Health Protection Scotland

NHS National Services Scotland

Rapid Review of Surgical Site Infection Risks Associated with Healthcare Ventilation Systems

Version: 1.0

Date: February 2019

Contents

Background

Surgical site infections (SSIs) are infections that occur in a wound following invasive surgical procedures and can be classified into three distinct types; superficial incisional (involving only the skin and subcutaneous tissue), deep incisional (involving deep soft tissues and muscle), and organ or space infection.[1] The majority of SSIs usually become apparent within 30 days of the operative procedure.

SSI is one of the most common healthcare associated infections (HAI) in Scotland, estimated to account for 16.5% of inpatient HAI.[2] SSIs cause excess morbidity and mortality and are estimated to double the cost of treatment owing to additional surgical intervention and increased length of stay.[3] Patients of all ages can develop a SSI however underlying illness (diabetes, cancer, malnutrition), immune-suppression, old age, obesity, and smoking, are associated with an increased risk of SSI.[4] Classification systems for assessing a patient's risk of developing a SSI are based on the patient's health at the time of surgery, the duration of the surgical procedure, and the type of wound that the surgery generates (i.e. clean, clean-contaminated, contaminated, dirty).

A significant proportion of SSIs are preventable.[5] The primary requirement for the design of the built environment, including healthcare ventilation systems, is to protect the patient from preventable infection. 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 SSI, there is the potential for ventilation systems to contribute to the development of SSI, either by a failure of design, substandard maintenance and cleaning protocols, noncompliance with said protocols, or contamination. There is a need to understand more about the infection risks associated with ventilation systems in the healthcare settings in which surgical procedures are carried out.

Aim

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

Objectives

Objectives for the rapid review were as follows:

- To assess the causative agents for surgical site infections associated with healthcare ventilation systems.
- To assess the sources of SSI 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 SSI 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 de-duplicated prior to screening. Papers were excluded if they did not focus on surgical site infection 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

Search terms:

1. surgical wound infection.mp.
2. surgical site infection.mp.
3. SSI.mp.
4. 1 or 2 or 3
5. ventilation.mp.
6. air exchange. mp
7. air flow.mp
8. air conditioning.mp
9. air conditioner.mp
10. chilled beam.mp
11. HVAC.mp
12. ultra clean.mp
13. laminar airflow.mp
14. 5 or 6 or 7 or 8 or 9 or 10 or 11 or 12 or 13
15. 4 and 14
16. limit 13 to english language limit 14 to humans
17. remove duplicates from 15

Results

The literature search returned 681 articles. After screening, a total of 6 articles were included and following additional hand searching, a further 5 articles were identified, providing 11 articles for the review. The selected articles described outbreaks that occurred between 1970 and 2006. Additional guidance documents were retrieved from World Health Organization, US Centres for Disease Prevention & Control, Health Facilities Scotland and Department of Health.

Microbiology

Evidence suggests that the majority of SSIs are caused by contamination of the incision with microorganisms from the patient's own body during surgery (endogenous), with infection caused by microorganisms from an outside source (exogenous) being less common.[4] In correlation, the most commonly cultured microorganism from a SSI is usually *Staphylococcus aureus*, a skin commensal.[4]

Airborne contamination can occur in one of two ways; microorganisms can land directly onto surgical wounds, or they can land on instruments, equipment and surgeons hands and later be transferred into the wound. Certain processes carried out during surgical procedures can generate the production of droplets or aerosols from the patient, for example orthopaedic processes that involve saws, bone drills, and irrigation/suction. These droplets/aerosols can land on the surgical wound or contaminate instruments, and, theoretically pose a risk to subsequent surgeries if not properly removed from the environment. Exogenous airborne sources of infection also include contaminants from inside the operating theatre (human skin squames, respiratory aerosols and dust[6]), and from the outside natural environment.

From the retrieved SSI outbreak reports, the following microorganisms were identified; *Staphylococcus aureus*, *Peptostreptococcus spp., Propionibacterium acnes, Paecilomyces variotti, Aspergillus spp., Acrenomium kiliense, and Penicillium spp.* (see Figure 1).

Notably, of the two outbreaks in which gram-positive bacteria were isolated, outbreak investigators were unable to definitively link the ventilation system to the infection owing to additional contributing factors including noncompliance with cleaning protocols[7] and infection control precautions.[8]

FIGURE 1: Microorganisms linked to ventilation-associated outbreaks identified in the rapid review.

Type of organism	Microorganism identified	Natural habitat
Gram positive bacteria	*Propionibacterium acnes*	*Human skin and sebaceous glands*
	Peptostreptococcus spp.	*Human mucocutaneous surfaces*
	Staphylococcus aureus	*Human skin and mucous membranes*
Fungi	*Aspergillus spp.*	*Natural environment (dead plant material)*
	Acremonium kiliense	*Natural environment (dead plant material)*
	Paecilomyces variotti	*Air, food, wood, carpet dust*
	Penicillium spp.	*Natural environment (dead plant material)*

Ventilation systems for surgical facilities

Ventilation systems are designed to reduce or dilute the presence of airborne contaminants and to limit contact of contaminants with the surgical site. This is achieved by air filtration, modification of airflow pathways, differential pressure, and air changes.

Surgical procedures are carried out in a variety of healthcare settings depending on the complexity of the surgical intervention. The Scottish Health Technical Memorandum (SHTM) 03-01 *Ventilation for healthcare premises – Part A Design and validation* lists the healthcare departments which require specialised ventilation systems, of which the operating department is one.[9] This encompasses conventional operating theatres, ultra-clean operating theatres, barn theatres, treatment rooms, endoscopy, day case and minimum invasive suites, cardiology and operative imaging suites, and recovery and ancillary areas.

In Scotland there are a total of 373 operating theatres, of which 335 are located at general (acute) hospitals.[10] The remaining theatres are located at long stay hospitals (6), community hospitals (2), one maternity hospital (1), and various clinics (29) which include day surgery and diagnostics (i.e. ophthalmic and endoscopy).

There are two types of specialised ventilation systems installed in operating departments; conventional and ultra clean laminar flow (UCLF). UCLF is used for high risk surgeries (i.e. orthopaedic) and in barn theatres. All other operating departments (treatment rooms, endoscopy, day case and minimum invasive suites, cardiology and operative imaging suites, conventional operating theatres, recovery and ancillary areas) are supplied with conventional systems.

Conventional ventilation systems

Conventional ventilation systems have a pre-programmed number of air-changes per hour during which clean filtered air is supplied to the operating theatre and 'old' air is extracted. Air movement between rooms i.e. between the operating theatre and the anaesthetic room, is controlled by maintaining positive pressure within the operating theatre. Pressure stabilisers, which operate in one direction only, maintain unidirectional air movement which assists with maintaining room pressure differentials. Transfer grilles enable air to pass in either direction between rooms of equal pressure. The relative position of supply and extract terminals, pressure stabilisers and transfer grilles controls airflow direction. If designed correctly, conventional ventilation systems are a simple and relatively cost effective way to dilute the presence of airborne contaminants.

Ultra-clean air

Ultra-clean air is defined as that containing not more than 10 CFU/m^3 (colony forming units). New or refurbished conventional theatres must pass commissioning tests prior to opening, and have to demonstrate ultra-clean air counts of 10 CFU/m^3 or lower.

High efficiency particulate air (HEPA) filters

It is widely accepted that high efficiency particulate air (HEPA) filters assist in protecting high-risk patients[11], however SHTM 03-01 states that – due to their cost - they should only be used for air supplied to aseptic suites in manufacturing pharmacies, the discharges from microbiological safety cabinets and isolation facilities.[9] Consequently, conventional ventilation systems rarely use HEPA filters for the entire system, instead installing terminal filters for individual high risk areas – including UCLF operating theatres and barn theatres.

Ultra clean laminar flow (UCLF)

Ultra clean laminar flow (UCLF) systems were developed in the 1970s for use in orthopaedic theatres and have since been adopted across multiple surgical specialities. UCLF significantly increases the dilution effect by releasing a large volume of HEPA filtered air directly above the operating table, creating a 'clean zone'. This downward flow of air (laminar flow) is intended to purge the clean zone of contaminants and particles generated by the surgical activities within it. The airflow in and around the clean zone also serves to prevent entry of particles from outside the zone. Barn theatres contain individual UCLF canopies above each operating table. If an operating theatre is supplied with UCLF, there is an option to omit a separate preparation room, as instruments can be prepped in the operating theatre below the UCLF canopy, as long as the canopy is large enough to accommodate all required theatre instrumentation for the planned procedure.

Reported efficacy

Evidence regarding the efficacy of various ventilation systems at reducing the risk of SSI is conflicting, particularly for UCLF.[12-18] In comparison to conventional systems, installation and maintenance of UCLF systems is expensive. Air sampling and CFU counts have consistently demonstrated the microbiological superiority of UCLF over conventional systems however clinical evidence of their efficacy is largely based on observational studies which have historically demonstrated an association of UCLF systems with lower rates of SSI following orthopaedic surgeries.[19;20] In contrast, a 2012 meta-analysis by Gastmeier and colleagues demonstrated significantly higher SSI rates following hip and knee prosthesis surgery under UCLF conditions.[17] However the evidence for the meta-analysis was from observational studies which are prone to bias and confounding from the multiple factors that can contribute to the development of a SSI. A meta-analysis conducted for the development of the 2017 World Health Organization (WHO) Global guidelines for the prevention of surgical site infection found no benefit of UCLF over conventional systems at reducing the risk of SSI following total hip and knee arthroplasty and abdominal surgery.[13] Based on this, the authors concluded that UCLF should not be considered a preventive measure to reduce the risk of SSI and should not be installed in new theatres.[13] Further research is required to provide stronger recommendations regarding UCLF theatres.

For existing and newly installed UCLF theatres, it is important to remember that noncompliance with best practice for a ventilation system can impact SSI risk. In the operating room, mechanical obstructions from objects such as operating lights[21] and equipment[22], has been shown to disrupt airflow in experimental studies, and excessive door opening and people traffic within an operating room can negatively impact pressure differentials and increase the amount of air contamination.[23;24]

SSI Outbreaks and incidents related to healthcare ventilation systems

To directly link airborne contamination to SSI development, researchers have attempted to demonstrate correlation between the number and identity of microbes isolated from the air and from the surgical site at the time of operation. Studies of this type tend to have high levels of bias and confounding and often do not assess SSI as an outcome.[25] Further wound contamination does not always result in SSI which highlights the contribution of multiple intrinsic and extrinsic factors to the development of a SSI.

Clinical evidence directly linking ventilation systems as the source of infection in SSI incidents is limited, in part owing to the often significantly delayed presentation of infection and the issues this presents for timely environmental sampling.

Ventilation systems as reservoirs

The components of ventilation systems can provide a suitable environment for the growth and colonisation of microbes, 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*.[26;27] 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.[28] 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 for microbes allowing potential infection at a later date.

Contaminated fibreglass insulation

An outbreak of SSI with *Aspergillus* spp (*A. fumigatus and A. flavus*) occurred in 2003 in 6 patients that underwent surgery in the same operating theatre within a 12 day period.[29] Inspection of the variable airflow ventilation system identified deteriorated internal fibreglass 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.

Contaminated internal fibreglass insulation was also linked to two cases of *Penicillium* spp surgical site infection following cardiac surgery in 1988.[30] *Candida parapsilosis* was also isolated from one of the patients during mediastinal exploration but was not detected in environmental sampling. Outside air mixed with recirculating air was filtered through a filter pad, filter bags and a HEPA filter which provided 95% reduction of more than 0.3 µm/L particles prior to entering the operating room. *Penicillium* spp. was recovered from air in 6 of the 10 new hospital building's operating theatres. Fiberglass insulation in terminal units was heavily contaminated (up to 2.5cm thick) with fungal growth. A total of 15 leaks were found in the recently installed filter bank. Decontamination of the ventilation system with chlorine gas was initially successful but required a second application after 7 months, which indicated the internal insulation was acting as a reservoir. A decision was made to replace the terminal units with ones which used external insulation. Construction work at the time may have disrupted positive pressure, further facilitating airborne spread.

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 4 adults after cataract surgery in the US in 1995.[31] 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 system; only steam-injection systems are permitted.[9;32]

Ventilation systems as facilitators of transmission

Microorganisms can gain entry to an operating theatre through the ventilation system. Breaches in environmental control, noncompliance with maintenance protocols, and substandard design, have all been directly involved in outbreaks and incidents of SSIs.

Non-compliance with environmental control

Poor environmental control was responsible for SSI in four patients following open heart surgery in 1990.[33] Pigeon droppings located in the vicinity of an air intake unit allowed *Aspergillus* spores to gain entry to the ventilation system. Air supply was shared by all rooms in the operating suite (lobby, anaesthetic room, scrub room, conventional theatre, laminar flow theatre) and *Aspergillus* spores were isolated from all areas of the operating suite apart from the laminar flow theatre. Infected patients were operated on in the conventional theatre, which was not supplied with HEPA filtered air. HEPA filters that remove particles of 0.3 µm and above are capable of containing *Aspergillus* spores (which are 2.5-3.0 µm in diameter).[11] Remedial actions involved a weekly scrub of filters and refrigeration coils, replacement of filters with a series of pre-filters and HEPA filters of 99% efficiency down to particle size of 0.3 µm, and an increased number of air changes (30 per hour). All open heart surgeries were restricted to laminar flow theatres only.

A similar *Aspergillus* outbreak occurred in 1966 prior to the development of laminar flow or HEPA filters.[34] Three of the four cardiac surgery patients developed endocarditis; the fourth patient had a bloodstream infection. *Aspergillus fumigatus* was isolated from pigeon droppings on a window ledge and from moss growing on the hospital roof, both located close to air intake units. Control measures included installation of higher quality air filters, the details of which were not provided, and the environmental contaminants were removed.

Non-compliance with maintenance protocols

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.[35] 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.

A single case of endophthalmitis caused by the fungus *Paecilomyces variotii* following cataract surgery was linked to poor maintenance protocols in 2004 in Finland.[36] 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.

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.[37] Remedial action included the installation of a separate HEPA filtered ventilation system for the operating theatre.

Substandard design

A higher than usual number of SSI cases following total knee replacement was linked to poor ventilation design in a hospital in Jerusalem in 2007.[38] 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%.

Poor design was also implicated in an outbreak of 10 cases of SSI following shoulder arthroplasty in France, 2006, in which *Propionibacterium acnes* and *Staphylococcus aureus*, both commensal skin organisms, were isolated in 3 cases.[7] *Peptostreptococcus* organisms were detected in a fourth case. Air sampling detected the first two organisms within the operating room. The outside air supply was unfiltered, which resulted in the HEPA filter being almost 100% blocked. This was compounded by airflow disruptions within the operating room, caused by inappropriately placed anaesthetic and video apparatus, and an automatic ventilator which was rerouting incoming air supply depositing dust at the surgical site. Airflow simulation demonstrated that the airflow was very low near the operating table. The clinicians stated that inadequate cleaning protocols may have compounded the risk of infection.

Inadequate ventilation provision for the climate 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.[8] 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.

Legislative requirements 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[9;39] provides 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[32] and B.[40]

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 4-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*[41]) and Part B (*Implementation strategy and assessment process*).[42] These documents provide practical advice regarding ventilation systems 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.

Guidance

Comprehensive international[43;44] and local guidance[4;45] exists for the prevention of SSIs in relation to patient care. Apart from the recommendation relating to UCLF operating theatres by 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 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 often extensive ductwork. Use of detergents and sealants containing fungicides was cited. The efficacy of these remedial actions is 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.'[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 SSIs, however from the studies retrieved the majority of outbreaks were linked to *Aspergillus* which is ubiquitous in the natural environment.

While it can be challenging to identify the source of an outbreak, ventilation systems have been implicated as reservoirs for infection, with fibreglass insulation providing a suitable environment for microorganisms to colonise and remain in situ. Where ventilation systems were found to facilitate transmission of infection, it was largely as a result of improperly designed and maintained ventilation systems.

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 SSI 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 minimizing the risk of SSI, particularly UCLF.

Recommendations

This review makes the following recommendations based on an assessment of the extant scientific literature on surgical site infection (SSI) associated with healthcare ventilation systems.

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

- HAI Scribe must be followed where planned installation or replacement of theatre 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 theatre 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.
- Theatre 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 National guidance SHTM 03-01.
- Theatre ventilation systems must be installed following strict adherence to manufacturer's instructions and National guidance SHTM 03-01.
- Commissioning of theatre 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 theatre ventilation systems must adhere to manufacturer's instructions and National guidance SHTM 03-01 to minimise the risk of contamination to the ventilation system and possible cross transmission to susceptible patient groups.
- Validation of theatre ventilation systems must be undertaken in accordance with manufacturer's instructions and National guidance 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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