in Scotland No. SC043254

PS1201.2/050820/PDF