

Literature Review and Practice Recommendations: Existing and emerging technologies for decontamination of the health and care environment

Airborne Hydrogen Peroxide

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- Description:** This literature aims to review the evidence base for using Airborne Hydrogen Peroxide for decontamination of the health and care environment.
- Purpose:** To inform the existing and emerging technologies used for decontamination of the health and care environment section on Airborne Hydrogen Peroxide.
- Target Audience:** All health and care staff involved in the prevention and control of infection in Scotland.

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Research - The implications for research are updated based on a review of the extant scientific literature on Airborne Hydrogen Peroxide used for decontamination of the health and care environment.

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Version History

This literature review will be updated in real time if any significant changes are found in the professional literature or from national guidance/policy.

Version	Date	Summary of changes
1.0	May 2015	Final for publication
1.1	December 2016	Addition of categories for recommendations. No changes made to the content of the literature review.
2.0	February 2022	Review of the extant scientific evidence on airborne hydrogen peroxide decontamination systems using the National Infection Prevention and Control Manual (NIPCM) methodology . New recommendations added.

Approvals

This document requires the following approvals

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2.0	January 2022	National Infection Prevention and Control (NIPC) Working Groups

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1. Objectives

The aim of this review is to examine the extant scientific literature regarding the use of airborne hydrogen peroxide (HP) decontamination systems in the health and care environment to form evidence-based recommendations for practice.

The specific objectives of the review are to determine:

- What is the actual or proposed mechanism of action of airborne hydrogen peroxide (HP) decontamination systems?
- Are airborne HP decontamination systems currently in use in UK health and care settings?
- When should airborne HP decontamination systems be used in health and care settings?
- What is the procedure for using airborne HP decontamination systems?
- What is the scientific evidence for effectiveness of airborne HP for decontamination of the health and care environment?
- Are there any safety considerations associated with using airborne HP decontamination systems in the health and care setting?
- Are there any practical or logistical considerations associated with using airborne HP decontamination systems in the health and care setting?
- What costs are associated with using airborne HP decontamination systems in the health and care setting?

2. Methodology

This systematic literature review was produced using a defined methodology as described in the [National Infection Prevention and Control Manual: Development Process](#).

Supplementary sections to the applied methodology for this specific literature review can be found in [Appendix 1](#).

3. Discussion

3.1 Implications for practice

What is the actual or proposed mechanism of action of airborne hydrogen peroxide (HP) decontamination systems?

Hydrogen peroxide (HP) is a colourless water-soluble liquid that breaks down into water and oxygen; it is a strong oxidising agent, responsible for the production of reactive oxygen species (free radicals) that are capable of damaging microbial structures, DNA, proteins, amino acids and cell constituents.¹ HP causes severe damage to microbial structures, releasing intracellular contents which are then oxidised.²

HP has many uses at various concentrations as a liquid and gas, such as in the bleaching industry, in disinfection of water systems, and in the pharmaceutical industry for the disinfection of aseptic packaging.³ HP gas plasma is also used in high-level sterilisation, for example in the decontamination of endoscopes, where HP vapour is inserted into a sealed chamber and converted to plasma, via an electrical field, under vacuum conditions.⁴

Airborne HP technology was developed as an environmentally friendly alternative to formaldehyde fogging, and has emerged as a novel “no-touch” disinfectant for use in environmental surface disinfection. Two common types/modalities of airborne HP technology used for decontamination of the health and care environment are HP vapour and aerosolised HP. The two methods have important distinctions in their proposed mechanisms of action.

HP vapour systems

HP vapour decontamination systems produce vapour from 30-35% HP solution through heat. These vapour particles are less than 1 micron in size, allowing the vapour to disperse effectively throughout an enclosed room or area; the vapour may be allowed to eventually reach a saturation (dew) point in the air where it will micro-condense and deposit onto surfaces, or alternatively dispersal is kept below the dew point as a dry vapour.⁵⁻⁷ The target HP concentration of approximately 8-10 g m⁻³ in the enclosed room/area has been reported.⁶ At the end of the process, the HP vapour is catalytically broken down into water and oxygen.⁶

Aerosolised HP systems

Aerosolised HP systems produce a fine mist by aerosolising a solution of 5-8% HP, via pressure, or ultrasonic nebulisation. The solution contains trace elements of silver ions and can include other reagents such as <50 parts per million (ppm) phosphoric acid, and <1 ppm gum arabic.^{8,9} Other aerosolised HP products also contain additional disinfectants such as peracetic or acetic acid.¹⁰ The antimicrobial silver ions help stabilise the aerosol along with other chemicals to avoid aggregation before the drops reach the target.^{9, 11} The particles are electrically charged, ranging in diameter from 8 to 12 microns, and are able to circulate freely in the air as a dry aerosol disinfectant and deposit onto surfaces.⁹ The target concentration for the room or enclosed area under treatment has been routinely reported as 6 mL m⁻³.^{8, 9, 12} This airborne HP system is alternatively referred to as a “dry mist”.⁹

Holmdahl *et al.*¹¹ compared two HP vapour and aerosolised HP systems and found that a key difference was the peak HP concentration, which was twice as high in HP vapour systems than in aerosolised HP systems, while the total HP concentration was also seen to be higher for HP vapour.

There are various airborne HP technologies commercially available which deviate from these common descriptions, including in HP concentration, the inclusion of additional disinfecting agents and particle size.¹³

Are airborne HP decontamination systems currently in use in UK health and care settings?

There is no mention of airborne HP decontamination systems in the Health Facilities Scotland National Cleaning Specifications for both acute and adult care home settings.^{14, 15} The National Infection Prevention and Control Manual (NIPCM) does not currently mention airborne HP technology for use in decontamination of health and care settings.¹⁶ According to Scottish expert opinion, HP vapour is used in acute settings as an adjunct to terminal decontamination in specific circumstances - including outbreaks of carbapenemase-producing *enterobacteriaceae* (CPE), linezolid resistant organisms including vancomycin-resistant *enterococcus* (VRE) and *Staphylococcus aureus*, as well as in the decontamination of rooms of patients with cystic fibrosis with known *Mycobacterium abscessus* colonisation. Periodic use of HP vapour (e.g. every six months) has been reported in some high-risk settings such as neonatal wards, as an additional infection control measure.

The UK government agency, the National Patient Safety Agency (NPSA) Revised Healthcare Cleaning Manual,¹⁷ features a section on airborne HP decontamination systems alongside other new technologies for environmental disinfection; the manual recognises that conditional use of airborne HP technology is increasing in use during disinfection of single patient rooms, but concludes there is currently insufficient evidence for cost-effectiveness. The use of airborne HP has been reported in nosocomial outbreaks in several NHS Trusts in England, as part of a wider programme of enhanced cleaning, particularly for emerging and drug-resistant pathogens. These have been specifically related to OXA-48 producing *Klebsiella pneumoniae*,¹⁸ group A *streptococcus*,¹⁹ CPE,^{20, 21} OXA-23 and OXA-51 producing *Acinetobacter baumannii*,¹³ and an emerging *Candida auris* strain.²²

The Rapid Review Panel (RRP)²³ is a panel of UK experts established by the Department of Health to review new technologies with the potential to aid in the prevention and control of healthcare-associated infections. The RRP has reviewed four airborne HP disinfection products between 2005 and 2019. The first aerosolised HP system assessed in 2005 was awarded a recommendation 4 status. The RRP has since altered their recommendation system to encompass 4a and 4b categories:

“Not a significant improvement on equipment/materials/products already available which claim to contribute to reducing health care associated infection; no further consideration needed.” (R4a)

“Unlikely to contribute to the reduction of health care associated infection; no further consideration needed.” (R4b)

A HP vapour system was later assessed in 2007 and awarded a recommendation 1 status:

“Basic research and development, validation and recent in use evaluations have shown benefits that should be available to NHS bodies to include as appropriate in their cleaning, hygiene or infection control protocols.” (R1)

An assessment of a different brand of HP vapour system took place in 2008 and awarded a recommendation 2 status:

“Basic research and development has been completed and the product may have potential value; in use evaluations/trials are now needed in an NHS clinical setting.” (R2)

In 2019, the RRP assessed another commercial airborne HP system; the technology is highly novel, involving continuous, low level flow of HP into the environment without the need for vacating rooms. The system was awarded recommendation E5:

“Evidence presented does not demonstrate that the product is more efficient or efficacious at improving infection prevention and control interventions to reduce healthcare associated infections than other available products currently in use”.

These findings suggest that airborne HP decontamination systems are not routinely in use within UK healthcare settings, but that certain airborne HP systems are employed in UK hospitals as an adjunct to terminal cleaning, or as part of enhanced cleaning during outbreaks for removal of environmental contamination, for particular pathogens, including drug-resistant Gram-negative bacteria.

When should airborne HP decontamination systems be used in health and care settings?

Studies included in the present literature review relate to acute or tertiary care settings. There was no evidence identified for the use of airborne HP systems in long-term residential care facilities or other community settings, or in the ambulance service. The majority of studies assessed the effectiveness of routine use of airborne HP as an adjunct to terminal

cleaning with sodium hypochlorite, while eight studies were related to the use of airborne HP as part of a deep clean bundle during whole unit or ward closures, to control an outbreak.^{13, 18-22, 24, 25} However, only one of these studies assessed the independent effectiveness of airborne HP separately from the bundled IPC measures.²⁵

Based on mandatory Scottish guidance, airborne HP should not be used routinely for standard terminal cleaning¹⁶ which is consistent with UK and international infection prevention and control guideline documents. The World Health Organisation (WHO) guidance for controlling Gram-negative bacteria,²⁶ the US Centers for Disease Control and Prevention (CDC) guideline for disinfection in healthcare facilities,⁴ as well as UK²⁷ and Irish²⁸ national guidance for controlling healthcare associated infections are in strong agreement. The shared position is that the evidence surrounding the use of HP systems for routine terminal cleaning of isolation rooms is immature, especially regarding effectiveness in reducing infection rates, the cost-effectiveness, safety and practicalities of using airborne HP, particularly in relation to its added value versus conventional cleaning.

The WHO has also stated that airborne HP systems, while seemingly effective, can be disruptive to hospital workflow and bed utilisation given the time and equipment required for their use, that there may be an increased workload and potential damage to some materials.²⁶ In the UK, the National Institute for Health and Care Excellence (NICE) published guidelines in 2014 for the prevention of healthcare associated infections in English hospitals. The guidelines stated that use of airborne HP in the variety of facilities in the UK has not been demonstrated.²⁷ Since all facilities need to have sealable rooms, ventilation systems which can be isolated, as well as the resource to use and implement HP safely, the challenges for implementing HP systems are considerable.

There have been several guidance documents concerning multidrug resistant organisms (MDROs) which have recommended consideration of airborne HP in specific circumstances. The NICE 2016 guideline for control of multidrug resistant Gram-negative bacteria recommend that airborne HP (specifically, HP vapour) should be considered as an adjunct to standard terminal disinfection with chlorine-releasing agents in vacated isolation rooms/areas for containing multidrug resistant Gram-negative bacteria.²⁹ In Ireland, guidance on prevention and control of MDROs (excluding methicillin-resistant *Staphylococcus aureus* (MRSA)) state that where there is failure to eliminate an environmental reservoir despite enhanced cleaning and disinfection, consideration may be given to the use of novel decontamination technologies such as HP vapour – but highlight drawbacks such as vacation of areas and sealing of areas which may be impractical. Public Health England

guidance for controlling norovirus outbreaks in care settings states that further research is necessary to fully evaluate their effectiveness against noroviruses.³⁰

Under special circumstances, HP vapour (or formaldehyde fumigation) is mandatory in UK health and care settings for management of viral haemorrhagic fevers, according to guidance by the Health and Safety Executive.^{31, 32}

What is the procedure for using airborne HP decontamination systems?

Airborne HP disinfection systems should only be used as an adjunct to standard terminal cleaning of rooms, following discharge of patients on isolation precautions, after standard terminal cleaning has removed biological soiling of surfaces; removal of soiling is important as soiling can reduce the effectiveness of decontamination.^{33, 34} A full evaluation of the compatibility of the technology with the healthcare setting in which it is to be used is required - since HP is hazardous to human health - it can only be used in areas which have been vacated of people and properly sealed, prior to the disinfection process.^{5, 11, 35, 36} Ventilation systems are required to be sealed off, prior to use.^{10, 35-37} For certain systems, including aerosolised HP systems, electronics such as computer monitors or screens require covering /protection.¹⁰ Since the HP systems rely on direct contact, objects in the room can be positioned optimally so that the air can access around them.³⁶ Certain materials are also incompatible with HP and this should be evaluated prior to use.³⁸ Once the room has been prepared with the HP unit placed inside, the procedure uses an automated generator to deliver the airborne HP into the enclosed area or space.

The most commonly used brand of HP vapour system consists of four portable units: a generator unit to produce HP vapour; an aeration unit to break down the HP vapour catalytically after the exposure period; an instrumentation module which measures the concentration of HP, as well as the temperature and relative humidity of the room; and a control computer situated outside the room.³⁵ The generator uniformly distributes the airborne HP after which the product is kept inside for the correct duration of exposure time.³⁵

HP systems may also include a dehumidification step prior to decontamination.³⁸ In some cases, fans are employed to promote circulation of the airborne HP throughout the room.¹¹ HP vapour systems include aeration devices or air scrubbers to remove the HP from the room at the end of the cycle via catalytic conversion.⁶ Alternatively, the HP will naturally slowly degrade into water and oxygen.

The time required to complete the process is proportional to the size of the area to be disinfected.^{8, 9} While the duration of the full cycle is variable, the procedure can last from over an hour to several hours, or overnight.^{10, 35, 36} The longest phase is the removal of HP from the air; for safety reasons which can be lengthy,⁵ HP vapour must reach <1 ppm concentration before it is safe to enter the room. This increases the time required for disinfection, since airborne HP must only be applied in rooms that have been vacated.

Due to the variation in devices available, validation of the specific selected airborne HP technology is advisable, and a standard operating procedure put in place. Incorrect procedure may result in compromises to staff and patient safety via exposure to illegal limits of HP, as well as inadequate decontamination and continued risk of infection transmission to staff and patients.

What is the scientific evidence for effectiveness of airborne HP for decontamination of the health and care environment?

All of the included evidence on scientific effectiveness related to bacteria; there were no included studies which examined decontamination of viral or fungal infectious agents in the health and care environment. A UK NICE guideline,²⁹ Cochrane systematic review,³⁹ as well as five primary studies assessed the effectiveness of airborne HP for decontamination of bacteria in the health and care environment.^{9, 25, 40-42} Primary studies included one cohort⁴⁰, two before and after studies,^{9, 25} one interrupted time series⁴¹ and one *in vitro* study.⁴² The most common organisms under study were *Clostridioides difficile*^{9, 40, 42} and MRSA⁴⁰⁻⁴² as well as other Gram-negative bacteria.^{25, 40-42} Two studies also included VRE.^{40, 41}

Both the UK NICE guideline as well as a Cochrane systematic review evaluated HP vapour technology. The Cochrane review reported that HP vapour may lead to reductions in hospital-acquired multidrug resistant bacteria based on low quality evidence,³⁹ while the guideline concluded it is effective in reducing environmental reservoirs of Gram-negative bacteria, with evidence rated as moderate quality.²⁹

Both the guideline and review reported that the highest quality of evidence was obtained from the same USA cohort study by Passaretti *et al.* which is also included in the present review.⁴⁰ This cohort included 1,790 patients and compared the risk of acquiring MDROs in patients admitted to rooms decontaminated using HP vapour as an adjunct to terminal cleaning compared to rooms terminally disinfected using standard methods. According to

researchers, the standard policy used as comparison was manual cleaning with quaternary ammonium compound, or with liquid HP-based disinfectant for *C. difficile* rooms.⁴⁰ Patients in the HP vapour cohort were 64% less likely to acquire MDROs (incidence rate ratio (IRR) 0.36 (95% CI 0.19, 0.70) than the patients in the standard cleaning cohort, after adjustment for important confounders, and the effect was largely driven by a considerable reduction in VRE acquisition (IRR 0.25 (95% 0.10, 0.60)). Reductions in the rates of MRSA (IRR 0.53 (95% 0.16, 1.79)), MDR-Gram-negative rods (IRR 0.55 (95% CI 0.20, 1.57)) and *C. difficile* (IRR 0.49 (0.16, 1.47)) were not statistically significant. However, only VRE and MRSA were routinely screened for among patients, so there was the potential for misclassification bias.

There were three studies which examined environmental bacterial bioburden as the primary outcome measure in assessing airborne HP; in all three studies, airborne HP was used after manual cleaning with various disinfectants to remove organic soiling.^{9, 25, 41} Two of the studies examined the effectiveness of HP vapour on reducing residual environmental bioburden remaining after terminal cleaning.^{25, 41} The first study took place in the Netherlands, during an enhanced cleaning of a closed ward due to an outbreak of multidrug resistant Gram-negative rods (GNRs)²⁵ whilst the second study, an interrupted time series design, included a single isolation room in a hospital in London, UK, which was occupied by a patient with ongoing MRSA, and historical GNR and VRE infection/ colonisations.⁴¹ Both of these small studies found that HP vapour was effective in removing residual contamination of bacteria after terminal cleaning. A larger study by Barbut *et al.*, took place at 2 hospital sites in France.⁹ In this study, an aerosolised HP system was compared to manual cleaning with 5,000 ppm sodium hypochlorite, and both interventions were evaluated after manual cleaning with a detergent-disinfectant. Assessing decontamination of 31 rooms (15 aerosolised HP, 16 hypochlorite), the researchers found aerosolised HP reduced the percentage of environmental samples positive for *C. difficile* spores from 19% to 2% of rooms, compared to sodium hypochlorite, where positive samples reduced from 24% to 12% (p=0.003).

Finally, one experimental *in vitro* study examined airborne HP for use in decontaminating suspensions of bacteria in a hospital in England.⁴² Ali *et al.* tested the effectiveness of two airborne HP technologies on stainless steel coupons inoculated with MRSA, *K. pneumoniae* and *C. difficile* spores and bovine serum albumin (BSA) to mimic organic soiling.⁴² Samples were placed throughout ten single en-suite isolation rooms. The study found that HP vapour and aerosolised HP were effective in achieving 5.1 log₁₀ reduction in colony forming units (CFU) of *C. difficile* spores, and 6.3 log₁₀ reduction of MRSA and *K. pneumoniae* CFUs, with

no difference in efficacy observed between HP vapour and aerosolised HP. However, *C. difficile* was found to persist on 7/8 samples left behind the door at floor level, underneath the bed and on the window frame, suggesting hard-to-reach areas might not have received the correct exposure of the HP treatment due to lack of access.

In summary, while airborne HP systems, including both HP vapour and aerosolised HP, have been shown to reduce bacterial bioburden which may be remaining in the health and care environment after a terminal clean has taken place, there is currently insufficient evidence that airborne HP systems can reduce acquisition rates of bacterial pathogens in health and care settings. In all studies, airborne HP was not used without prior cleaning to remove soiling and physical dirt which is essential to its mechanism of action.

While there is a greater volume of evidence available for HP vapour, the majority of studies were of low quality and involved heterogeneous study designs. Studies assessed different organisms, with different prevalence rates across hospitals, but there were also differences in how the technology was applied – studies with different room sizes/volumes along with HP exposure times meant that the concentration of airborne HP applied in settings was broadly inconsistent, along with many different commercial technologies in use.

Only one primary study was conducted in the UK⁴¹ therefore the IPC practices involved do not have direct applicability in health and care settings in Scotland. This is most clearly reflected in the wide variation of terminal cleaning policies employed at hospitals that were commonly used as the comparison group. Two studies used quaternary ammonium compound based disinfectants,^{40, 41} two used sodium hypochlorite between 2,000 -5,000 ppm^{9, 25} and one study used 1,000 ppm peracetic acid.⁴²

A further consideration was ubiquitous involvement of the private manufacturers of airborne HP technology in the studies, either through funding, provision of employees or equipment, including the UK guideline, and all six primary studies. This represents a potential conflict of interest that should be considered when assessing the evidence. All these limitations in the evidence restrict the generalisability of the findings. Further research with greater scientific rigour is required before conclusions regarding the routine use of airborne HP in controlling bacterial pathogens is supported. There is currently no included evidence to support its use for controlling viral or fungal infectious agents in the health and care environment. There were no studies that took place in community settings, and effectiveness against biofilms, non-porous surfaces or different types of equipment has also not been assessed.

Are there any safety considerations associated with using airborne HP decontamination systems in the health and care setting?

Airborne HP systems have intrinsic safety issues due to the use of HP above legal exposure limits which requires the evacuation of the room for lengthy periods of time.^{35, 40} The UK Health and Safety Executive have legislated that the legal workplace exposure limit is 1 part per million (ppm) for long-term exposure (e.g. weighted average over a typical 8 hour shift), while short term exposure should be below 2 ppm during acute exposures (over 15 minutes).⁴³ Airborne HP inside the room is required to be well above these levels for decontamination purposes, but this is overcome by vacating the room or area, turning off ventilation, and sealing off all entrances and windows. The passive conversion of HP to water and oxygen, or in some cases, the active catalytic degradation of HP, allows for staff or patients to re-enter the room after the procedure. While some studies have not reported any safety concerns with relation to the use of airborne HP in hospital settings,^{36, 40} there have been studies reporting concerns about unsafe HP concentration levels. When Fu *et al.*⁶ reported that during use of aerosolised HP, the sealing of doors was not performed, unsafe concentrations of HP were found (>2 ppm); sealing of doors reduced leakage to <1 ppm, highlighting the importance of safety training for conducting HP decontamination. French *et al.* also reported leakage of harmful concentrations (>10 ppm) of HP vapour into the ceiling space of the adjacent hospital rooms. During the before and after study by Blazejewski and colleagues, it was reported that upon re-entering the room, staff reported irritation to the eyes and respiratory tract after completion of aerosolised HP decontamination.¹⁰ While airborne HP systems have concentration monitors for reporting when HP is at safe levels (i.e. the cycle is finished), the risk remains that concentrations are higher than permitted levels at the point staff enter the room.

Independent HP concentration monitoring units or hand-held sensors are a useful tool for measuring the residual concentrations of airborne HP to ensure that exposure is avoided.^{6, 35, 36} Post-exposure plans should also be in place for accidental or inadvertent exposure.

The USA-based Association for Professionals in Infection Control and Epidemiology (APIC), and the Society for Healthcare Epidemiology of America (SHEA), stated in 2011 that a key issue for implementing HP vapour or mist systems was whether exposure limits were permissible, especially as a time-weighted average associated with repeated use. In a letter to the Environmental Protection Agency, they highlighted the importance of careful communication of and attention to worker safety, with proper planning and instruction

regarding room sealing, to avoid worker apprehension when working with HP as a hazardous chemical.⁴⁴

Ernstgard *et al.* tested the effects of short-term exposure to HP vapour in 11 volunteers and found mild irritation of the upper respiratory airways was observed when people were exposed to HP vapour at 2.2 ppm, though no effects were observed at 0.5 ppm.⁴⁵ In this study, no exposure-related effects on pulmonary function were observed and there were no exposure-related effects on markers of inflammation or coagulation. There were no effects on lung function or inflammatory markers at either exposure level. While self-reported rating of irritation and symptoms were low, there was large inter-individual variation – with females rating significantly more symptoms than males.

Are there any practical or logistical considerations associated with using airborne HP decontamination systems in the health and care setting?

There are a number of practical and logistical considerations with using airborne HP systems. One key limitation is the need to remove debris and organic matter from all surfaces so that the HP is not prevented from accessing micro-organisms.^{33, 34} As a result, HP systems do not provide any time saving benefits to the process of environmental and equipment decontamination. Additionally, the airborne HP systems require a team of trained personnel to operate the specialised machinery.⁴⁶

The use of airborne HP decontamination systems also requires the area to be vacated for the duration of the decontamination process.⁴⁰ This is particularly challenging where bed occupancy is high and for terminal cleaning of areas under contact precautions which have multiple beds and mixed-occupancy; HP systems cannot be implemented in these circumstances without moving or transferring patients. Some studies have reported using airborne HP systems via temporary ward closures.^{13, 24, 25, 47} However, if a ward requires decontamination, it is not necessarily required to close; a staged approach could be adopted, such as the partitioning of multi-bed bays and sealing off of occupied areas. This may not always be possible depending on availability of space or other practical reasons. As well as disruption to IPC isolation measures, patient transfer can also be potentially harmful to very vulnerable patients such as those in intensive care.²⁴ Therefore the technology would be best suited to single occupancy isolation rooms. Airborne HP systems require full assessment of heating, ventilation and air conditioning ducts in the area to be decontaminated, which must be sealed, along with any doors/windows.^{5, 40} As well as a

safety issue, this prevents the airborne product from becoming too diluted in volume to reach its target concentration.

Airborne HP decontamination is relatively time-consuming due to the need for an effective initial clean, followed by the use of airborne HP decontamination and aeration processes, and then monitoring of the environment to ensure that it is safe to re-enter. This adds considerable length to the terminal cleaning turn-around time which can add pressure to hospital occupancy. Passaretti *et al.*⁴⁰ found that after introduction of HP vapour to the hospital terminal cleaning policy, only 50% patients in 6 months were in rooms that had received the HP treatment, due to practical reasons. Manian *et al.*³⁶ reported similar problems and a score system was devised to prioritise its use; terminal cleaning for multidrug resistant *A. baumannii* positive rooms were prioritised whilst only 54% rooms positive for *C. difficile*, 17% of VRE positive rooms and 19% MRSA positive rooms received HP decontamination. Both studies were conducted in the USA, however they highlight the practical limitations when implementing airborne HP into routine terminal cleaning.

One further consideration is the compatibility of HP with various materials. There were no studies identified that assessed effectiveness with porous surfaces such as fabrics or textiles. Kimura *et al.*³⁸ conducted a small experimental study assessing damage to various test materials through repeated exposure to aerosolised HP and HP vapour decontamination cycles, similar to operational concentrations found in health and care settings. The researchers found aerosolised HP caused serious damage or corrosion to bronze plating and steel, marked damage to plastic coatings on common objects including epoxy, silicone, and urethane coatings as well as blistering to paint and wood bleaching. Dehumidification prior to HP vapour use was found to result in less damage. There is insufficient evidence on the compatibility of HP with common materials found in the health and care setting.

Another key issue to be considered when using airborne HP decontamination is the rapid rate of recontamination with pathogens that occurs as soon as patients are readmitted.⁴¹

What costs are associated with using airborne HP decontamination systems in the health and care setting?

While cost is not directly related to infection prevention and control, the higher cost of implementing airborne HP decontamination systems is a practical consideration. There is currently very limited evidence on the cost-effectiveness of airborne HP systems, however

airborne HP systems are significantly more expensive than the hypochlorite solutions used in standard cleaning. Otter *et al.* reported the costs (in Euros) associated with a lengthy outbreak of CPE in an English hospital in 2015; HP vapour was reported to cost an average €1,785 per room, across 24 rooms.²⁰ Doan *et al.* compared the cost-effectiveness of HP vapour and a chlorine-releasing agent; the chlorine-releasing agent cost £14.14 per use and £149.65 per month, compared with £108.96 per use and £1,154.98 per month for HP vapour.⁴⁸ Additional costs are incurred beyond the expense of investing in the technology, or paying for subcontractors. Best *et al.*⁴⁷ reported in 2014 that the cost of using airborne HP amounted to about £7,000 per ward, including staff costs and materials, and therefore use of airborne HP may only be justifiable in some cases, e.g. following an outbreak. The requirement for areas to be vacated while they are being decontaminated using airborne HP systems incurs additional costs and can potentially lead to delays in bed availability.⁴⁰ Another factor to consider in terms of the cost of airborne HP decontamination is the rapid rate of recontamination seen to take place.⁴⁶ APIC and SHEA also outlined the extent of both direct and indirect costs, in their 2011 published letter on use of airborne HP systems – direct costs can include training, equipment, personnel, supervision and logistics while indirect costs are related to facilities/operator exposures, potential liability costs, and disruption to the availability of rooms through increased turn-around time.⁴⁴ High costs should also be weighed against the actual contribution of environmental contamination to an ongoing infection risk, especially when other IPC measures may be effective.

3.2 Implications for research

The review identified several gaps in the literature in relation to airborne HP decontamination systems. Future research on the impact and cost of implementing airborne HP in health and care settings should include randomised trials measuring infection rates of common healthcare associated infections, ideally in hospitals with high incidence, in order to fully assess the contribution of HP technology to decontamination of the health and care environment.

The existing studies in the literature base employed various comparison groups such as sodium hypochlorite at a range of concentrations, quaternary ammonium compound disinfectants, or the use of detergent only. Future studies assessing the clinical effectiveness of airborne HP systems for decontamination should include suitable comparison groups to enable the results to be transferable to health and care settings in Scotland.

It was also notable that several of the studies such as those assessing airborne HP use in ward closures undergoing deep cleaning combined multiple infection control interventions with the use of airborne HP, such as the provision of staff feedback on terminal cleaning, and additional screening for colonised patients. The observational nature of these studies make it difficult to interpret the causality separately from important confounders, including fluctuations in infection rates. Ideally, studies that evaluate the effectiveness of airborne HP decontamination systems should adjust for other infection control interventions in order to minimise the risk of confounding factors producing a spurious result.

Very few studies thus far have evaluated the cost-effectiveness of airborne HP decontamination systems. Of the few that have, the majority have primarily considered the capital costs of the necessary equipment and the cost of manual labour to operate the devices, in comparison against the costs of disinfectants used for traditional cleaning. It can be seen from these studies that a comprehensive cost-effectiveness evaluation for the use of airborne HP decontamination systems in health and care settings in Scotland would be timely.

Further research is also needed to understand the limits and sensitivity of airborne HP technology. The effect of larger room sizes on the effectiveness of airborne HP is not well documented - whilst the technology takes into account the volume of the room in the calculation of HP concentration, ultimately there was little evidence investigating the potential dilution of the biocidal action of HP in the air via increased distance from the device, in very large rooms or rooms with side chambers or en-suites.

Additionally, the mechanism of action with regards to the role of silver ions in aerosolised HP systems was not evident. Silver has antimicrobial properties and the contribution of silver ions to the biocidal action of aerosolised HP has not been well elucidated in studies, or whether any sublethal concentrations of silver may be selective for the evolution of resistance in bacteria.

There was no information found on the potential interaction of the airborne HP product with other biocidal agents which may be present on wet surfaces- especially since time-pressures may prevent adequate drying following terminal cleaning. Residual sodium hypochlorite or alcohol-based disinfectants have the potential to affect the activity of HP condensate on surfaces.

Finally, future research is needed concerning potential damage from the use of repeated HP technology on materials which are common to health and care settings.

4. Recommendations

This review makes the following recommendations based on an assessment of the extant scientific literature on airborne hydrogen peroxide used for decontamination of the healthcare environment:

What is the actual or proposed mechanism of action of airborne HP decontamination systems?

The mechanism of action of hydrogen peroxide as a disinfectant is achieved through its oxidising properties which causes damage to microbial DNA, proteins and cell constituents.

(Category B recommendation)

Airborne HP technology used for decontamination of the health and care environment includes HP vapour and aerosolised HP. HP vapour involves heating 30-35% HP to generate <1 micron size vapour particles. Aerosolised HP is generated from 5-8% HP solution which contains silver ions. In both cases, the HP is dispersed fully into an enclosed space, and inactivates microorganisms upon direct contact.

(Category B recommendation)

Are airborne HP decontamination systems currently in use in UK health and care settings?

Airborne HP decontamination systems are not in use for routine cleaning within UK health and care settings. At the time of publication there is no mention of airborne HP decontamination systems in the National Infection Prevention and Control Manual.

(Mandatory Recommendation)

Airborne HP decontamination systems have been used in UK hospital settings as part of wider infection control measures when controlling outbreaks, particularly for emerging or drug-resistant pathogens such as multidrug resistant Gram-negative bacteria

(Category B Recommendation)

When should airborne HP decontamination systems be used in health and care settings?

Airborne HP systems should **not** be used for routine cleaning, but it may be used as part of an additional deep clean.

(Category B recommendation)

Airborne HP systems can be used as an adjunct to manual cleaning when performing terminal room decontamination.

(Category C recommendation)

Airborne HP may be considered for cleaning of the environment where ongoing transmission of an infectious agent has occurred and the environment is considered a route of transmission.

(Category B recommendation)

The use of airborne HP systems for environmental decontamination should only be adopted following completion of a manual clean as residual dirt and soiling can reduce efficacy. The use of airborne HP cleaning does **not** reduce the importance of general cleaning routinely and between patients.

(Category B recommendation)

If fumigation is the mandatory decontamination process, e.g for terminal cleaning of Ebola/VHF- positive patient rooms, as per Health and Safety Executive, then HP should be considered with specialist advice.

(Mandatory recommendation)

What is the procedure for using airborne HP decontamination systems?

All users of airborne HP systems, whether a health or care professional, NHS Board employee or an external contractor, must be trained in the product's use and potential hazards of the system, and have assurance of product safety.

(Category B recommendation)

Validation processes must be in place to ensure that prior to HP use, terminal cleaning has been effective in removing organic soiling from surfaces, as well as to ensure the airborne HP decontamination system has been effective.

(Category C recommendation)

Local estates should be involved in the management of the ventilation system. Consideration must be given to whether airborne HP will interact with the fire alarm system and, if so, ensure that local estates are involved to isolate the fire alarm system.

(Category C recommendation)

A Standard Operating Procedure (SOP) must be established and detail processes of when and how airborne HP cleaning is used, regardless of the provision of use by health and care facilities, NHS Boards or external contractors.

(Category C Recommendation)

Airborne HP systems in use must be maintained in good working order and a system of programmed maintenance in place with documented evidence.

(Category C Recommendation)

What is the scientific evidence for effectiveness of airborne HP for decontamination of the health and care environment?

There is currently insufficient evidence that airborne HP systems can reduce acquisition rates of bacterial infectious agents in health and care settings

(Category B recommendation)

Airborne HP decontamination systems can reduce persistent bacterial contamination in the environment when used after terminal cleaning, in single isolation rooms.

(Category B recommendation)

There is insufficient evidence of airborne HP systems efficacy against viruses or fungal infectious agents.

(Category B recommendation)

Are there any safety considerations associated with using airborne HP decontamination systems in the health and care setting?

Hydrogen peroxide is a hazardous chemical, and exposure to high concentrations is toxic. All rooms undergoing airborne HP decontamination must be vacated and only trained personnel should be present.

(Category B recommendation)

A communication plan for staff, patients and visitors should be undertaken where airborne HP decontamination is being conducted, including signage and attention to safety.

(Category C Recommendation)

A full risk assessment prior to use should be performed to identify and mitigate any risk of exposure to high concentrations of HP during decontamination. A post-exposure plan should be in place.

(Category C recommendation)

Hydrogen peroxide concentration should be monitored throughout the procedure including outside the room and in adjacent areas where possible.

(Category B recommendation)

Are there any practical or logistical considerations associated with using airborne HP decontamination systems in the health and care setting?

Airborne HP requires a manual cleaning step prior to use to remove any biological soiling from the environment.

(Category B recommendation)

Following manual cleaning, prior to use of airborne HP decontamination systems, surfaces should be allowed to dry, with no visible wet patches.

(Category C recommendation)

Following manual cleaning, prior to use of airborne HP decontamination systems, and where it is reasonable to do so, positioning of equipment should be optimised so that the maximum surface area is exposed to the air.

(Category C recommendation)

Areas or rooms undergoing airborne HP decontamination must be fully vacated of all persons therefore may be inappropriate for decontaminating rooms with multiple bed occupancies in hospitals, such as bays, or ward corridors.

(Category B recommendation)

All room entrances and windows are required to be sealed with adhesive tape as well as heating, ventilation and air conditioning sealed or isolated in preparation for airborne HP decontamination, to prevent leakage

(Category B recommendation)

Airborne HP requires several hours to perform, including aeration of HP from the air, which can significantly increase the time taken to complete the terminal clean and therefore result in significant delays to room turn-around time.

(Category B recommendation)

Assessment of room building materials and contents are required prior to airborne HP decontamination, since the active ingredient is incompatible with certain metals, plastics and other materials and can cause damage to paint.

(Category B recommendation)

What costs are associated with using airborne HP decontamination systems in the health and care setting?

There is limited evidence on cost-effectiveness of airborne HP technology equipment, however there are considerable costs associated with start-up and maintenance.

(Category C recommendation)

Prior to using airborne HP technology, an assessment specific to the setting should be conducted to estimate the costs involved, including equipment, staff time, and removal of rooms from use.

(Category C recommendation)

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Appendix 1: Search strategies

Search strategy

V1.0: searches were run between 24/06/2014 and 01/07/2014 with date limits 2004-2014

V1.1: search performed on 08/08/2016 with date limits 2014-2016

V2.0 (current update): search performed on 10/03/2021 with date limits: 2016-current

The following search strategies was applied in previous versions:

Version 1.0 search strategy:

1. Hydrogen peroxide/
2. Hydrogen peroxide.mp
3. HPV.mp
4. Sterilization/
5. Decontamination/
6. Disinfection/
7. Housekeeping, Hospital/
8. Clean*.mp
9. Aerosols/
10. Volatilization/
11. Mist*.mp
12. Fog*.mp
13. Vapo?r*.mp
14. 1 OR 2 OR 3
15. 4 OR 5 OR 6 OR 7 OR 8
16. 9 OR 10 OR 11 OR 12 OR 13
17. 14 AND 15 AND 16

Search findings were restricted using English language filter

Version 1.1 search strategy:

1. (hydrogen peroxide adj2 disinfect*).mp
2. (hydrogen peroxide adj2 decontaminat*).mp
3. (hydrogen peroxide adj2 vapo?r*).mp
4. (hydrogen peroxide adj2 aerosol*).mp
5. Sterilization/
6. Decontamination/
7. Disinfection/
8. Housekeeping, Hospital/
9. Clean*.mp
10. 1 OR 2 OR 3 OR 4
11. 5 OR 6 OR 7 OR 8 OR 9
12. 10 AND 11

Search findings were restricted using English language filter

The following search strategy was applied in the latest version.

Embase/Medline:

1. (hydrogen peroxide adj5 disinfect*).mp.
2. (hydrogen peroxide adj5 decontaminat*).mp.
3. (hydrogen peroxide adj5 vapo?r*).mp.
4. (hydrogen peroxide adj5 aerosol*).mp.
5. (hydrogen peroxide adj5 dry mist*).mp.
6. Sterilization/ or sterili?*.mp.
7. Decontamination/ or decontamin*.mp.
8. Disinfection/ or disinfect*.mp
9. Housekeeping, Hospital/ or housekeeping, hospital*.mp.
10. clean*.mp.
11. 1 or 2 or 3 or 4 or 5
12. 6 or 7 or 8 or 9 or 10
13. 11 and 12
14. limit 13 to english language
15. limit 14 to yr="2016 -Current"

CINAHL:

S1 (hydrogen peroxide) N5 (disinfect*)
S2 (hydrogen peroxide N5 (decontaminat*))
S3 (hydrogen peroxide N5 (vapo?r*))
S4 (hydrogen peroxide N5 (dry mist))
S5 (hydrogen peroxide) N5 (aerosol*)
S6 Sterilisation/ or sterili?*)
S7 Decontamination/ or decontamin*
S8 Disinfection/ or “disinfect*
S9 (Housekeeping and (hospital))
S10 clean*
S11 S1 OR S2 OR S3 OR S4 OR S5
S12 S6 OR S7 OR S8 OR S9 OR S10
S13 S11 AND S12

Databases and resources searched

The databases and resources searched for this literature review are specified in the [NIPCM methodology](#). The following online resources were searched additionally to identify any relevant policy or guidance documents or any significant grey literature:

- [NHS Evidence](#)
- [Health Technology Assessment \(HTA\) database](#)
- [Database of Abstracts of Reviews of Effects \(DARE\)](#)
- [National Patient Safety Agency \(NPSA\)](#)
- [National Institute for Health and Care Excellence \(NICE\)](#)
- [Medicines & Healthcare products Regulatory Agency \(MHRA\)](#)
- [Rapid Review Panel \(RRP\): product evaluation statements](#)

Appendix 2: Grades of Recommendation

Final recommendations are given a grade to highlight the strength of evidence underpinning them, the NIPCM grades of recommendations are as follows:

Grade	Descriptor	Levels of evidence
Mandatory	Recommendations' that are directives from government policy, regulations or legislation	N/A
Category A	Based on high to moderate quality evidence	SIGN level 1++, 1+, 2++, 2+, AGREE strongly recommend
Category B	Based on low to moderate quality of evidence which suggest net clinical benefits over harm	SIGN level 2+, 3, 4, AGREE recommend
Category C	Expert opinion, these may be formed by the NIPC groups when there is no robust professional or scientific literature available to inform guidance.	SIGN level 4, or opinion of NIPC group
No recommendation	Insufficient evidence to recommend one way or another	N/A