Health Protection Scotland

NHS National Services Scotland

Rapid Review of Healthcare Associated Infection Risks and Outbreaks Associated with Healthcare Ventilation Systems

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Contents

Background

A healthcare associated infection (HAI) is any infection occurring in a patient during the process of care in a hospital or other healthcare facility which was not present at the time of admission.[1] HAIs result in significant morbidity and mortality, prolonging the length of hospital stays and resulting in additional diagnostic and therapeutic interventions including increased antimicrobial use. As a significant proportion of HAIs are preventable[2], they are considered a patient safety issue and an indicator of the quality of patient care.

Transmission of infection within a healthcare setting requires three elements – a source of infectious microorganisms, susceptible hosts, and a means of transmission for the microorganism to the host. Certain factors increase the risk of a HAI developing. Patients that are immunocompromised through underlying disease, age (neonate, elderly), immune suppression, and medical trauma, are significantly more likely to develop infection.[3] Prolonged hospitalisation, invasive procedures, and diagnostic or therapeutic interventions increase the risk of exposure to microbes.[3]

A significant proportion of HAIs are preventable.[2] The primary requirement for the design of the built environment, including healthcare ventilation systems, is to protect the patient from preventable infection. Healthcare ventilation systems have become highly sophisticated and are considered integral to infection prevention and control in healthcare facilities worldwide. Although designed to reduce the risk of HAI, there is the potential for ventilation systems to contribute to their development, either by acting as a reservoir for the infectious microorganism, or by facilitating transmission of infection. There is a need to understand more about the infection risks and the types of outbreaks associated with ventilation systems in healthcare settings.

Aim

To provide a rapid review of available guidance and extant scientific literature of the HAI risks and outbreaks associated with healthcare ventilation systems.

Objectives

Objectives for the rapid review were as follows:

- To assess the causative agents for healthcare associated infections associated with healthcare ventilation systems.
- To assess the sources of HAI associated with healthcare ventilation systems.
- To assess the factors facilitating transmission associated with healthcare ventilation systems.

- To assess the infection control measures for reducing the risk of HAIs associated with healthcare ventilation systems.

Search Strategy

Academic databases were searched to identify relevant academic and grey literature. Results were limited to English language and human subjects and were deduplicated prior to screening. Papers were excluded if they did not focus on outbreaks within healthcare facilities associated with ventilation systems. Additional hand searching, and online searching using the Google search engine was carried out.

The following databases and websites were searched to identify relevant academic literature:

- Ovid MEDLINE
- EMBASE
- Maternity and Infant Care (MIDIRIS)
- NICE, PHE, CDC, WHO, ECDC, Cochrane Library

The search terms were as follows:

1. Ventilation
2. Air exchange
3. Air flow
4. Air changes
5. Air conditioning
6. Air conditioner
7. Chilled beam
8. HVAC
9. (outbreak* or infection*)
10. (healthcare or hospital*)
11. 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8
12. 9 and 10 and 11
13. Limit to English language, humans

Results

The literature search returned 1398 articles. After screening, a total of 13 articles were included and following additional hand searching, a further 12 articles were identified, providing 25 articles for the review. Articles included outbreak reports and environmental sampling studies. Additional guidance documents were retrieved from World Health Organization, Health Facilities Scotland and Department of Health.

Ventilation in healthcare settings

Ventilation systems are designed to reduce or dilute the presence of airborne contaminants, to limit transmission of contaminants, and to limit contact of contaminants with critical areas i.e. operating tables. This is achieved by modification of airflow pathways, differential pressure, air filtration, and air changes.

Ventilation systems exist in three main forms according to the level of complexity; natural ventilation, mechanical ventilation, and specialised mechanical ventilation. Natural ventilation relies on naturally occurring air flow patterns and a system may incorporate fans and motorised dampers to provide better control. Mechanical systems are required when there is a need to heat, cool and filter the air. Air-conditioning is a component of mechanical ventilation. Specialised systems have additional features for use in higher risk areas – for example in operating departments, and may incorporate specialised ultra-clean air provided by high efficiency particular air (HEPA) filters and laminar air flow. The full list of healthcare settings which require specialised ventilation, as well as a full description of the multiple types of mechanical ventilation systems is provided in the Scottish Health Technical Memorandum 03-01 (Part A) Specialised ventilation for healthcare premises, published by Health Facilities Scotland in 2014.[4]

Microbiology

The 2013 European Centre for Disease Prevention and Control point prevalence study of healthcare associated infections and antimicrobial use in acute care hospitals reported that the most frequently isolated microorganisms in HAIs were, in decreasing order, *Escherichia coli (E. coli), Staphylococcus aureus (S. aureus), Enterococcus spp., Pseudomonas aeruginosa, Klebsiella spp.*, Coagulase-negative staphylococci, *Candida spp., Clostridium difficile, Enterobacter spp., Proteus spp.* and *Acinetobacter spp.*.[5] The majority of those listed i.e. *E. Coli, S. aureus, Enterococcus spp.*, are ubiquitous on the skin of patients and are typically spread by direct contact. Of those listed, only meticillin-resistant *Staphylococcus aureus* (MRSA) and *Acinetobacter spp.* were identified in the outbreak reports retrieved in the search. Fungal microbes, which are ubiquitous in the environment and would not normally cause harm to a healthy individual, were also implicated in ventilation-associated HAIs. The most commonly identified was *Aspergillus spp*.

Table 1 lists the microorganisms identified in this rapid review. The following fungal microbes were involved in ventilation system-associated HAIs; *Aspergillus spp., Penicillium spp., Acremonium kiliense, Phialemonium spp., Rhizomucor* and *Paecilomyces variotti*. A number of bacterial microbes were also identified; gram negative *Serratia marcescens* and *Acinetobacter baumannii*, and gram positive *S. aureus*, *Propionibacterium acnes*, and *Bacillus cereus*. There were no viral microorganisms identified in the retrieved outbreak reports.

TABLE 1: Microorganisms identified in the rapid review linked to ventilation associated HAIs.

Type of organism	Microorganism identified	Natural habitat
Gram negative bacteria	Serratia marcescens	Natural environment
	Acinetobacter baumannii	Natural & human environment
Gram positive bacteria	Staphylococcus aureus	Human skin and mucous membranes
	Bacillus cereus	Soil and food
	Propionibacterium acnes	Human skin and sebaceous glands
Fungi	Aspergillus spp.	Natural environment
	Acremonium kiliense	Natural environment
	Paecilomyces variotti	Air, food, wood, carpet dust
	Penicillium spp.	Natural environment
	Phialemonium spp.	Air, soil, industrial water, sewage
	Rhizomucor	Natural environment
Virus	-	

Ventilation systems as reservoirs

The components of ventilation systems can provide a suitable environment for the growth and colonisation of microorganisms, especially if the components become damp. Colonisation of the insulation material and filters of ventilation systems by fungal microorganisms has been extensively reported, with the following fungi identified; *Aspergillus, Cladosporium, Penicillium, Acremonium, Alternaria, Chaetomium*.[6;7] A sampling study in Brazil detected *Aspergillus spp., Penicillium spp., Cladosporium spp.*, and *Cryptococcus spp.*, on air conditioning components (cooling coils, ventilators and filters) at counts higher than that permitted by the Brazilian Ministry for Health.[8] In these cases, colonisation of the system did not coincide with outbreaks or incidents in the patient population, highlighting the fact that ventilation systems can act as reservoirs allowing potential infection at a later date.

Insulation

A study in Japan linked cases of invasive pulmonary mycosis to a contaminated heating, ventilation and air conditioning (HVAC) system, in which the fibreglass insulation was found to be highly colonised with a number of fungal microbes including *Penicillium spp., Cladosporium spp., Alternaria spp., Ulocladium spp.*, and *Aspergillus spp.*.[9]

An outbreak of surgical site infection (SSI) with *Aspergillus* occurred in 6 patients undergoing surgery in the same operating theatre in the US in 2003.[10] Inspection of the variable airflow ventilation system identified deteriorated insulation (blackened and wet) installed for noise reduction, which was found to contain *Aspergillus spp.*. A confined space video camera was

required to locate the deteriorated insulation material, which had developed despite compliance with the existing ventilation system cleaning and maintenance programmes.

Humidifiers

A HVAC system that filtered air before but not after humidification was implicated as the source of an outbreak of *Acremonium kiliense* infection in four adults after cataract surgery in the US in 1995.[11] The fungal microbe was isolated in the humidifier water which was located immediately upstream of the operating room outlet vent which lacked final filtration devices. Further, the HVAC system was shut down over the weekend when not in operation and restarted immediately prior to the first procedures of the week; the four infected case patients' surgeries started significantly sooner after the operating room had been opened than those of controls. Regulations in the UK do not allow water-based humidifiers for use in air conditioning systems; only steam-injection systems are premitted.[4;12]

Phialemonium species were isolated from condensation drip pans under air-conditioning units in an investigation of an outbreak in a haemodialysis unit in the US in 2006, however samples from within the ventilation system were negative.[13] In this case, the ventilation system may have facilitated transmission, acting as a reservoir, but it could not be confirmed to be the source.

Ventilation systems as facilitators of transmission

Microorganisms can gain entry to a healthcare environment through the ventilation system. This can happen due to extremes in climate[14], and from construction work.[15;16] Ventilation systems can facilitate transmission of these externally derived microbes into the healthcare environment in the form of dust and other particulate, and can also facilitate transmission of internal sources of infection from one patient to another, or from an infected area to a non-infected area when the microorganisms becomes aerosolised. Transmission typically results from a failure of design[17-20], noncompliance with best practice for the ventilation system[21;22], or inadequate cleaning and maintenance.[23-26]

Climate

The source of an outbreak of *Rhizomucor* in five paediatric cancer patients in Egypt, 2010, was the hospital ventilation system following introduction of sand and particles from a recent sand storm; a change of filters and cleaning proved to be effective.[14] Details on the type of filter were not provided in this study.

Construction work

Hospital construction work was linked to an outbreak of *Bacillus cereus* bacteraemia in a Japanese teaching hospital in 2005.[15] Dust from recent construction work had accumulated in the inlet and outlet ducts of the ventilation system, as well as in the plastic-fibre net air filter of an air-conditioning unit. *B. cereus* was also detected on clean towels and gowns, suggesting a potential transmission route from the air-conditioning unit to the towels to the patients.

It is well recognised that indoor construction work can increase the risk of infection. Construction work in a cardiac ICU in 1987 which shared the same air supply as the adjacent operating theatre, was linked to an outbreak of *Aspergillus* in cardiac surgery patients.[16] Remedial action included the installation of a separate HEPA filtered ventilation system for the operating theatre.

Inadequate design

An outbreak of MRSA in 1993 within an NHS England hospital intensive therapy unit was linked to placement of a ventilation exhaust duct from an isolation room on an outside wall, the output of which blew directly into an unknowingly opened window in the adjacent ward for the duration of the outbreak.[17] Although this theory was not confirmed by microbiological sampling, all the patients that developed infection, except one, had occupied the bed below the window.

A report from a hospital in London in 2003 described a situation in which windows were sealed to prevent natural ventilation, and portable air conditioning units were used to cool the ward during summer months.[18] These measures coincided with an increase in the number of invasive pulmonary *Aspergillus* cases.

A higher than usual number of surgical site infection (SSI) cases following total knee replacement was linked to poor ventilation design in a hospital in Jerusalem in 2007.[19] A non-standard wall-mounted horizontal-flow air-conditioner (AC) was installed above the main door in the operating room, in addition to the built-in ventilation system which consisted of HEPA filtered air to 95% efficiency, positive pressure, and 26 air changes per hour. Directly outside the main door, a sink used for rinsing used tools prior to decontamination was located; it is possible that the AC unit transmitted airborne contaminants from the sink directly into the operating room. Control measures included removal of the sink and AC unit, and door locking during operations to ensure maintenance of positive pressure, after which the SSI rate decreased from 5.6% to 2.2%.

Inadequate ventilation provision has also been implicated as a contributing factor in outbreaks, although not the source. Five cases of *Staphylococcus aureus* infection following cardiovascular thoracic surgery were linked to a prolonged period of unusually hot and humid weather in Canada in 1988.[20] The HVAC system in place was inadequate, allowing the temperature in the operating theatre to reach as high as 30°c (far above the required 21-24°C) and healthcare workers reported

perspiring profusely. Additionally, theatre doors were left open to increase air flow for comfort. The source of infection was not reported, however the ability to maintain aseptic technique and a sterile environment was negatively impacted by the lack of ventilation, which likely facilitated ongoing transmission.

Airflow imbalances

A shared ventilation system contributed to the spread of an outbreak of MRSA infection in an English hospital involving six patients in 1996.[21] Environmental sampling detected MRSA on the ventilation grilles. The system was working on an intermittent cycle in which daily shut-down temporarily created a negative pressure, sucking air from the ward into the ventilation system. Contaminated air was then blown back out when the cycle restarted.

An outbreak of *Bacillus cereus* in 16 neonates occurred in a Japanese neonatal ICU in 2005 in which the incoming air supply was filtered by HEPA filters prior to entry to the ICU, and was extracted by vents in the ceiling. [22] The ceiling vent grilles and air samples tested positive for *B. cereus*, as did swabs from a table located directly below the ceiling vents. High person traffic in the facility as well as doors being left open were thought to create high turbulence which might have facilitated contamination of the grilles from a colonised patient. The ventilation system then facilitated ongoing transmission within the area. This case also serves as an example of inadequate ventilation system design.

Inadequate cleaning and maintenance

An outbreak of *Acinetobacter baumannii* infections in a surgical ICU ward in Taiwan in 2003 was linked to dysfunctional HEPA air filters in the ventilation system supplying the ICU.[24] Replacement of the filters in combination with infection control measures was successful in controlling the outbreak.

A single case of endophthalmitis caused by the fungus *Paecilomyces variotii* following cataract surgery was linked to poor maintenance protocols in 2004 in Finland.[23] The air-conditioning ventilation system was undergoing repairs at the time of surgery however there was no environmental sampling to confirm a source, owing to the delayed presentation of infection.

A retrospective analysis of cases of sternal SSI following cardiac surgery at a hospital in Turkey in 2006 (microorganisms not reported) demonstrated poor door maintenance to be a contributing factor.[25] Patients operated on in a conventional theatre in which the doors remained open due to a fault with the automatic doors, were at greater risk compared to those operated on in a laminar flow theatre in which doors remained closed. While it is not possible to determine to what degree the risk was reduced by the laminar flow, the complete disruption to positive pressure brought about by opened doors is likely to have increased the amount of airborne contamination.

An outbreak of SSI in which *Aspergillus* was isolated occurred in 1966 prior to the development of laminar flow or HEPA filters.[26] Three of the four cardiac surgery patients developed endocarditis; the 4th patient had a bloodstream infection. *Aspergillus fumigatus* was isolated from pigeon droppings on a window ledge and moss growing on the hospital roof, both located close to the air intake unit. Control measures included installation of improved air filters, the details of which were not provided. The environmental sources were removed.

Aerosolisation

An outbreak of *Serratia marcescens* infection in 2000 in a special-care baby unit (SCBU) in the United Arab Emirates (UAE) involving 36 infants was postulated to be due to aerosolisation from the ventilation system.[27] *S. marcescens* isolates were recovered from air conditioning grills. The high rate of positive cultures from mucosal surfaces such as respiratory, eye and umbilical sites, suggested aerosolisation by the ventilation system followed by dispersal and subsequent contact with surfaces and neonates. *S. marcescens* is ubiquitous to the climate of the UAE and can be passed from mother to baby at birth; however the exact source could not be determined in this outbreak. The ventilation system ducts were cleaned using a specialised robotic video-controlled device however details on environmental sampling of the other ventilation system components (if conducted) were not provided.

Aerosolisation was also implicated in an outbreak of eight cases of neonatal *Acinetobacter baumannii* bloodstream infection in a hospital in Barbados in 1996.[28] Environmental sampling found that settle plates placed in the nursery were significantly more likely to grow *Acinetobacter* spp. than those at other hospital sites (8/9 vs. 0/5, $p < 0.005$). Air conditioner filters were found to be improperly functioning. Cleaning protocols for filters and the frequency of filter changes were found to be inadequate; thick dust was observed on external surfaces of grates and near cooling vents. Increased absolute humidity was recorded at the time of the outbreak which led the authors to suggest that condensation build up in the air conditioning system may have led to aerosol dissemination of any organisms present in the condensate. A number of additional risk factors are likely to have contributed to the outbreak, including poorly maintained facilities (broken sinks and soap dispensers), and - most significantly - the use of multi-dose vials shared among patients receiving intravenous medications. The authors concluded that the outbreak was associated with the use of multi-use vials on multiple patients in the context of environmental contamination linked to air conditioners on the unit.

Legislative guidance for infection control

Strategies to minimise infection have been incorporated into national guidelines for the design and validation of ventilation systems. The Scottish Health Technical Memorandum 03-01 (Parts A and B), published by Health Facilities Scotland in 2014[4;29] provide guidance on the design, validation

and ongoing maintenance of heating and ventilation systems in health sector buildings. Both documents are similar to those published by The Department of Health - Health Technical Memorandum (HTM) 03-01 Specialised ventilation for healthcare premises - Parts A[12] and B.[30]

In 2007, Health Facilities Scotland developed HAI-SCRIBE (Healthcare Associated Infection – System for Controlling Risk in the Built Environment) to assist teams in identifying, managing and recording built environment infection control risks. It involves a four stage approach that takes teams from early development and planning through to the completed construction in operation, and is presented in two parts; SHFN 30 Part A (*Information for Design Teams, Construction Teams, Estates & Facilities and Infection Prevention & Control Teams*)[31] and Part B (*Implementation strategy and assessment process*).[32] These documents provide practical advice for how to minimise the risk of infection associated with construction work, and the steps to take for commissioning prior to reopening.

While these documents detail the tests required for commissioning and validation of conventional and UCLF operating theatres, in relation to microbiological sampling, air pressure, air flow and air change testing, little information is offered regarding the remedial actions to be taken in the event of an outbreak in which the ventilation system is directly implicated.

Infection control measures

Comprehensive international[33;34] and local guidance[35;36] exists for the prevention of SSIs in relation to patient care. Apart from the recommendation relating to UCLF operating theatres by the World Health Organization, there is little to no consideration of the impact of ventilation systems with regards to infection prevention and control.

In addition to compliance with standard infection control precautions (SICPs) and transmission based precautions (TBPs), corrective measures in response to a ventilation-associated HAI outbreak are concerned with decontamination of the system, and typically involve cleaning, filter changes and upgrades, and in some cases removal of defective material or a complete upgrade of the system. Specific guidance in this regard is lacking. Analysis of the retrieved outbreak reports demonstrated the challenges in cleaning ventilation systems, due to the extensive and often inaccessible duct work. Remote control video-assisted robotic devices were used in a number of studies to locate and clean areas within a system. Detergents and sealants containing fungicides were also cited. The efficacy of these remedial actions are measured by environmental sampling or by a cease in ongoing transmission, both of which are influenced by multiple confounding factors. SHTM 03-01 provides limited guidance in terms of decontamination and is largely concerned with preserving the life of the system; ‘On completion of cleaning, the ductwork should not be ‘fogged’ with chemicals. This treatment has no lasting biocidal effect and is responsible for initiating the breakdown of the galvanised coating of ductwork.’[29]

Aspects of the ventilation system design can impact on the risk of ventilation-associated HAIs. While the complexity of ventilation systems has increased in an effort to reduce the risk of infection, evidence of efficacy is limited. Much controversy has surrounded the development of ultra-clean laminar flow ventilation systems for orthopaedic surgery, which is expensive to install and maintain. Air sampling and plate counts have consistently demonstrated the microbiological superiority of laminar flow systems over conventional systems however clinical evidence to justify their use (and expense) is largely based on observational studies in which ultra-clean systems were associated with significant reductions in SSI following orthopaedic surgeries.[37;38] In 2016 World Health Organization recommended against the use of laminar airflow ventilation as a measure to reduce the risk of SSI for patients undergoing total arthroplasty surgery.[33] A meta-analysis conducted to form WHO guidance could not demonstrate a benefit of laminar airflow compared with conventional turbulent ventilation in surgical theatres for orthopaedic, abdominal, and vascular surgery.[39]

Owing to the lack of scientific evidence, validation for the efficacy of ventilation systems continues to rely on environmental sampling, the limits for which are set by industry experts. In accordance with legislative guidance, healthcare facilities are required to have planned inspections, scheduled cleaning and maintenance programmes, and ongoing validation tests in place to ensure that airflow differentials are functioning correctly, the pre-specified number of air changes is occurring, airflow and velocity is not compromised, and that filtration systems are robust. The specific requirements will depend on the ventilation system and building design of the healthcare facility, and the decisions of the Estates and Facilities and Infection Control team. A number of the outbreaks identified in this rapid review may have been prevented had ongoing validation tests been performed and maintenance protocols followed.

Conclusion

This rapid review identified a variety of microorganisms which are associated with ventilation-associated HAIs, however from the studies retrieved, the majority of outbreaks were linked to *Aspergillus* and *Staphylococcus aureus*, both ubiquitous in the environment and on human skin respectively.

In the studies retrieved, outbreaks were largely as a result of improperly designed and maintained ventilation systems. While it can be challenging to identify the source of an outbreak, ventilation systems have been implicated as reservoirs for infection, allowing microorganisms to colonise and remain in situ. Ventilation systems can also facilitate transmission of infection within a healthcare setting via aerosolisation of the microorganism, airflow imbalances, inadequate design and poor maintenance.

Strategies outlined in national guidance for the design and maintenance of ventilation systems in combination with compliance with standard and transmission based infection control precautions are effective in minimising the risk of HAIs associated with ventilation systems. Analysis of outbreak reports highlights the need for continual assessment of the ventilation system capabilities in response to any changes in the healthcare setting or external environment. For example, construction work, disruption to airflow pathways, and extremes in climate, can all impact the efficacy of a ventilation system.

Future research is required to provide additional guidance regarding the appropriate actions to take following an outbreak, including the most suitable decontamination methods for ventilation systems. Further research is also required to determine the efficacy of ventilation systems at minimising the risk of SSI, particularly UCLF.

Recommendations

This review makes the following recommendations based on an assessment of the extant scientific literature on HAI risks and outbreaks associated with healthcare ventilation systems.

Where mechanical ventilation is used NHS boards must consider the following:

- HAI-Scribe must be followed where planned installation or replacement of ventilation systems or part systems is planned. This will ensure a multidisciplinary approach to the planning and development of the project, ensuring infection control is included from the beginning.
- Any incidents or breeches to ventilation systems found by local estates or contractors must be reported to the infection control team for risk assessment to mitigate any clinical risks to susceptible patient groups.
- Ventilation systems must be designed for use within the healthcare setting and appropriate to the susceptibility of patient groups to protect patients from preventable infection as laid out in SHTM 03-01.
- Ventilation systems must be installed following strict adherence to manufacturer's instructions and National guidance SHTM 03-01.
- Commissioning of ventilation systems must be performed prior to handover to the healthcare provider to ensure the functioning system meets the criteria laid out within the design specification. Results of commissioning tests must be shared with the infection control doctor and local infection control committee for approval.

- Maintenance of healthcare ventilation systems must adhere to manufacturer's instructions and SHTM 03-01 to minimise the risk of contamination to the ventilation system and possible cross transmission to susceptible patient groups.
- Validation of ventilation systems must be undertaken in accordance with manufacturer's instructions and SHTM 03-01 to ensure the system is functioning in accordance with the criteria laid out within the design specification. Results of validation testing must be shared with the infection control doctor and local infection control committee for approval.
- Health Protection Scotland will undertake scientific literature reviews of the design, installation, commissioning, testing, operational measures, cleaning requirements, maintenance requirements and control measures for healthcare ventilation systems. These reviews will provide national guidance for the recommendations above where evidence is not available within the national guidance documents.

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