Automated room decontamination: report of a Healthcare Infection Society Working Party

Alan J. Beswicka, Carole Fry,b Christina W. Bradley,c Thomas Pottage,b Simon Sharpe,d Claire F. Haill,e Moira A. Mugglestone,f Aggie Bak,f Gemma L. Marsden,f Allan Bennett,b Mark Garvey,c A. Peter R. Wilsong

## Affiliations

aHealth and Safety Executive, bUK Health Security Agency, cUniversity Hospitals Birmingham NHS Foundation Trust, dBlack Country Healthcare NHS Foundation Trust, eUniversity Hospitals Plymouth NHS Trust, fHealthcare Infection Society, gUniversity College London Hospitals NHS Foundation Trust

## Key words

Automated decontamination, surface contamination, patients’ rooms, multi-drug resistant organisms, hydrogen peroxide, ultraviolet light

# 1 Executive summary

This report provides advice to hospital managers, hospital-based service providers, infection prevention and control (IPC) teams and end users who intend to employ automated room decontamination devices as part of their IPC regimens. Conventional cleaning and disinfection approaches are long established and can be very effective if thorough, but recently automated systems have become available that offer the effectiveness and safety to supplement manual methods. Some chemicals such as formaldehyde have had a place within the contained laboratory setting for many years but are too toxic for use in patient areas. Biocidal ultraviolet C light (UV-C) has long been used to treat water systems, but whole-room treatment systems have become available following improved electrical safety and componentry.

Although suppliers of fumigation systems have offered decontamination services for over 20 years, new companies have entered the marketplace providing a greater choice of machine designs, catering for different budgets and usage requirements. As a result of the growth in equipment availability the choice has increased dramatically. This brings consumer benefits but can also be confusing to the potential end user, who might not be familiar with the wealth of technical specifications for these specialized systems.

This report is independent and aims to provide useful, generic information that will help healthcare professionals make a well-informed choice if they are intending to buy or rent/lease the automated technology. The aim is to provide guidance on the types of device available, the various active chemicals (where relevant), the biocidal mechanism underpinning the technology, suggested information to be sought from the supplier before purchase, and general precautions recommended for the safe and effective use of the equipment.

## Recommendations

Consider use of an automated decontamination device as a supplement to manual cleaning in the context of rising or high prevalence of nosocomial infection, such as *Clostridioides difficile*, methicillin-resistant *Staphylococcus aureus* or vancomycin-resistant *Enterococcus*.

Consider use of hydrogen peroxide vapour or pulsed-xenon ultraviolet light in room decontamination during an outbreak of *Clostridioides difficile* infection when other modalities have failed to reduce acquisition.

## Good practice points

Manual cleaning should be completed to the same high standard regardless of the subsequent use of automated cleaning devices.

On first use of a fumigant or ultraviolet light in a specific room design, efficacy of sealing should be monitored to ensure safety.

Prioritize different cleaning systems to the type of infection of the most recent room occupant by use of a red/amber/green rating based on local nosocomial infection rates.

Remove foam materials from the room if fumigant is used unless sealed under an impervious cover.

Before purchasing or renting a system run a mock decontamination cycle in a hospital room to determine turnaround times.

After purchasing an ultraviolet-light decontamination system, consider the impact on surface finishes such as whitened PVC before purchasing other equipment, and ask the equipment supplier to confirm compatibility.

Monitor levels of fumigant or ultraviolet light at regular intervals during the contract to ensure efficacy.

When adopting a new automated system or disinfecting a new room design, conduct microbiological culture tests (if permitted in the hospital) or take in-use environmental swab tests before and after disinfection to confirm efficacy.

# 2 Lay summary

Acquiring an infection in hospital is undesirable, especially if the infection is resistant to antibiotic treatment. Manual cleaning and disinfection of patient rooms and areas in which care is delivered can leave surfaces contaminated with bacteria that might lead to infection. This report considers the effectiveness of automated (or no-touch) decontamination devices used in addition to ordinary cleaning and disinfection in patient areas. For example, the microbiological benefit versus time taken for automated decontamination of patient rooms between one patient vacating the room and another occupying it. The main types of devices considered are those using ultraviolet light or hydrogen peroxide for the decontamination process. The report describes which devices are recommended in which circumstances, as well as practical advice on their procurement and operation. Although the devices are effective the benefit in terms of preventing patient infections needs further research.

A glossary explaining key terms used in the report is presented in Appendix A.

# 3 Introduction

Infection prevention and control (IPC) measures in healthcare settings include manual cleaning (using detergent) and disinfection (using a chemical agent such as bleach). For simplicity, such procedures (which can take many and varied forms) are referred to as ‘manual cleaning/disinfection’ in this report. The procedures can be implemented one or more times per day and when patient rooms and other clinical areas are vacated (the latter being referred to as terminal cleaning/disinfection). The effectiveness of manual cleaning/disinfection depends on the thoroughness of designated procedures and the adherence of the cleaners to those procedures. Microbiological contamination of surfaces in the healthcare environment that persists due to incomplete manual cleaning/disinfection increases the risk of healthcare-associated infection, particularly for people with weakened immune systems. A potential solution is an enhanced approach to environmental surface decontamination, including those offered by automated (no-touch) room decontamination devices and systems.

This Healthcare Infection Society (HIS) guidance incorporates a systematic evidence review evaluating the effectiveness of automated approaches to room decontamination in healthcare settings compared with manual cleaning/disinfection. The automated decontamination techniques considered include ultraviolet light, either as ultraviolet C (UV-C) or pulsed-xenon ultraviolet (PX-UV) systems, and hydrogen peroxide, either as hydrogen peroxide vapour (HPV) or aerosolized hydrogen peroxide (AHP). HPV and AHP are distinguished by the concentration of hydrogen peroxide used in the decontamination process: HPV is used for systems employing 30–35% hydrogen peroxide whereas AHP refers to systems using 5–6% hydrogen peroxide.[1] Microorganisms used to evaluate automated decontamination in healthcare settings include both Gram-positive and Gram-negative bacteria associated with healthcare-associated infection, for example, *Acinetobacter* spp., *Clostridioides difficile*, meticillin-resistant *Staphylococcus aureus* (MRSA) and vancomycin-resistant *Enterococcus* (VRE). The primary focus of the systematic evidence review underpinning the guidance is an evaluation of the effectiveness of automated decontamination in preventing infection or colonization, either in relation to specific microorganisms or particular types of infection, for example, surgical site infection or device-associated infection (including catheter-associated urinary tract infection (CAUTI) and central line-associated bloodstream infection (CLABSI)). The evidence review highlights published research evaluating the effectiveness of automated decontamination in terms of reducing microbiological environmental contamination in healthcare settings. The guidance overall was intended to address practicalities related to the selection and implementation of an automated decontamination system. These considerations were based on the expertise and experience of the Working Party convened by HIS to develop the guidance.

# 4 Guidance development team

## 4.1 Acknowledgments

APRW was part funded by the National Institute for Health Research University College London Hospitals Biomedical Research Centre. The Working Party gratefully acknowledges the contribution of the late Christina (Tina) Bradley who was influential in proposing the topic, establishing the Working Party and developing the guidance.

## 4.2 Source of funding

There was no external funding for development of the guidance.

## 4.3 Disclosure of potential conflicts of interest

All members of the Working Party completed conflict-of-interest forms in line with HIS policy. No material conflicts of interest were identified.

## 4.4 Relationship of authors with sponsor

HIS commissioned the Working Party to develop the guidance. Several authors are members of HIS (ABe, APRW, CF, CFH and MG) or HIS staff (ABa, GLM and MAM).

## 4.5 Responsibility for the guidance

The views expressed in the report are those of the authors and have been endorsed by HIS following an external consultation process.

# 5 Working Party Report

Date of publication: TBC (published online TBC)

## 5.1 What is the Working Party Report?

The report comprises recommendations related to automated room decontamination in healthcare settings. The methodology used to develop the recommendations combines a systematic evidence review and synthesis and expert opinion (see Section 7 for further details).

## 5.2 Why do we need a Working Party Report for this topic?

The need for guidance was prompted by a recognition that many hospitals are either already operating or preparing to purchase automated decontamination systems. Suppliers of such systems act in an intensely competitive market with no independent oversight in terms of responsibility for comparing systems and advising on their application. The guidance was intended to include practical advice for prospective purchasers considering implementation of an automated decontamination system (for example, as part of a tender process).

## 5.3 What is the purpose of the Working Party Report’s recommendations?

The main purpose of the recommendations is to inform IPC practitioners about the options available for automated room decontamination in healthcare settings. The report includes research recommendations highlighting gaps in knowledge and evidence.

## 5.4 What is the scope of the guidance?

The guidance covers automated systems for decontaminating environmental surfaces in healthcare settings. It does not cover decontamination of equipment, devices, or the air in healthcare facilities. The guidance was largely developed with hospitals in mind, but the recommendations might be useful in other healthcare settings where microbiological environmental contamination and associated risk of a healthcare-associated infection is of concern.

## 5.5 What is the evidence for the guidance?

The guidance topic was proposed by the former HIS Scientific Development Committee (whose remit was transferred to the HIS Guidelines Committee in 2019) and approved by the HIS Council. The Working Party’s considerations regarding the effectiveness of automated room decontamination devices were based on a systematic review and evidence synthesis of peer-reviewed research literature, including quality assessment of the evidence using validated techniques. The members of the Working Party used their experience and expertise to supplement analysis of the published literature regarding the practicalities of selecting and implementing automated decontamination systems.

## 5.6 Who developed the guidance?

The Working Party comprised infectious diseases/microbiology clinicians, other IPC specialists such as infection control nurses, microbiologists, engineers and facilities managers specialising in healthcare cleaning. HIS staff with expertise in systematic reviewing prepared the evidence synthesis.

## 5.7 Who is the guidance for?

Any healthcare practitioner may use the guidance and adapt it as needed. Users will include clinical staff and in particular, IPC teams. The guidance aims to provide recommendations for all health and care settings and to include the available evidence for all settings where microbiological environmental contamination of surfaces is of concern. However, the studies included in the evidence review and synthesis were predominantly conducted in hospital settings. The Working Party believes that while many sections of the guidance are particularly relevant to hospitals, some evidence and recommendations could be extrapolated to other health and social care settings such as nursing homes.

## 5.8 How is the guidance structured?

The rationale for the advice is presented in the context of the supporting evidence identified through systematic literature searches or, in the case of the practicalities of selecting and implementing an automated decontamination system, the expert opinion of the Working Party. Evidence statements summarize the results of the systematic literature searches and evidence synthesis. The phrasing and classification of recommendations reflects the strength of the supporting evidence or reliance on expert opinion. It should be noted that the guidance is of a general nature and that an employer should consider the specific conditions of each individual place of work and comply with all applicable legislation, including the Health and Safety at Work etc Act 1974 (see <https://www.legislation.gov.uk/ukpga/1974/37/contents>).

## 5.9 How frequently will the guidance be reviewed and updated?

The guidance will be reviewed at least every four years and updated if changes are necessary or if new evidence emerges that requires a change in practice.

## 5.10 Aim

The primary aims of the guidance were to evaluate the effectiveness of different approaches to automated room decontamination in healthcare settings and to support decision making regarding the practicalities of selecting and implementing a particular approach. A secondary aim was to identify areas in need of further research.

# 6 Implementation of the guidance

## 6.1 How can the guidance be used to improve clinical effectiveness?

The guidance can be used to inform local IPC advice and in the procurement process for automated room disinfection devices. It provides a framework for audit for quality improvement in maintaining a safe patient environment.

## 6.2 How much will it cost to implement the guidance?

Automated room disinfection devices represent significant revenue and capital expenditure which will need to be balanced against potential reduction in hospital-acquired infection and improved quality of life for patients. Similar benefits can be achieved by increasing investment in standard cleaning.

## 6.3 Summary of audit measures

The following expressed as percentage compliance:

* All rooms receive enhanced disinfection (either automated or additional manual cleaning) where a patient with *C. difficile* infection has been discharged or transferred.
* All rooms given the appropriate level of cleaning according to the patient pathogens present and not derogated due to patient accommodation pressures.

## 6.4 Supplementary tools

Continuing professional development (CPD) questions and model answers for self-assessment are presented in Appendix B.

# 7 Methodology

## 7.1 Overview

The processes and methods used to develop the systematic evidence review evaluating the effectiveness of automated approaches to decontamination were based on those described in the National Institute for Health and Care Excellence (NICE) guidelines manual.[2] The review question was expressed in the patient-intervention-comparator-outcome (PICO) framework as presented in Table 1.

## Table 1: The review question formulated using the PICO framework

|  |  |  |  |
| --- | --- | --- | --- |
| **Population/setting** | **Intervention** | **Comparator** | **Outcomes** |
| Patients in any healthcare setting*Additional evidence:microorganisms, including those experimentally inoculated* | Use of an automated device to decontaminate a patient room or other clinical area | No cleaning, manual cleaning/disinfection or another automated decontamination device | Patients – infection or colonization with any pathogen*Microorganisms – microbial count (on any surface)* |

PICO patient-intervention-comparator-outcome
Exclusion criteria: studies describing decontamination of equipment or devices; automated devices used for decontamination of air; non-comparative clinical outbreak studies; studies reporting a total count, but not specific types of microorganisms

## 7.2 Data sources and search strategy

Three electronic databases (Embase, MEDLINE and CINAHL) were searched for published articles using medical subject headings (MeSH) and free-text terms. Reference lists from published reviews identified in the literature searches were used to identify additional studies to be considered for inclusion in the guidance review. No date or language restrictions were applied as part of the searches, which were completed in February 2021. Further details of the searches are presented in Appendix C.

## 7.3 Study eligibility and selection criteria

Published articles identified through the literature searches were screened for relevance against the PICO framework. One reviewer examined titles, abstracts and full texts of all records identified through the searches. A second reviewer checked at least 10% of records earmarked for exclusion at each stage of screening. Disagreements were first discussed between the two reviewers and, if consensus was not reached, a third reviewer was consulted. The results are presented in the study selection flowchart in Appendix D. A list of studies excluded after full-text screening is presented in Appendix E.

## 7.4 Data extraction, preliminary analysis and quality assessment

The characteristics of included studies were summarized in the evidence tables presented in Appendix F. For each included study, data were extracted into an evidence table by one reviewer while a second reviewer checked the data extraction for 10% of studies. Priority was given to studies reporting the clinical outcomes of infection or colonization, while additional studies reporting only environmental sampling outcomes were highlighted in a separate evidence table.

The preferred outcome measure for extraction of clinical outcomes was the incidence rate in each treatment arm since these are used to calculate incidence rate ratios (IRRs) for interventions and comparators in the same study. An IRR of one implies no difference between the incidence rates for two treatments under comparison, whereas an IRR less (greater) than one implies a reduction (increase) in the incidence rate relative to the reference treatment (which, for the purposes of this evidence review, was defined as the most conservative approach to manual cleaning/disinfection evaluated in each study). Further details relevant to the calculation of incidence rates and IRRs are described in Appendix F.

Included studies reporting the clinical outcomes of infection or colonization were appraised for quality using checklists recommended in the NICE guidelines manual.[2] Critical appraisal was conducted by one reviewer, and appraisal outcomes for at least 10% of studies were checked by a second reviewer. The results of study-level quality appraisal are presented in Appendix G, with results stratified (organized) by study design.

## 7.5 Network meta-analysis

Network meta-analysis (NMA) was considered relevant for quantitative synthesis of the clinical outcomes of infection or colonization because of the multiplicity of automated approaches to decontamination under consideration. Whereas pairwise meta-analysis allows comparison of two treatments (for example, treatment A versus treatment B), NMA allows a unified (and therefore more powerful and informative) comparison of three or more treatments (for example, treatment A versus treatment B, treatment A versus treatment C, and treatment B versus treatment C). Studies involving head-to-head comparisons of treatments provide direct evidence related to those treatment comparisons; however, NMA also allows indirect evidence to be incorporated in the analysis (for example, one study comparing treatments A and B directly and another study comparing treatments A and C directly provide indirect evidence for the comparison of treatments B and C).

In this evidence review, NMA was planned to allow comparison of a variety of automated decontamination systems with manual cleaning/disinfection and with each other. In contrast, previously published meta-analyses have been restricted to pairwise comparisons of either ultraviolet light or hydrogen peroxide systems with manual cleaning/disinfection (for example, Marra 2018[3] and Dong 2020[4]). NMA is becoming increasingly common within guideline development, and the statistical methodology used in this evidence review mirrors that used in the NICE guideline development programme.[5] Generic code for Bayesian NMA using the statistical software WinBUGS (see <https://www.mrc-bsu.cam.ac.uk/software/bugs/the-bugs-project-winbugs/>) was adapted for the analyses conducted for the guidance (see below).[6] The statistical package R (see <https://www.r-project.org/>) was used for graphical presentation of NMA data structures.

The NMAs conducted as part of this evidence review met good practice criteria[7] covering: creation of network diagrams and examination of the geometry of each network and implications for the analysis (for example, in terms of risk of bias); adjustments for correlated outcomes in multi-arm studies (studies evaluating three or more treatments); model fitting (including assessment of convergence in the Bayesian computational framework); model checking (for example, using deviance residuals); interpretation of results both as IRRs for all pairwise treatment contrasts supported by the network and by considering surface under cumulative ranking (SUCRA) scores for individual treatments; and exploration of model assumptions including transitivity (by comparing study designs in relation to the PICO framework) and inconsistency (by comparing direct and indirect treatment effect estimates) where possible. Further details of these aspects of the methodology are presented in Appendix H.

IRRs for all pairwise treatment contrasts supported by each network were calculated as part of NMA model fitting. IRRs are easier to interpret than the log-IRRs and associated standard errors (SEs) that formed the data inputs for the NMAs (see Appendix H). Posterior distributions for the IRRs were summarized in terms of medians and 95% credible intervals (CrIs; analogous to 95% confidence intervals (CIs) used in frequentist approaches to statistical inference). Treatment rankings were also calculated for each iteration of model fitting, and these were summarized using SUCRA scores expressed as percentages such that a treatment uniformly ranked most (least) effective over all iterations would have a score of 100% (0%).

## 7.6 Rating of evidence and recommendations

Evidence synthesized in the guidance review was assessed for quality at outcome level using the approach known as Grading of Recommendations Assessment, Development and Evaluation (GRADE; see <https://www.gradeworkinggroup.org/> for details). The resulting GRADE tables are presented in Appendix I, with results stratified by the microorganisms associated with infection or colonization, or type of infection (surgical site infection, device-associated infection or infection specific to a body organ or system). Using GRADE, the overall quality of the evidence for each clinical outcome of infection or colonization was classified as very low, low, moderate or high.

Evidence statements for the clinical outcomes of infection or colonization were constructed by combining the outcome-level classification of evidence quality determined using GRADE and the following terms reflecting the overall confidence in using the evidence to formulate recommendations:

* strong evidence – further research is unlikely to alter confidence in the estimated effect
* moderate evidence – further research might alter the estimated effect and its strength
* weak evidence – further research is very likely to alter the estimated effect and its strength
* inconsistent evidence – current studies report conflicting evidence and further research is very likely to alter the estimated effect.

In accordance with the GRADE approach, the Working Party’s recommendations related to the clinical outcomes of infection or colonization were phrased to reflect the strength of the evidence and the Working Party’s confidence in using it as the basis for developing recommendations.

Where there was little or no evidence related to the clinical outcomes of infection or colonization that could be used to guide recommendations, the Working Party used informal consensus to formulate good practice points based on their collective experience and expertise. The Working Party also used this approach to formulate advice regarding the practicalities of choosing and implementing automated decontamination systems. In addition, the Working Party formulated recommendations for further research to address identified gaps in the evidence.

## 7.7 Consultation process

Feedback on the draft guidance was received from the HIS Guidelines Committee and through consultation with relevant stakeholders. The draft report was placed on the HIS website for 10 working days along with the HIS standard response form, including a conflict-of-interest disclosure form. The availability of the draft guidance was communicated via email and social media. Stakeholders were invited to comment on the format, content, local applicability, patient acceptability and recommendations. The Working Party reviewed stakeholder comments and collectively agreed revisions in response to the comments (see Appendix J). Comments received from individuals who disclosed conflicts of interest, or who did not submit a conflict-of-interest disclosure form, were not considered by the Working Party.

# 8 Rationale for recommendations

## 8.1 Which automated room decontamination devices are effective for reducing microbial burden and preventing infection or colonization in healthcare settings?

### 8.1.1 Search results and study selection

The literature searches, which were performed in accordance with the search terms in Tables C.1 and C.2, identified 1,041 articles; a further 13 articles were identified by handsearching reference lists etc (see Figure D.1). One thousand and one articles were eventually excluded, with those considered at the full-text stage being listed in Table E.1 together with reasons for exclusion. A total of 53 articles were selected for inclusion, representing 29 distinct studies reporting clinical outcomes (see Table F.1)[8-39] and 21 further studies reporting only environmental sampling outcomes involving either detection of clinically occurring environmental contamination[40-53] or experimental inoculation of surfaces[54-60](see Table F.2).

Among the 29 studies reporting clinical outcomes, some focused specifically on infection and one focused specifically on colonization; the remainder focused on acquisition (infection or colonization without distinguishing between the two). Subsequent sections of this report are, therefore, structured and phrased according to the clinical outcomes of infection or acquisition. The evidence identified for inclusion covered infection or acquisition due to specific microorganisms or groups of microorganisms, surgical site infection, device-associated infection and infection specific to body organ or system (see below for further details).

The most frequently evaluated automated room decontamination systems in terms of clinical outcomes were UV-C (eight studies),[8, 15, 25, 29, 32, 34, 35, 38] PX-UV (13 studies)[10, 13, 14, 16, 17, 20-22, 25, 26, 28, 37, 39] and HPV (six studies).[11, 18, 19, 23, 24, 33] AHP was compared with manual cleaning/disinfection in one study,[27] as was a visible (indigo and white) light continuous disinfection system.[30] Most studies focused on the use of automated decontamination devices after manual cleaning/disinfection (most frequently in the context of terminal cleaning/disinfection of patient rooms). However, one study[29] compared UV-C at every terminal discharge to UV-C only at terminal discharge of patients with *C. difficile* infection.

### 8.1.2 Assessment of methodological quality

Two of the studies reporting clinical outcomes were conducted as controlled trials,[8, 12] five were conducted as controlled before–after studies,[20, 28, 30, 33, 37] seven were conducted as interrupted time series,[13, 15, 24, 27, 29, 34, 38] and the remainder were conducted as quasi-experimental (uncontrolled before–after) studies.[10, 11, 14, 16-19, 21-23, 25, 26, 32, 35, 39] Where controlled before–after studies reported adjusted IRRs these were used to calculate data inputs for the relevant NMAs (see Appendix H). Methodological quality assessments for the included studies are presented according to study design in Tables G.1, G.2, G.3 and G.4, respectively.

### 8.1.3 Network meta-analysis

NMA was performed for the clinical outcomes of infection or acquisition due to *Acinetobacter* spp. (four studies),[8, 28, 32, 35] *C. difficile* (18 studies),[8, 10-13, 16, 17, 19, 22-26, 32-34, 37, 39] MRSA (12 studies)[8, 12, 16, 17, 19, 20, 27, 28, 32, 33, 35, 39] and VRE (10 studies).[8, 12, 13, 17, 19, 32, 33, 35, 37, 39] The data inputs for the NMAs (including log-IRRs and associated SEs) are presented in Tables H.1, H.2, H.3 and H.4, respectively. One multi-arm study[8] was included in several of the NMAs. This study compared four treatments: UV-C after bleach disinfection; UV-C after standard manual cleaning/disinfection; bleach disinfection; and standard manual cleaning/disinfection. Where relevant, the NMAs incorporated adjustments for correlations between IRRs involving the three alternatives to standard manual cleaning/disinfection in this study. Another study[25] evaluated both UV-C and PX-UV through comparisons with manual cleaning/disinfection, but these comparisons were conducted in different hospitals and contributed statistically independent IRRs to the relevant NMA. One study comparing different approaches to manual cleaning/disinfection[12] was also included in several of the NMAs. This ensured that the approaches to manual cleaning/disinfection represented in the analyses reflected the wide variety of approaches that might be used in practice (see Appendix H). However, the purpose of the analyses was not to compare the effectiveness of different approaches to manual cleaning/disinfection *per se*.

Network diagrams corresponding to each NMA are presented in Figure H.1. The automated approaches to decontamination represented in the NMAs were UV-C, PX-UV, HPV and AHP. The total number of patient days represented in the networks of evidence was greatest for *C. difficile* (more than 3.5 million patient days), lower for MRSA and VRE (approximately 1.5 million patient days each), and lowest for *Acinetobacter* spp. (approximately 170,000 patient days). None of the included studies involved head-to-head comparisons between different approaches to automated decontamination. The resulting star networks, in which the only direct comparisons were those between automated decontamination systems and the reference treatment (manual cleaning/disinfection) did not allow investigation of the consistency assumption underpinning each NMA, but the width of the 95% CrIs for indirect treatment effect estimates was taken into account when determining GRADE quality ratings for the domain of imprecision (see Appendix H). The transitivity assumption that also underpins each NMA was expected to hold because it was plausible that any automated decontamination system could have been implemented in any of the study settings represented in the networks of evidence.

The numerical results (IRRs for relevant treatment contrasts and SUCRA scores) from the NMAs are presented in Tables H.5, H.6, H.7, H.8 and H.9. The IRRs (and 95% CrIs) are presented graphically in Figure 1.

### 8.1.4 GRADE tables

A separate GRADE table was constructed for each type of evidence identified for the clinical outcomes of infection or acquisition. Thus, GRADE tables were produced for infection or acquisition due to the specific microorganisms *Acinetobacter* spp., *C. difficile*, *Klebsiella pneumoniae*, MRSA, *Pseudomonas aeruginosa*, *Stenotrophomonas maltophilia* and VRE (see Tables I.1, I.2, I.3, I.4, I.5, I.6 and I.7, respectively) and for the groups of microorganisms Enterobacteriaceae (including extended-spectrum beta lactamase-producing (ESBL) Enterobacteriaceae; see Table I.8), multidrug-resistant Gram-negative rods (MDR-GNR; see Table I.9), extended-spectrum beta lactamase-producing Gram-negative bacteria (ESBL-GNB; see Table I.10) and multidrug-resistant Gram-negative bacteria (MDR-GNB; see Table I.11). The GRADE tables related to infection or acquisition due to specific microorganisms refer to NMA results where relevant. Further GRADE tables summarize evidence for surgical site infection (see Table I.12), device-associated infection (CAUTI, CLABSI and ventilator-associated pneumonia; see Table I.13), and infection of specific body organs or systems (enteric infection, respiratory infection, skin and soft tissue infections, and urinary tract infection (UTI); see Table I.14).

All the evidence was assigned an overall quality rating of very low or low. Frequently occurring reasons for downgrading the quality of individual outcomes were serious risk of bias (as identified through the methodological quality assessments based on study design referred to above) and serious (or very serious) imprecision (where 95% CrIs or CIs for relative treatment effects such as IRRs or odds ratios (ORs) crossed one (or both) prespecified thresholds of 0.8 and 1.25).

### 8.1.5 Evidence statements

### *Acinetobacter* spp. infection or acquisition

There was weak evidence from an NMA based on a controlled trial,[8] a controlled before–after study[28] and two uncontrolled before–after studies[32, 35] that using UV-C or PX-UV in addition to manual cleaning/disinfection might reduce the incidence of *Acinetobacter* spp. infection or acquisition in subsequent patients compared with manual cleaning/disinfection alone. However, the reductions were not statistically significant, nor was the difference in effectiveness between UV-C and PX-UV (UV-C versus manual cleaning/disinfection, IRR=0.376 (95% CrI 0.068 to 1.638); PX-UV versus manual cleaning/disinfection, IRR=0.370 (95% CrI 0.023 to 5.755); PX-UV versus UV-C, IRR=0.987 (95% CrI 0.046 to 26.310)). Treatment rankings (from best to worst) based on SUCRA scores were as follows: UV-C (SUCRA=36%); PX-UV (SUCRA=34%); and manual cleaning/disinfection (SUCRA=11%).

### *Clostridioides difficile* infection or acquisition

There was moderate evidence from an NMA based on based on two controlled trials,[8, 12] two controlled before–after studies,[33, 37] three interrupted time series[13, 24, 34] and 11 uncontrolled before–after studies[10, 11, 16, 17, 19, 22, 23, 25, 26, 32, 39] that using UV-C, PX-UV or HPV in addition to manual cleaning/disinfection reduced the incidence of *C. difficile* infection compared with manual cleaning/disinfection alone (UV-C versus manual cleaning/disinfection, IRR=0.822 (95% CrI 0.525 to 1.258); PX-UV versus manual cleaning/disinfection, IRR=0.761 (95% CrI 0.571 to 0.972); HPV versus manual cleaning/disinfection, IRR=0.532 (95% CrI 0.372 to 0.755); PX-UV versus UV-C, IRR=0.925 (95% CrI 0.553 to 1.531); HPV versus UV-C, IRR=0.646 (95% CrI 0.373 to 1.145); HPV versus PX-UV, IRR=0.699 (95% CrI 0.458 to 1.108)). Treatment rankings (from best to worst) based on SUCRA scores were as follows: HPV (SUCRA=72%); PX-UV (SUCRA=42%); UV-C (SUCRA=32%); and manual cleaning/disinfection (SUCRA=6%).

There was inconsistent evidence regarding *C. difficile* infection from an interrupted time series[29] comparing UV-C at every terminal discharge to UV-C only at terminal discharge of patients with *C. difficile* infection. In a bone marrow transplant unit, using UV-C at every terminal discharge reduced the baseline incidence of *C. difficile* infection and slowed the rate of increase over time compared with using UV-C only at terminal discharge of patients with *C. difficile* infection. The change in baseline incidence was statistically significant, but not the change in the rate of increase over time (segmented regression change in intercept, p=0.044 and change in slope, p=0.417).

## Figure 1: Forest plots for network meta-analysis of the clinical outcomes of infection or acquisition\*



\* IRRs with 95% CrIs that do not cross the line of no effect (IRR=1) shown in red; upper limits of 95% CrIs truncated at ~ 2 (see Appendix H for exact results); dashed vertical lines show thresholds for defining imprecision (IRR=0.8 and IRR=1.25)
AHP aerosolized hydrogen peroxide; CrI credible interval; HPV hydrogen peroxide vapour; IRR incidence rate ratio; MRSA meticillin-resistant *Staphylococcus aureus*; PX-UV pulsed-xenon ultraviolet; UV-C ultraviolet C; VRE vancomycin-resistant *Enterococcu*s

### *Klebsiella pneumoniae* infection or acquisition

There was weak evidence regarding *K. pneumoniae* infection from two uncontrolled before–after studies[32, 35] comparing UV-C to manual cleaning/disinfection. There were no statistically significant differences between UV-C and manual cleaning/disinfection.

### Meticillin-resistant *Staphylococcus aureus* infection or acquisition

There was weak evidence from an NMA based on two controlled trials,[8, 12] three controlled before–after studies,[20, 28, 33] an interrupted times series[27] and six uncontrolled before–after studies[16, 17, 19, 32, 35, 39] that using UV-C, PX-UV, HPV or AHP in addition to manual cleaning/disinfection reduced the incidence of MRSA infection or acquisition compared with manual cleaning/disinfection alone. The reduction was statistically significant with PX-UV, but not with UV-C, HPV or AHP nor when comparing differences in effectiveness between UV-C, PX-UV, HPV and AHP (UV-C versus manual cleaning/disinfection, IRR=0.838 (95% CrI 0.656 to 1.052); PX-UV versus manual cleaning/disinfection, IRR=0.760 (95% CrI 0.621 to 0.966); HPV versus manual cleaning/disinfection, IRR=0.554 (95% CrI 0.272 to 1.150); AHP versus manual cleaning/disinfection, IRR=0.701 (95% CrI 0.170 to 2.677). Treatment rankings (from best to worst) based on SUCRA scores were as follows: HPV (SUCRA=81%); PX-UV (SUCRA=60%); AHP (SUCRA=56%); UV-C (SUCRA=44%); and manual cleaning/disinfection (SUCRA=11%).

### *Pseudomonas aeruginosa* infection or acquisition

There was moderate evidence from an uncontrolled before–after study[35] that using UV-C in addition to manual cleaning/disinfection did not significantly reduce the incidence of *P. aeruginosa* infection compared with manual cleaning/disinfection alone (IRR=0.871 (95% CI 0.634 to 1.197)).

There was weak evidence from an uncontrolled before–after study[16] that using PX-UV in addition to manual cleaning/disinfection did not significantly reduce the incidence of multidrug-resistant *P. aeruginosa* acquisition compared with manual cleaning/disinfection alone (IRR=0.670 (95% CI 0.032 to 13.947)).

### *Stenotrophomonas maltophilia* infection or acquisition

There was weak evidence from an uncontrolled before–after study[16] that using PX-UV in addition to manual cleaning/disinfection did not significantly change the incidence of *S. maltophilia* acquisition compared with manual cleaning/disinfection alone (IRR=2.511 (95% CI 0.562 to 11.218)).

### Vancomycin-resistant *Enterococcus* infection or acquisition

There was moderate evidence from an NMA based on two controlled trials,[8, 12] two controlled before–after studies,[33, 37] an interrupted time series[13] and five uncontrolled before–after studies[17, 19, 32, 35, 39] that using UV-C, PX-UV or HPV in addition to manual cleaning/disinfection reduced the incidence of VRE infection or acquisition compared with manual cleaning/disinfection alone. The reduction was statistically significant with HPV, but not with UV-C or PX-UV; HPV also reduced the incidence of VRE infection or acquisition compared with UV-C and PX-UV and these reductions were statistically significant (UV-C versus manual cleaning/disinfection, IRR=0.626 (95% CrI 0.376 to 1.075); PX-UV versus manual cleaning/disinfection, IRR=0.740 (95% CrI 0.427 to 1.139); HPV versus manual cleaning/disinfection, IRR=0.180 (95% CrI 0.060 to 0.482)). Treatment rankings (from best to worst) based on SUCRA scores were as follows: HPV (SUCRA=74%); UV-C (SUCRA=42%); PX-UV (SUCRA=31%); and manual cleaning/disinfection (SUCRA=3%).

### Enterobacteriaceae infection or acquisition

There was weak evidence from an uncontrolled before–after study[16] that using PX-UV in addition to manual cleaning/disinfection did not significantly change the incidence of ESBL Enterobacteriaceae acquisition compared with manual cleaning/disinfection alone (IRR=1.674 (95% CI 0.152 to 18.460)).

### Multidrug-resistant Gram-negative rod infection or acquisition

There was weak evidence from an uncontrolled before–after study[16] that using PX-UV in addition to manual cleaning/disinfection did not significantly change the incidence of MDR-GNR acquisition compared with manual cleaning/disinfection alone (IRR=1.674 (95% CI 0.504 to 5.559)).

There was weak evidence from a controlled before–after study[33] that using HPV in addition to manual cleaning/disinfection did not significantly change the incidence of MDR-GNR acquisition compared with manual cleaning/disinfection alone (IRR=0.715 (95% CI 0.307 to 1.667)).

### Extended-spectrum beta lactamase-producing Gram-negative bacterial infection or acquisition

There was moderate evidence from an uncontrolled before–after study[19] that using HPV in addition to manual cleaning/disinfection reduced the incidence of ESBL-GNB acquisition compared with manual cleaning/disinfection alone. The reduction was statistically significant (IRR=0.063 (95% CI 0.008 to 0.500)).

### Multidrug-resistant Gram-negative bacterial infection or acquisition

There was moderate evidence from an uncontrolled before–after study[17] that using PX-UV in addition to manual cleaning/disinfection reduced the incidence of MDR-GNB acquisition compared with manual cleaning/disinfection alone. The reduction was statistically significant (IRR=0.81 (95% CI 0.66 to 0.98)).

### Surgical site infection

There was inconsistent evidence regarding surgical site infection from an uncontrolled before–after study[14] comparing PX-UV to manual cleaning/disinfection. Among class 1 (clean wound) surgical procedures, using PX-UV in addition to manual cleaning/disinfection reduced the incidence of surgical site infection. The reduction was statistically significant (IRR=0.553 (95% CI 0.334 to 0.918)). However, among class 2 (clean contaminated wound) procedures, using PX-UV in addition to manual cleaning/disinfection increased the incidence of surgical site infection. The increase was not statistically significant (IRR=1.230 (95% CI 0.632 to 2.393)).

There was moderate evidence from a controlled before–after study[30] that using visible (indigo and white) light in addition to manual cleaning/disinfection reduced the incidence of surgical site infection compared with manual cleaning/disinfection alone. The reduction was statistically significant (adjusted OR=0.22 (95% CI 0.05 to 0.90)).

### Device-associated infection

There was weak evidence regarding device-associated infection from an uncontrolled before–after study.[16] Using PX-UV in addition to manual cleaning/disinfection, there was no statistically significant change in the incidence of CAUTI or CLABSI compared with manual cleaning/disinfection alone (p=0.23 and p=0.20, respectively).

There was weak evidence regarding CLABSI from an interrupted time series[29] comparing UV-C at every terminal discharge to UV-C only at terminal discharge of patients with *C. difficile* infection. In a bone marrow transplant unit, using UV-C at every terminal discharge reduced the baseline incidence of CLABSI and slowed the rate of increase over time compared with using UV-C only at terminal discharge of patients with *C. difficile* infection. The change in baseline incidence was statistically significant, but not the change in the rate of increase over time (segmented regression change in intercept, p=0.048 and change in slope, p=0.204).

There was weak evidence regarding ventilator-associated pneumonia from an uncontrolled before–after study.[16] Using PX-UV in addition to manual cleaning/disinfection, there was no statistically significant change in the incidence of ventilator-associated pneumonia compared with manual cleaning/disinfection alone (p=0.12).

### Infection of specific body organs or systems

There was weak evidence regarding infection of specific body organs or systems from an uncontrolled before–after study[21] comparing PX-UV to manual cleaning/disinfection. Using PX-UV in addition to manual cleaning/disinfection, there were no inferential analyses reported regarding the incidence of enteric infection compared with manual cleaning/disinfection alone. However, there were statistically significant differences in the incidence of respiratory system infections, skin and soft tissue infections, and UTIs (p=0.017, p=0.014 and p=0.014, respectively).

There was weak evidence regarding respiratory viral infection from an interrupted time series[29] comparing UV-C at every terminal discharge to UV-C only at terminal discharge of patients with *C. difficile* infection. In a bone marrow transplant unit and an oncology unit, using UV-C at every terminal discharge did not significantly change the baseline incidence of respiratory viral infection or the rate of increase over time compared with using UV-C only at terminal discharge of patients with *C. difficile* infection.

### 8.1.6 Interpretation of the evidence

### Outcomes that matter most

The Working Party focused on the clinical outcomes of infection or acquisition as these reflect the direct impact on patients in healthcare settings when exposed to microbiological environmental contamination. In many studies infection and acquisition were not distinguished, although all included studies that evaluated *C. difficile* reported infection as the clinical outcome.

### Quality of the evidence

All the evidence was of very low or low quality, reflecting potential for bias in the design, analysis and reporting of individual studies, and in many cases imprecise estimates of treatment effects (as reflected by wide CrIs/CIs or those that crossed predetermined thresholds for precision). The Working Party emphasized the potential for bias when reporting study results in research funded by manufacturers of devices being evaluated.

One study evaluated the effectiveness of AHP compared with manual cleaning/disinfection,[27] but AHP was used only in single-occupancy rooms while hydrogen peroxide was applied manually in shared rooms. The quality of the evidence from this study was, therefore, downgraded for indirectness; the consequence of the indirectness would be to dilute any real effect of AHP compared with manual cleaning/disinfection alone.

In accordance with the overall quality of the evidence, the Working Party formulated weak/conditional recommendations for practice (that is, starting with the verb ‘consider’).

### Benefits and harms

The NMA results suggest that using the different forms of automated decontamination (UV-C, PX-UV, HPV and AHP) in addition to manual cleaning/disinfection have some benefits compared with manual cleaning/disinfection alone.

There was moderate evidence of benefit against *C. difficile* infection, with HPV and PX-UV having statistically significant effects; the effect of UV-C was also in the direction of benefit but was not statistically significant.

There was moderate evidence of benefit against VRE infection or acquisition, with HPV having a statistically significant effect; the effects of UV-C and PX-UV were also in the direction of benefit although not statistically significant. HPV was associated with statistically significant reductions in the incidence of VRE infection or acquisition compared with UV-C and PX-UV. This might reflect the persistence of VRE in clinical environments and the ability of HPV to reach all surfaces whereas UV light might be subject to shadowing effects, etc.

No evidence was identified in relation to the effectiveness of HPV when considering *Acinetobacter* spp. infection or acquisition. The evidence identified for *Acinetobacter* spp. was regarded as weak: the included studies were small and this resulted in effect estimates for UV-C and PX-UV being very imprecise and not statistically significant.

There was weak evidence of benefit against MRSA infection or acquisition, with PX-UV having a statistically significant effect; the effects of UV-C, HPV and AHP were also in the direction of benefit but were not statistically significant.

The Working Party’s overall conclusion from the NMAs was that, where evidence was available, HPV was consistently most effective based on SUCRA scores; conversely, UV-C was generally the least effective of the automated approaches to decontamination, while still providing a marginal reduction in infection or acquisition of clinically relevant microorganisms compared with manual cleaning/disinfection alone. The Working Party noted that the findings were consistent with *in vitro* research demonstrating that ultraviolet light delivers a lower log-kill rate than does hydrogen peroxide.[61] However, the bacterial load used in these studies far exceeds that likely to be encountered in the environment.[51]

Most of the single-study analyses related to clinical outcomes with UV-C, PX-UV or HPV, although one study evaluated the effectiveness of visible (indigo and white) light. The incidence of clinical events was reduced in some single-study reports, but the reductions were statistically significant in very few cases (for example, infection or acquisition due to ESBL-GNB, MDR-GNB and surgical site infection). A recent systematic review with 43 included articles found insufficient assessment of patient outcome because many were before–after studies and sponsored by industry; most were confounded by other infection control or audit interventions.[62]

The Working Party emphasized that the theoretical superiority of HPV reflected the increased effectiveness in killing spores demonstrated in laboratory studies,[61] but that practical considerations might outweigh the theoretical advantages, for example, room turnaround times and training of operational staff. Use of lower concentrations of hydrogen peroxide might be attractive in practice, as would use of an alternative automated decontamination method allowing rapid re-entry of patient rooms. These considerations are explored further in Sections 8.2 and 8.3.

### Cost effectiveness and resource use

The implementation of automated decontamination devices to enhance terminal cleaning of patient rooms and other clinical areas will have a cost impact. The exact costs will be dependent on the particular type of device.

The cost consequences of healthcare-associated infection might be reduced using automated decontamination, particularly in elderly populations or clinical groups with weakened immune systems, and this might influence settings in which automated decontamination devices are recommended. Although the Working Party did not undertake a formal economic evaluation the cost-effectiveness of automated decontamination is explored further in Section 8.2.1.

### Other considerations

The Working Party highlighted the scarcity of evidence regarding the effectiveness of automated decontamination using AHP and visible (indigo and white) light. Although the literature searches were broad enough to identify clinical evidence related to high-intensity narrow-spectrum (HINS) light, steam and ozone no such evidence was identified.

The evidence for *Acinetobacter* spp. displayed moderate heterogeneity, possibly due to the clinical outcomes of infection or acquisition being defined somewhat differently across the included studies. In contrast, the definitions of *C. difficile*, MRSA and VRE infections or acquisitions were more consistent across studies (see Appendix H for further details).

The evidence identified by the Working Party involved direct (head-to-head) comparisons only with manual cleaning/disinfection. Comparisons between different automated room decontamination devices were, therefore, made through indirect comparisons in the corresponding NMAs; the resulting effect estimates were subject to much uncertainty (as reflected in the GRADE imprecision domain). The study designs encountered in the evidence might reflect difficulties in implementing different automated decontamination systems in the same setting.

### Recommendations

Consider use of an automated decontamination device as a supplement to manual cleaning in the context of rising or high prevalence of nosocomial infection, such as *Clostridioides difficile*, methicillin-resistant *Staphylococcus aureus* or vancomycin-resistant *Enterococcus*.

Consider use of hydrogen peroxide vapour or pulsed-xenon ultraviolet light in room decontamination during an outbreak of *Clostridioides difficile* infection when other modalities have failed to reduce acquisition.

## 8.2 Procuring an automated room decontamination device

### 8.2.1 How cost effective are automated room decontamination devices?

The decision on which equipment to purchase or rent will depend on user needs, budget and service contract provisions. Contractors commonly have a preferred system, but the choice needs to be reviewed for effectiveness by the client. Cost is likely to be a key influencer, as well as the profile and reputation of the manufacturer. Some devices cost in excess of £50,000 to purchase outright from larger suppliers. Service contracts are an added cost but might often be attractive as the supplier company will risk assess use, train staff and include the cost of consumables. There is insufficient published information to recommend specific decontamination systems on the basis of cost savings due to reduced infections.[62]

### 8.2.2 What are the considerations for the relative benefits of hiring versus buying a device?

The relative cost of purchase compared with lease should be investigated with prospective contractors. Options might include outright purchase, long-term hire or loan, rental or rental period with the option to purchase at the end. There may be benefits in terms of mitigating breakdown costs between the different purchase options. Differences between the different service options and related response times to breakdowns or repairs should be ascertained. The contractor should offer potential upgrades to the system as new developments occur but there may be additional costs best managed with a rental arrangement. However, in a hire or lease arrangement, there need to be adequate safeguards in place if the company goes into liquidation. The expected life span of the equipment is an important consideration in the case of purchase.

### 8.2.3 Does the system come with guarantees, service agreements and recommendations on whether it requires recalibration and if so the frequency of this?

In the procurement process, the lengths of time that standard guarantees can be extended should be determined with the associated costs. The breadth of the guarantee (parts, labour, manufacture fault and operator fault) should be ascertained. If there any disputes, the resolution process and the cover, for example, misuse by operators, is important. The published response time for callouts and supportive data on average response times is essential information during an outbreak or equipment failure. The requirements for the client when calling out an engineer must be clearly understood, particularly whether an order number is required to cover those items that might not be covered by a guarantee or warranty. The provisions for the replacement of faulty equipment must be agreed. The client will need to confirm the recommended period or number of uses after which the system should be recalibrated or checked by the provider and the associated cost.

### 8.2.4 What key information should be requested from the manufacturer?

Medical engineering, infection control, facilities management and procurement services should be consulted in all decisions regarding adoption of new devices as most information will be gathered by those departments as part of due diligence in the tendering process. All responsible suppliers/manufacturers should be able to provide the following information to the end user for any purchased system.

* Written instructions on the correct use of the system, including safety-related information on the storage and handling of any hazardous chemicals required for filling the machine.
* A full demonstration of the safe operation of the machine. A certificate for those receiving training should be provided as a record.
* Electrical safety information.
* Validation information relating to any known levels of efficacy of the system against defined groups of microorganisms. National standards will be available shortly (see <https://standardsdevelopment.bsigroup.com/projects/2019-00332#/section>).
* For the device, ease of use, quality control and functionality and reliability.

In the case of fumigants, the supplier should provide a monitoring device for end users to check residual levels of fumigant in treated areas prior to full room re-entry. Such monitors should be calibrated against the fumigant in use and should be accompanied by a calibration certificate. Premature entry by cleaning staff can result in adverse effects.

Regarding device maintenance and product life, the following should be established:

* whether maintenance and repair are undertaken by the supplier or a third party
* data showing the frequency of breakdown (on an annual basis) following purchase of equipment and itemized into the types of faults with the system
* availability and source of spare parts, and the timeframe for accessing spare parts
* whether the provider has systems in place for decontamination of any equipment or materials used in the maintenance of equipment during visits to other organizations
* the shelf life of any consumables used with the system and the length of time after manufacturing consumables are stored prior to shipping.

The proposed method of monitoring effectiveness should enable comparison between each treatment and should automatically record treatments carried out. The following information should be provided:

* the means of recording within the system and how data are transferred and to whom
* the security measures in place to safeguard any data
* the ease of use, required education of users, supply of training (users vary but may be dedicated staff from the supplier or client staff who have been trained in the use of the equipment)
* an operational manual for ongoing reference
* safety measures such as lock or tamper-proofing, physical or software setting of the system, adjustment of the programme for room size, recording of every operation and setting, means of monitoring any leakage from the room or to monitor the system while in use
* accessories supplied or recommended such as air vent covers, door seals, tape, hand-held hydrogen peroxide vapour gas monitors.

Room-sealing devices are essential for both fumigant and ultraviolet-light systems, with signage to warn patients and staff that an area or room is being treated. Monitoring devices to determine the level of active agent and any leakage are desirable. Accessories should be provided to allow the system to be transported easily.

### 8.2.5 What are the limitations of automated room decontamination devices?

Automated room decontamination can assist IPC activities within the hospital setting by adding assurance to existing cleaning/disinfection procedures. They can treat areas that might not otherwise receive regular cleaning attention, for example, the treatment of high-level surfaces and, using fumigants, undersides of furnishings.[27, 63]

In addition, when used at higher intensity, some of these systems might offer effective interventions during outbreaks, allowing hospital areas to be treated and returned to normal operational conditions more rapidly than might otherwise be possible. There is greater confidence in the standards of surface disinfection achieved.[24]

Automated room decontamination systems are not designed to be used in isolation or as a standalone solution to hard surface disinfection of hospital ward and clinical treatment areas. Surfaces such as floors, tables, wash areas or toilets, still require physical cleaning. This basic requirement removes organic soiling, making surfaces appear acceptably clean and facilitates a more effective fumigation process or permits better access of ultraviolet light. Biocidal processes using chemicals or ultraviolet light are more effective when associated organic soiling is removed or reduced. Due to toxicity, both hydrogen peroxide and ultraviolet systems are used in single patient rooms and not in shared ward bays. Although temporary single-bed enclosures have been tested, none have been widely adopted.

For systems using a fumigant, performance is affected by:[63]

* the size and sealability of the treated area – leaks can result in failure to maintain effective levels of fumigant in the decontamination process and threaten the safety of those potentially exposed in surrounding areas
* the type and levels of fumigant delivered into the treated area
* the physical nature of the gas, vapour or aerosolization, for example, small droplets will only reach shadowed areas if the particles generated are small enough to be buoyant and to mix well in the treated room air; a truly gaseous product will not suffer such problems
* the nature of challenge microorganisms (and concentration) that require eradication; for example, *C. difficile* spores are likely to be more difficult to kill than *P. aeruginosa* vegetative cells; however, some vegetative microorganisms might be more resistant than spores due to physiological characteristics such as catalase production
* the presence of cold surfaces in rooms, such as outside windows and doors, might increase localized condensation of vapourised product limiting deposition (micro-condensation) of fumigant onto other surfaces in the room
* some equipment in a treated area might be sensitive to the effects of raised chemical and moisture levels, limiting the areas of use, for example, avoiding microelectronics, mild steel, and porous surfaces such as wood and textiles
* presence of organic matter can reduce penetration of the fumigant or break it down.

Similarly, ultraviolet light systems have limitations, which include:[63]

* shadowing effects produced by surface soiling or furniture and room geometry
* reduced biocidal effect due to distance of the contaminant from the ultraviolet light source
* type and energy level of ultraviolet light delivered
* position and number of units used to treat the area (that is, triangulation and overlap effects of three systems enhance effectiveness)
* age of the units, which will affect the energy level of the ultraviolet light emission
* presence/absence of low-level light units which can influence floor-level energy delivery – a luminometer can be used for quality purposes as independent measure
* penetration of glass might be uncertain.

## 8.3 Using an automated room decontamination device

### 8.3.1 What standard of manual cleaning/disinfection should be evident before using an automated device?

The use of automated decontamination equipment does not negate the need for physical cleaning of healthcare surfaces. When used alongside traditional (manual) cleaning/disinfection methods the two represent distinct but recognized hygiene approaches that seek to achieve the same endpoint – a safe, clean hospital environment. Both are generally used to deliver effective IPC.[63]

The purpose of environmental cleaning is to remove debris and organic matter. For a fully effective physical process, a properly prepared environment, trained and competent staff, ergonomically designed equipment and chemical contact are all required. The time taken to clean a patient room between occupation depends on the space, *en suite* facilities, ventilator grills, radiators and the general condition of the area. Turnaround can be reduced by effective collaboration between clinical and domestic staff. A standard operating procedure detailing staff responsibilities will improve efficiency and set expectations of management.

A visual inspection undertaken jointly by clinical and domestic supervisors who are competent at inspections will ensure the standard is achieved consistently. Routine ward-based cleaning of solid surfaces, such as bed frames, bedside cabinets, over-bed tables and bathroom areas, is typically undertaken using approaches specified in national guidance. For example, in the UK, professionals should refer to National Standards of Healthcare Cleanliness 2021[64] and the standard for providing a clean and safe hospital environment.[65] An initial physical cleaning step, using detergent and warm water, is followed in high-risk areas by wiping over the same areas with a disinfectant, either using disposable wipes or a freshly prepared solution of a chlorinated disinfectant.

The standard achieved by manual cleaning can be assessed by a rapid test for adenosine triphosphate (ATP), which is present in all organic material but not a direct measure of bacterial, viral or sporal loading on a surface. Presence of ATP can be linked to improvements in training in cleaning processes and improving the cleanliness of surfaces.

Automated decontamination systems, whether chemical or ultraviolet light-based, are likely to work less effectively if surfaces are visibly dirty.[61, 63] This is because, in the case of chemical fumigants, organic residues will react with micro-condensed disinfectant on material surfaces and might neutralize it, reducing its activity before it can impact on contaminating microorganisms. Physical soiling can shield microorganisms exposed to ultraviolet light, masking the contaminants from full exposure to the treatment and again reducing the beneficial impact. Treated surfaces should first be cleaned to maximize the enhanced hygiene offered by automated decontamination.[63]

### Good practice point

Manual cleaning should be completed to the same high standard regardless of the subsequent use of automated cleaning devices.

### 8.3.2 Is there a potential risk of bacterial resistance to the decontamination method?

Fumigant automated decontamination systems may deliver: a true gas such as ozone or chlorine dioxide; heat-generated vapour (for example, hydrogen peroxide or formaldehyde) or cold-generated fogs or dry mists from aqueous liquid disinfectants such as hydrogen peroxide, quaternary ammonium compounds and peracetic acid.[66-69] The delivery system should ensure that the disinfectant chemicals reach the targeted area, with active agents typically designed to give a powerful oxidizing effect on pathogenic microorganisms. This effect damages microbial cell structures, including cell membranes and internal cellular components such as nucleic acids. The levels of chemical delivery are high and even spores are not immune to most oxidizing treatments. Some protection might be conferred where microorganisms are associated with high levels of organic soiling (for example, faeces or blood), but this should not occur if physical cleaning of surfaces has been undertaken. Penetration of any liquid contaminant is challenging for most fumigation systems. In addition, complex room structures/furnishings and tubular (hollow) objects limit fumigant ingress and result in reduced effectiveness.

Ultraviolet-based systems rely on energy delivery to surfaces, rather than chemical action, to disrupt target cells that lie within the line of sight of the treatment unit(s).[61] All ultraviolet-based biocidal treatments are therefore limited by the amount of shadowing of surfaces intended for treatment. The evidence for successfully treating surfaces not in line of sight or for using methods of ultraviolet reflection under or around static objects remains mixed. As with fumigation delivery, any organic co-contaminants that confer physical protection to the microorganisms will shield them from ultraviolet exposure, thus reducing the effectiveness of the treatment. The positioning of the emitters accounts for most differences in bactericidal efficacy between systems.[55] Physical cleaning therefore remains an important prerequisite to environmental decontamination involving ultraviolet-light treatment delivery.

### 8.3.3 What are the health and safety considerations of using automated room decontamination devices?

Automated room decontamination devices comprise fumigation systems and devices used to deliver biocidal ultraviolet light (UV-C and PX-UV). Most published research focuses on treatment efficacy, rather than safety. However, there are health and safety issues that require consideration prior to deploying the equipment.

The chemicals delivered by fumigation systems are harmful if exposure occurs during use. Products may be based on hydrogen peroxide, ozone or chlorine dioxide. Hydrogen peroxide can be present as the only active substance or in combination with other components such as silver or peracetic acid. Systems delivering this chemical may achieve hydrogen peroxide concentrations of several hundred parts per million (ppm) in air, whereas the workplace exposure limit (WEL) for this chemical in the UK is just 1 ppm for long-term exposure and 2 ppm for short-term exposure.[70, 71] Similarly, other widely used fumigants, such as ozone, have a low WEL (ozone = 0.2 ppm). The potential for harmful chemical exposure is, therefore, clear and should be controlled. The whole process should be risk assessed, with procedures in place to ensure the room is sealed to retain the fumigant, preventing room entry during treatment, monitoring for fumigant leaks during and after treatment, and effective fumigant removal and room aeration to complete the process. There is no justification for unnecessarily exposing staff or patients to harmful chemicals during fumigation treatments.

The availability of the correct gas monitoring equipment is crucial to ensuring appropriate measurements can be made during or after the treatment process.[72] These items typically cost a fraction of the price of the fumigation equipment and their use is central to safe working with any fumigant.[70]

As with other forms of high-intensity light, biocidal ultraviolet light is potentially harmful and can damage the eyes and skin if they are exposed.[73, 74] Ultraviolet-light carousels vary in terms of their energy delivery, but all are designed to cause cellular damage to microorganisms and should, therefore, be used with control measures in place to prevent human exposure. As with fumigation systems, it is important to avoid entry of the area during treatment. Modern carousels may be fitted with motion sensors that immediately turn off the system if any motion is detected in the room. In addition, ultraviolet light does not usually penetrate double-glazed windows, although any assumption that glass is protecting an observer outside the room should be checked with a light meter capable of measuring ultraviolet emissions between 100 and 280 nm. There have been anecdotal reports of some ultraviolet-light systems generating localized ozone around high-energy lamps, but this effect would need to be investigated if suspected. Ozone could, if present even at low residual levels after treatment, potentially cause respiratory irritation for those exposed.

### Good practice point

On first use of a fumigant or ultraviolet light in a specific room design, efficacy of sealing should be monitored to ensure safety.

### 8.3.4 How easy is the equipment to use, what standard of education are users expected to have, and what training and training materials are supplied?

The operation of earlier systems could be complex and sometimes required open handling of potentially harmful chemicals. However, in modern machine designs, disinfectants are often supplied in sealed or smart cartridges or decanting of chemicals is minimized with use of protective gloves and eye protection.[75]

The operational interfaces on both fumigation and ultraviolet-light systems may range between ‘on-off’ switch activation with a timer delay to allow staff to safely leave the room, to more complex touchscreen interfaces with multiple programmes. Regardless of the method, all systems should be provided with effective training from the supplier.

### 8.3.5 What indicators should trigger use of an automated device?

IPC teams in collaboration with domestic services will determine the appropriate use of hydrogen peroxide and ultraviolet light systems in addition to standard manual cleaning. The indication to use hydrogen peroxide, ultraviolet light or other systems in addition to manual cleaning will depend on the terms of the contract agreed with the suppliers, cost and availability of staff, as well as a risk assessment of the pathogenicity of the organisms that caused infection in the last occupant of the room. Prevalence of, or outbreaks due to, certain pathogens may be deemed higher priority for additional room disinfection by local IPC teams. Automated devices are not usually practicable in shared bays, unless the area is free of patients and staff and can be sealed. Where available, hydrogen peroxide cleaning may be used following discharge of patients with *C. difficile*, Norovirus, multi-resistant organisms, such as Acinetobacter, carbapenem-resistant Enterobacteriaceae and tuberculosis, and viral haemorrhagic fever.[33, 51] Turnaround times are usually between 3 and 4 hours depending on local circumstances. An ultraviolet-light cleaning system may be used following occupation by a patient with Norovirus or Rotavirus, COVID-19, MRSA, *Streptococcus* group A, extended-spectrum beta lactamase producers, VRE and during outbreaks of infection not successfully managed by increased manual cleaning (or any of the above if hydrogen peroxide is not available).[8, 9, 55] Turnaround times are shorter (1.5 to 2 hours) but depend on local circumstances. In the absence of either fumigant or ultraviolet-light systems, a second manual clean can reduce environmental contamination and transient flora acquired on the hands of staff to a similar degree.[76]

### Good practice point

Prioritize different cleaning systems to the type of infection of the most recent room occupant by use of a red/amber/green rating based on local nosocomial infection rates.

### 8.3.6 What are the requirements in terms of engineer audit and user audit?

Prior to any work commencing, it is important to audit the information provided with the device, which should include the engineering and calibration protocols/results that the generator has undergone, with any corrective measures.

Validation data should be generated to demonstrate that an effective cycle can be completed in each enclosure prior to the generator’s use for decontamination. Biological indicators should be positioned around the enclosure and an effective fumigation process determined by the inactivation of the indicators. For validation purposes, the enclosure should be set up to replicate actual use, allowing optimization of cycle conditions before use in the target area. The room design and set up should be as similar as possible to that intended for use, or a room in the target area temporarily set aside for the test. Usually a 3–5 log reduction in bacterial numbers is required in the healthcare environment.[63] As the devices provide disinfection not sterilization, survival of some microorganisms may be acceptable, provided any residual levels can be tolerated.

Data generated from the automated decontamination device can be used to document an effective cycle, preferably every time, together with surface cultures (before and after) or biological indicators if available (see Section 8.4.5).[54, 55, 77] Some devices will provide a printout of the different parameters used during a cycle as a record to form part of audit to ensure that the decontamination process is effective and repeatable. Other devices will provide real-time feedback on a display screen that can be checked against records to ensure the correct parameters have been achieved. For devices that need to be inside the enclosure and do not have a visible display during operation then it is important to ensure there is a method of accurately determining that a cycle has been completed successfully, for example, a download from the device to a computer to check that the cycle has been completed. All cycle-monitoring data should be adequately organized (by reporting date, location, cycle type, etc) to allow processes to be audited. Some providers have maintenance audit and calibration checks within their contract with the client. Fumigant chemicals should be used within date and some smart systems may not accept out of date cartridges.

### 8.3.7 Can extra equipment be placed in the room during decontamination?

Any future standard fumigation or ultraviolet-light test is likely to avoid the placement of additional equipment or furnishings in the treated area, other than the fumigation machine and test coupons. In practice other items such as furniture will be present and other equipment needing decontamination may be placed in the room.[78] The number of items should be controlled to a reasonable level following the supplier's advice. However, some items are difficult to disinfect because of their shape, for example, convoluted or tubular, or if too many items are moved into the room, then the surface area to treat may exceed the dose of fumigant supplied or in the case of UV-C result in excessive shadowing. For fumigant systems, porous materials will absorb the active agent and off-gas (see Section 8.3.8).

### 8.3.8 How does effectiveness of decontamination compare for hard and soft surfaces?

During automated chemical disinfection processes porous materials should be removed from rooms for reasons related to effectiveness and safety. If common porous materials such as textiles, foams and cardboard are left in a room they can absorb fumigant chemicals during treatment. These are released slowly afterwards, a process known as off-gassing. This phenomenon might influence fumigant performance on surfaces, with overall effectiveness becoming less certain than if all surfaces are non-porous. If all surfaces in a room are smooth and impervious, then this problem will be avoided because fumigant levels in the treated area will be more predictable.[66] Seemingly protected items such as foam-filled mattresses with waterproof covers might still absorb chemical fumigant via zip closure.[79] Foam-filled items are best removed from the room and treated separately with wet surface disinfectant.

Even when a fumigation system has a chemical removal step this might not remove all fumigant from porous materials. These can continue to off-gas chemicals beyond treatment completion and chemical levels might rise above WELs. For this reason, it is recommended that a portable sensor is used to check fumigant levels at the point of room re-entry, even when such levels are expected to be safe. In some situations, small ‘pockets’ of the fumigant can remain (for example, under solid surfaces, where aeration might not fully take place).

In contrast to fumigant chemicals, ultraviolet light does not penetrate porous surfaces such as sheets, upholstery and curtains. In addition, any shadowing effect caused by a material’s porosity, shape and softness is likely to inhibit the exposure of contaminants to the full ultraviolet dose.[80, 81] This will in turn cause uncertainty in machine performance and would require site-specific validation to confirm that required microbiological kill is being achieved. There is no reason why softer or more porous materials cannot be left in a room being treated with ultraviolet light, but the success of the treatment would be dependent on the amount of light energy hitting exposed surfaces; harder, more even surfaces are always easier to treat with light-based technology.

### Good practice point

Remove foam materials from the room if fumigant is used unless sealed under an impervious cover.

### 8.3.9 How many times can the device be used in a room?

There is no imposed or recognized limit on how many times a device can be used in a particular room or treatment space. Multiple treatments would be expected, depending on the nature of the room’s use. The room and its resident equipment should be able to tolerate the intended treatment, preferably be free from porous or absorbent materials, and any ‘leaky’ areas of the room should be sealed if fumigant chemicals are to be used. Losses could not only reduce the effectiveness of the treatment but might also allow the seepage of fumigant into sensitive areas outside the intended treatment location. Such considerations should be built into an appropriate risk assessment for the treatment of any room, healthcare or otherwise.

There are reports of certain types of fumigant chemicals damaging surfaces after only small numbers of treatments and the powerful oxidizing effect of the chemicals is the most likely cause.[82] HPV and chlorine dioxide gas have been particularly implicated because of their corrosive properties, especially when unwanted condensate pools on surfaces or inside sensitive equipment.[83-85] Consideration should also be given to seals around doors, utilities such as pipes and cables passing through walls etc, where sealant or bespoke seals around these items will be required to contain fumigant chemicals. Such seals may deteriorate over multiple treatments, requiring examination and testing to ensure that no leaks have appeared in the fabric of the room. For non-specialized areas that are treated repeatedly, the risk is greater than in laboratories where the fabric of the room has been designed to tolerate such treatments.

Similar principles can be applied to ultraviolet-light treatments, in that multiple treatments can be delivered if required, but it should be confirmed that materials in a room can tolerate the energy delivery over time. Ultraviolet light would not be expected to have major cumulative effects on room infrastructure and integrity (wall and ceiling materials, seals around doors, windows etc), although some polymers (including some plastics) might be affected after prolonged exposure.

### 8.3.10 Does decontamination degrade room equipment?

There have been reports of equipment and surfaces being damaged by repeated automated disinfection treatments. Electronic equipment, stainless steel, powder-coated paint, anodized metals and enamelled surfaces have reportedly suffered damage. Metal corrosion, surface tarnishing, material colour ‘bleaching’ and enamel loss have all been described, with hydrogen peroxide and chlorine dioxide treatments implicated most commonly.

These effects have been an end-user concern since fumigation treatments became more commercially focused in the 1990s, and system suppliers have sought to demonstrate safety and reproducibility, publishing a number of articles to support their use with sensitive materials.[84] The potential for bias in such articles should, however, be considered, especially in terms of funding from or association with device manufacturers. Most chemical fumigation systems operate at relative humidity levels in excess of 65%, and this level of moisture alone might be incompatible with some types of complex electrical equipment.[86] Where high humidity meets cold surfaces, such as external walls and windows in a treated room, condensation can pool in a form that contains the concentrated active chemical.[66] This might in turn cause damage to paint work and some metals, particularly after repeated treatments.[87]

For biocidal ultraviolet light, the rate and extent of any material degradation is also likely to relate to the levels of ultraviolet energy delivered, usually measured in Joules (J) or mJ/cm2 of surface treated. Prolonged exposure has been associated with damage in endoscope storage facilities.[88]

The compatibility of any surface materials or equipment should be discussed with the equipment suppliers prior to procurement or embarking on room treatments.

### 8.3.11 Are there any limitations on use of the active agent on some materials (including compatibility with equipment used in intensive care units)?

In areas where microelectronic circuitry is present, such as critical care equipment, there is potential for damage to metals and delicate circuit boards by the fumigant.[84, 86] Proving that this will not occur requires validation and prior testing on similar equipment and may not be feasible. The integrity of plastic and rubber used in seals on or within equipment might be susceptible to degradation because of chemical exposure. If there is any doubt about the impact of fumigant chemicals on sensitive and important equipment, the automated device supplier should be consulted before any treatment is undertaken.

High-intensity ultraviolet light is less likely to damage internal electronic componentry but might affect surface finishes such as whitened PVC.[88, 89] The flexibility of some softer materials such as sealants might also be affected, resulting in shrinkage and cracking. The extent of this damage will depend on the material composition, the intensity of ultraviolet energy delivery and the frequency of treatments. If there is any doubt, the automated device supplier should be consulted before any treatment is undertaken.

### Good practice point

After purchasing an ultraviolet-light decontamination system, consider the impact on surface finishes such as whitened PVC before purchasing other equipment, and ask the equipment supplier to confirm compatibility.

### 8.3.12 Do damaged surfaces need to be sealed before use of the device?

Normally impervious surfaces that already show signs of cracks, fissures and flaking may be further damaged by fumigation. Surface imperfections can allow colonization by microorganisms that avoid exposure to the active agent. Removal of damaged items from the area to be treated is advisable. Trying to seal off surfaces with plastic or tape will trap fumigant or the contamination.

For ultraviolet-light treatment, sealing of surfaces is not necessary and the problem relates more to the ability of light energy to penetrate a breach or depression in an otherwise smooth surface. Unevenness due to pitting and flaking is likely to cause small shadowing effects, which means that full ultraviolet energy delivery to the damaged region cannot be assumed.

### 8.3.13 Can a device be used in rooms with positive or negative pressure ventilation?

Under normal circumstances a ventilation system that maintains a positive or negative air pressure in a clinical workspace would be switched off during fumigation treatment. Most ventilation control is based on total air loss, that is, feeding air in and out of the room space at a pre-set flow rate to refresh and mix the air and achieve the required air flow and pressure conditions. The movement of air can rapidly dilute fumigant in the room and would reduce treatment effectiveness. In addition, a room maintained at positive pressure would be at higher risk of leaking toxic fumigant chemicals. Keeping the ventilation running and simply blocking off the vents could adversely affect air pressurization in other critical areas such as isolation rooms.[90, 91] For these reasons, and to control the fumigation process, the room ventilation should be turned off during these procedures, unless a room air recirculation function is available.

For ultraviolet-light systems any air flow or air pressure changes should not undermine the performance of the light-based treatment, although if expected air pressure changes are well above or below ambient then it would be prudent to check with the equipment supplier to ensure no damage to the system electronics is likely.

### 8.3.14 What measurements are required when calculating the dose of active chemical for the room size? Is this carried out by the supplier/manufacturer or can the machine be programmed by the user?

Many modern automated fumigation systems have a user-control panel (touchscreen) or remote PC/tablet operation that allows the machine to be programmed with the required treatment conditions. The machine control software might already be pre-programmed with a variety of cycle conditions. Although different manufacturers take different approaches to machine set up, the volume of the room to be treated is often the basis for calculating fumigant chemical delivery, with the machine automatically calculating the required dosage once these dimensions have been entered into the software. For some simpler and less expensive machines, where software programming might be absent, an ‘on-off’ approach is often used, with a set volume of liquid disinfectant added to the machine prior to treatment. The amount of disinfectant would typically be informed by the supplier, a user manual or both. In the event of a purely gaseous product being used, such as ozone generated from ambient air, there is no requirement for liquid disinfectant calculations and the duration of delivery is again likely to be calculated from treated area volume. Before using any fumigation system, detailed advice should be sought from the supplier regarding the set up and use of the system. This is likely to vary between different rooms and particularly if room geometry varies. The cycle should be validated when used for the first time using representative microorganisms if possible.

The amount of energy delivered by different ultraviolet-light devices is likely to vary and will be dependent on the energy output from ultraviolet-light units, the number of units present on the device, the number of devices used to treat a room and the distance of the ultraviolet-light emission system from the target surface. Detailed advice should be sought from the suppliers regarding the positioning and duration of use for these systems, which is likely to vary from room to room.

### 8.3.15 What is the cycle time?

The term ‘cycle time’ is often used to describe the time required for an automated decontamination device to go from start to finish of its treatment, at the point where staff and patients can safely re-enter the treated area.

For chemical systems this normally includes clearing and sealing of the room, followed by placement of the system in an agreed position and:

* a room air conditioning step – where the room air might be treated in some way before delivery of the disinfectant (for example, reduction of humidity); this step is often absent for smaller devices
* the fumigant delivery step – where the fumigant is sprayed or pumped into the room; some systems will inject until a set point is reached others will inject a certain volume of the fumigant
* the dwell or exposure time – where the fumigant chemical remains in the air, or is deposited onto surfaces, often mixed by the delivery system fan or some other means; some advanced systems will constantly ‘top up’ the fumigant levels during this period, to maximise treatment effectiveness
* the removal or aeration step – this might be an active chemical removal phase completed by the same machine that delivers the chemical or it might involve mechanical ventilation being reactivated to dilute and remove the chemical and promote its breakdown; indeed it might involve a suitably protected operator entering the treated area and opening external windows to facilitate natural aeration of the room (this option requires the use of appropriate personal protective equipment, namely respirator, skin and eye protection and should be avoided if possible or used only as a last resort or emergency procedure).

Cycle times might vary from ~ 1 hour to several hours, or even overnight, depending on the circumstances and the type of chemical in use. The aeration period may need to be extended due to incomplete removal of the fumigant from the room by the automated device in the time allowed, therefore it is necessary to monitor the level prior to entry with a calibrated handheld monitor.

For ultraviolet-light systems the cycle steps are far simpler and generally shorter. There are normally no chemical residues generated and so no requirement for a ‘removal’ step. Typical treatment steps would be:

* placement of the ultraviolet-light unit(s) in the room and covering of windows/closure of doors to prevent any risk of human exposure for those outside the treated area
* safe activation of the system once the room is clear of staff and patients; this is normally achieved using a timer delay of 1 minute or more, to allow machine activation and then time for room clearing
* the delivery step – this typically lasts 15–30 minutes, but might involve stopping the system thereafter, relocating it and then repeating the treatment, to make sure all areas receive equal coverage
* room re-entry once the treatment is complete, removal of machines and re-occupation; most modern ultraviolet-light systems have motion sensors attached as a safety feature, such that the machine will shut down if any movement is detected in the room during treatment.

### 8.3.16 For a single-occupancy patient room of typical size what is the time requirement for the process from completing manual cleaning/disinfection to being able to enter the room to set up for the next patient?

Following physical cleaning of a room, the duration of the fumigation process might vary considerably between systems and is influenced by the type of room.[66, 67] To complete the full cycle time 3–4 hours may need to pass before a small side room of 40 m3 can be safely re-entered[90] (see Section 8.3.19). Consideration should be given to the use of a gas detector to ensure safe levels of fumigation are met before re-occupation; alternatively detailed calculations should be made with periodic testing to determine the time requirement. A longer period would be required for a large room or if the fumigant were difficult to clear (for example, due to unusual room geometry or because insufficient room aeration is available to clear the fumigant).

### Good practice point

Before purchasing or renting a system run a mock decontamination cycle in a hospital room to determine turnaround times.

### 8.3.17 What is required to prepare a patient room or other clinical area for treatment?

For fumigation, where non-sealable treatment and clinical work areas are being fumigated, the following should be implemented:

* physical cleaning to remove dust and biological fluids
* removal of any porous materials, such as textiles, cardboard or paper; it is advisable to remove foam mattresses, even if they have waterproof covers, as some fumigants are extremely penetrative and might come out of the foam later; otherwise ensure there are no cracks in the covering and any zips are fully closed, leaving the mattress on its side to allow access to contaminated surfaces
* mechanical ventilation to the treated area should be switched off or at least vents covered
* ventilation inlet and exhaust vents should be occluded to prevent fumigant loss into ductwork; if poorly sealed there can be unsafe leakage to areas beyond the room to be treated and reduced fumigant levels within the room
* if a room has a false ceiling then care should be taken to ensure that fumigant is not trapped above it and that the fumigant cannot leak into upper floors via ceiling spaces; advice should be taken from equipment suppliers or other decontamination specialists to avoid risk of human exposure due to false ceilings
* the room should be sealed as far as possible around door gaps and windows; gas-impermeable tape should be used and normally obtained from the equipment supplier; waterproof duct tape is advisable for use but can leave residues on surfaces after removal; do not use gaffer tape
* a portable, accurate gas monitor should be available to the operator to check door seals periodically for leakage and to take corrective action if leakage is detected; the monitor can be used to assist safe room re-entry at the end of treatment
* the machine should be switched off from outside the room, either by remote control or by running the power lead outside the treated area; this gives the operator final control in the event of an emergency or unforeseen equipment failure.

For ultraviolet-light treatment of clinical areas the following should be implemented:

* any windows to the room should be covered to avoid exposure of those outside the room to ultraviolet light; this is strongly recommended even if the equipment supplier indicates that the high-energy ultraviolet light cannot travel through glass
* the ultraviolet-light unit(s) should be positioned away from heat-sensitive objects and where maximum light delivery can be achieved over contaminated surfaces
* the machine should be switched off from outside the room, either by remote control or by running the power lead outside the treated area; as above, this gives the operator final control
* anyone re-entering the room should wear approved ultraviolet-light protective spectacles and opaque hand protection to avoid the risk of accidental exposure to the high-energy light; these should be removed only after the system is confirmed as having been powered down.

### 8.3.18 Can the wavelength of ultraviolet light or concentration of chemical be measured during use?

Calibrated hand-held meters are available for both chemical and light emission measurement. For fumigation systems these are important for safety reasons during room re-entry, to check that the air is clear, but otherwise are normally used only for experimental purposes when measuring the specific level of fumigant might be important (usually read as ppm or mg/m3). Evidence for the success of any routine treatment is obtained either by placing bacterial indicators in the treated area to indicate biocidal kill, or by using before–after swab checks from treated surfaces if bacterial indicators cannot be used (for example, in hospital wards). However, levels of chemical fumigant or ultraviolet light are not a guarantee of overall treatment effectiveness. The ultimate indicator is the impact the treatment has on existing surface contaminants or on bacterial indicators placed strategically in the room.

Some automated decontamination systems provide real-time feedback regarding the concentration of fumigant chemicals in the room, but such measurements might not always be reliable because accuracy of electrochemical sensors can decline when exposed to high concentrations of chemicals.

Some light-based technologies record the amount of energy delivered per unit area of treated surface. Ultraviolet-light emissions are more usually measured using a portable ultraviolet light irradiance and exposure meter, which might be placed in a room during treatment to confirm energy delivered to different surfaces. Because ultraviolet-light systems are either on or off, and normally have a defined delivery period and no residual effects, light meters are not normally required for safe re-entry to the treated area.

### Good practice point

Monitor levels of fumigant or ultraviolet light at regular intervals during the contract to ensure efficacy.

### 8.3.19 When is it safe to go back into the room?

Automated room decontamination technologies are designed to kill microbial cell structures and as such the treatments are normally toxic or harmful to other life. For fumigation systems the chemicals used mostly have low WELs, some of less than 1 ppm,[71, 92] above which adverse health effects are likely to occur. Hydrogen peroxide, chlorine dioxide, ozone, quaternary ammonium compounds, peracetic acid and formaldehyde all fall into this harmful chemical classification and the silver added to some hydrogen peroxide products can have associated exposure risks, depending on its source. For oxidizing chemicals, the exposure effects can escalate from acute eye and throat irritation at levels just above the WEL, to major toxicity and permanent damage to the lungs and mucous membranes following exposure to high levels of fumigant. Any exposure should therefore be avoided.

Most of the above chemicals, with the exception of quaternary compounds, can be monitored using real-time calibrated hand-held monitors. The monitoring equipment should be used prior to fumigated room re-entry even if the equipment supplier states that the device can remove chemicals from treated areas at the end of cycles. This process is not always successful and is highly dependent on the size, design and contents of the area to be treated. Some service providers are prepared and equipped to re-enter rooms with full personal protective equipment, including respiratory protective equipment, to open external windows or to open air vents to aid aeration, but this is not recommended for other users.

For ultraviolet-light equipment, rooms should always be locked and re-entered only when light-emitting systems are switched off. Some systems have audible alarms or voice alerts when the cycle is completed and ideally these systems should be linked to motion sensors that are interlocked to the ultraviolet-light device and will switch it off if anyone enters the room.

### 8.3.20 Is a material safety data sheet available for the active agent?

Material safety data sheets (MSDSs) contain information for each of the chemical groups discussed in this report, although for quaternary ammonium compounds – a large group of related chemicals – the generic reference chemical is often benzalkonium chloride. An MSDS should always be provided by the automated decontamination device supplier and should be relevant to the chemicals that accompany their machine or should come from the disinfectant supplier if purchased separately. The MSDS contains all essential hazard and toxicity information about the active chemical and actions to be taken if exposure occurs; it thus provides important information that can be used to help prepare risk assessments for chemical handling. WEL information for most of the chemicals used is available from open, reliable sources such as the UK Health and Safety Executive (HSE) website.[92]

Equipment associated with ultraviolet-light emissions might also be accompanied by an MSDS or other technical information that describes the product and any known hazard. However, if the specific item does not contain hazardous substances or substances of very high concern as defined, for example, by European Community (EC) WELs, then an MSDS might not be legally required (under EC law).

### 8.3.21 Decision algorithm

A decision algorithm for procedures involving fumigation or ultraviolet light is presented in Figure 2. The advantages and disadvantages of different fumigants[1] should be used to guide the choice between them.

## 8.4 Microbiological testing

### 8.4.1 What is the effectiveness of the device against pathogens including spores?

Automated room decontamination devices are effective against a wide range of pathogens including spores, although differences exist between them (see Section 8.3.2). However, the chosen automated decontamination method should be tested within the area in which it is intended to be deployed, using a microbiological test challenge. Microbiological tests of detection of common pathogens can be used in practice as a measure but the use of log reductions in target microorganisms is more informative, providing a better indication of equipment efficacy against a defined level of challenge.

### 8.4.2 What considerations are important in terms of bacterial colony count, target log reduction and cleanliness threshold definition?

Automated room decontamination devices are designed to reduce the bioburden on surfaces (or in room air), but do not guarantee eradication of microorganisms.[91, 93] Within the UK healthcare setting the desired log reduction in target microorganisms – typically measured as colony forming units (CFUs) – is normally a 3–5 log reduction for British and European Standards disinfection tests.[55, 80] Further standards are due to be published shortly (see <https://standardsdevelopment.bsigroup.com/projects/2019-00332#/section>).

Because automated room decontamination devices are designed to be used alongside traditional (manual) cleaning/disinfection methods, the levels of microbiological environmental contamination present are unlikely to exceed 105 microorganisms on a given surface area.[94-97] Some overseas authorities require hospital disinfectants to achieve at least a 6 log reduction of certain vegetative bacteria *in vitro*. This is clearly higher than the concentration typically found on hospital surfaces but may provide further assurance that the disinfectant will be effective even under the more unpredictable conditions of the real world.[98] For this reason, commercial spore challenges of 106 *Geobacillus stearothermophilus* per coupon, or alternatively coupons seeded with *Bacillus atrophaeus*, continue to be used as a measure of fumigation success.[99] The bacterial endospores of *G. stearothermophilus*, while not directly reflecting some contaminating agents found, are used as biological indicators because they provide a consistent and well understood challenge for automated decontamination systems. They are easy to handle and process, and being in Tyvek pouches and growing at 60°C helps to limit any potential contamination during handling. Testing against spores of *C. difficile*, without vegetative organisms, is preferable but more complex and restricted to research.[100] Contaminating microorganisms are rarely seen in isolation and are usually associated with surface soiling. The physical soiling levels normally used for standard testing approaches might include the addition of milk powder or protein soilant such as bovine serum albumen (BSA). BSA would, for example, be typically added at high (0.3%) or low (0.03%) concentrations, depending on the test challenge requirement.

## Figure 2: Decision algorithm for automated room decontamination systems

1. ultraviolet light versus fumigation\*



\* IPC infection prevention and control; UV ultraviolet

1. ultraviolet-light decision algorithm\*



\* UV ultraviolet

1. fumigation decision algorithm



### 8.4.3 What considerations are important in terms of penetration of dry biofilm and environmental soil?

In the natural environment microorganisms rarely exist in the absence of associated organic residues. Within the healthcare setting these residues might take the form of environmental dust, urine or faecal material or blood. These associated organic materials can protect harmful microorganisms, inhibiting the access of disinfectant treatments.[68, 101] For ultraviolet-light treatments heavy soiling that has not been physically cleaned away might shadow underlying surfaces, again limiting the effect of the delivered treatment. Disinfection test methods require the addition of organic soil to make the test more realistic. The soil is usually added to test microorganisms in the form of animal protein (albumin) or milk residues, to simulate organic soil in the real-world healthcare setting. Once dried down with test microorganisms on the surface of test carriers these residues can present a dried ‘film’ that can be a difficult challenge for automated decontamination procedures.[55]

### 8.4.4 What are the essential requirements for a microbiological test to establish effectiveness in the clinical environment?

Laboratory tests might have been used to support the claims for microbiological efficacy made by the manufacturer, but the user should conduct verification tests in their clinical environment.

There are two options for testing. The first involves using a swab or sponge to sample defined areas such as mattress covers, tables and patient chairs within the clinical area where the system is to be used. Sampling should be before and after cleaning and after use of the automated decontamination device. This will give an indication of the efficacy of cleaning as well as the automated system.[97] A template could be used (for example, defined as an 5x5 cm2 area) so that the results can be quantified rather than just recording presence/absence. The swab or sponge is placed in a defined volume of recovery medium (containing an appropriate neutralizer if required), vigorously agitated and defined volumes plated onto a nutrient media (for total viable counts) or a selective media (if a specific organism is being investigated).

The second option requires test carriers (for example, stainless steel discs or other representative materials found in the area to be treated) to be inoculated with specific test bacteria or bacterial spores. The addition of 0.03% albumin will mimic low soiling and is described in EN standards for assessing the efficacy of chemical disinfectants.[55] The culture is allowed to dry before placing in defined locations within the area to be treated. After processing, the carriers plus a control that has not been exposed are recovered and placed into a defined volume of recovery media and colonies counted after incubation. As a simpler, qualitative approach carriers can be recovered directly into appropriate culture broth and incubated to record presence/absence, rather than using quantitative culture methods.

The advantages and disadvantages of each option are summarized in Table 2.

If the manufacturers of the automated decontamination device have previously validated the system with *G. stearothermophilus* or *B. atrophaeus* and claim efficacy against these spores then commercial spore strips are available for these tests.

### Good practice point

When adopting a new automated system or disinfecting a new room design, conduct microbiological culture tests (if permitted in the hospital) or take in-use environmental swab tests before and after disinfection to confirm efficacy.

## Table 2: Options for microbiological testing of effectiveness of automated decontamination systems in clinical settings

|  |  |  |  |
| --- | --- | --- | --- |
| **Option** | **Procedure** | **Advantages** | **Disadvantages** |
| 1 | Detection of naturally occurring contamination before and after the decontamination process | Relatively simple to carry out | The level of naturally occurring contamination detected might be unpredictable so difficult to express results as a log reduction |
| 2 | Using artificially contaminated carriers with defined numbers of specific microorganisms | Allows for a log reduction in test microorganisms to be assessed | Expertise on preparation of carriers might be required as these are not available commercially for all microorganisms |

### 8.4.5 How often should testing be performed?

It is advisable to perform testing in a variety of room sizes when the system is first commissioned or introduced, after any maintenance or servicing of the system and possibly, if used during an outbreak, to establish that the implicated microorganism is being eradicated. Any change to the internal structure of regularly treated areas might also justify repeat validation. If the surface area within a room increases, more fumigant chemical would then be needed to deposit the same concentration of disinfectant onto all surfaces.

### 8.4.6 What checks are required to show dissemination of antimicrobial agents used in automated room decontamination devices (such as those required to show all surfaces have been treated adequately)?

This section is mainly relevant for fumigation systems, where contact of the antimicrobial agent with all surfaces is essential to ensure effectiveness of the system. It is advisable to use a chemical indicator test strip specific to the antimicrobial agent as proof of process every time the system is used. Chemical indicator strips are available for agents such as hydrogen peroxide which could be placed in defined locations within the area to be treated. Most available chemical indicators involve a colour change when the fumigant is in contact with the strip. The colour change will initiate on contact and might not be concentration dependent but will indicate that the agent has been in contact with target surfaces. Alternatively, dosimeters are available for some agents and could be used to establish distribution to hard-to-reach surfaces and the dose of the antimicrobial agent. Some gaseous decontamination generators will monitor the enclosure for the presence of the chemical fumigant when air is returned to the generator.

For ultraviolet-light systems, the main risk is shadowing, particularly in a room with furniture or a complex design. Meters and data logs are incorporated into some machines. Disposable indicators using photoactive ink are more convenient than radiometers.[102] The manufacturer/supplier of the system should provide recommendations/advice on the most suitable method to use for their system.

# 9 Further research

The Working Party identified the following as priorities for future research.

* Randomized multicentre comparative trials to determine relative effectiveness of different automated systems in preventing nosocomial infection or acquisition, including *C. difficile*, MRSA and multidrug-resistant Gram-negative pathogens.
* A randomized multicentre study comparing use of automated systems following one cycle of manual cleaning with two cycles of standard manual cleaning and no automated cleaning.
* Automated systems that can be used in patient bays without risk of toxicity to patients or staff.
* Economic evaluation of automated systems in terms of acquisition/leasing, repair, staffing, turnaround and monitoring in different healthcare environments.
* Cleaning agents for manual cleaning that show temporary colour to demonstrate areas missed by cleaners.
* Effects of repeated exposure of plastics used in the healthcare environment to chemical or ultraviolet-light disinfection.
* Measurement of residual levels of fumigant in different environments and ventilation rates, particularly in the presence of foam mattresses.
* Development of disposable tests to demonstrate efficacy against *C. difficile* spores rather than surrogates.

# References

*[Names of microorganisms to be italicized in final version to align with source article titles]*

1. HSE. Fumigation: Health and safety guidance for employers and technicians carrying out fumigation operations, HSG251: Health and Safety Executive (HSE); 2015 [Available from: https://www.hse.gov.uk/pubns/priced/hsg251.pdf; accessed 8 November 2021].

2. NICE. Developing NICE guidelines: the manual: National Institute for Health and Care Excellence (NICE); 2014 [Available from: https://www.nice.org.uk/process/pmg20/; accessed 8 November 2021].

3. Marra AR, Schweizer ML, Edmond MB. No-touch disinfection methods to decrease multidrug-resistant organism infections: A systematic review and meta-analysis. Infection Control & Hospital Epidemiology. 2018;39(1):20-31.

4. Dong Z, Zhou N, Liu G, Zhao L. Role of pulsed-xenon ultraviolet light in reducing healthcare-associated infections: A systematic review and meta-analysis. Epidemiology & Infection. 2020;e165:1-10.

5. NICE. Developing NICE guidelines: the manual, Appendix K: Network meta-analysis reporting standards: National Institute for Health and Care Excellence (NICE); 2014 [Available from: https://www.nice.org.uk/process/pmg20/resources/developing-nice-guidelines-the-manual-appendices-2549710189/chapter/appendix-k-network-meta-analysis-reporting-standards; accessed 8 November 2021].

6. Dias S, Welton NJ, Sutton AJ, Ades AE. NICE DSU Technical Support Document 2: A Generalised Linear Modelling Framework for Pairwise and Network Meta-Analysis of Randomised Controlled Trials. 2011 [updated September 2016. Available from: http://nicedsu.org.uk/wp-content/uploads/2017/05/TSD2-General-meta-analysis-corrected-2Sep2016v2.pdf; accessed 8 November 2021].

7. Hutton B, Cameron C, Moher D, Salanti G, Chaimani A, Caldwell DM, et al. The PRISMA extension statement for reporting of systematic reviews incorporating network meta-analyses of health care interventions: Checklist and explanations. Annals of Internal Medicine. 2015;162(11):777-84.

8. Anderson DJ, Chen LF, Weber DJ, Moehring RW, Lewis SS, Triplett PF, et al. Enhanced terminal room disinfection and acquisition and infection caused by multidrug-resistant organisms and Clostridium difficile (the Benefits of Enhanced Terminal Room Disinfection study): a cluster-randomised, multicentre, crossover study. The Lancet. 2017;389(10071):805-14.

9. Anderson DJ, Moehring RW, Weber DJ, Lewis SS, Chen LF, Schwab JC, et al. Effectiveness of targeted enhanced terminal room disinfection on hospital-wide acquisition and infection with multidrug-resistant organisms and Clostridium difficile: a secondary analysis of a multicentre cluster randomised controlled trial with crossover design (BETR Disinfection). The Lancet Infectious Diseases. 2018;18(8):845-53.

10. Attia F, Whitener C, Mincemoyer S, Houck J, Julian K. The effect of pulsed xenon ultraviolet light disinfection on healthcare-associated Clostridioides difficile rates in a tertiary care hospital. American Journal of Infection Control. 2020;48(9):1116-8.

11. Boyce JM, Havill NL, Otter JA, McDonald LC, Adams NMT, Cooper T, et al. Impact of hydrogen peroxide vapor room decontamination on Clostridium difficile environmental contamination and transmission in a healthcare setting. Infection Control & Hospital Epidemiology. 2008;29(8):723-9.

12. Boyce JM, Guercia KA, Sullivan L, Havill NL, Fekieta R, Kozakiewicz J, et al. Prospective cluster controlled crossover trial to compare the impact of an improved hydrogen peroxide disinfectant and a quaternary ammonium-based disinfectant on surface contamination and health care outcomes. American Journal of Infection Control. 2017;45(9):1006-10.

13. Brite J, McMillen T, Robilotti E, Sun J, Chow HY, Stell F, et al. Effectiveness of ultraviolet disinfection in reducing hospital-acquired Clostridium difficile and vancomycin-resistant Enterococcus on a bone marrow transplant unit. Infection Control & Hospital Epidemiology. 2018;39(11):1301-6.

14. Catalanotti A, Abbe D, Simmons S, Stibich M. Influence of pulsed-xenon ultraviolet light-based environmental disinfection on surgical site infections. American Journal of Infection Control. 2016;44(6):e99-e101.

15. Doll ME, Zhao J, Kang L, Rittmann B, Alvarez M, Fleming M, et al. Chasing the rate: An interrupted time series analysis of interventions targeting reported hospital onset Clostridioides difficile , 2013–2018. Infection Control & Hospital Epidemiology. 2020;41(10):1142-7.

16. Green C, Pamplin JC, Chafin KN, Murray CK, Yun HC. Pulsed-xenon ultraviolet light disinfection in a burn unit: Impact on environmental bioburden, multidrug-resistant organism acquisition and healthcare associated infections. Burns. 2017;43(2):388-96.

17. Haas JP, Menz J, Dusza S, Montecalvo MA. Implementation and impact of ultraviolet environmental disinfection in an acute care setting. American Journal of Infection Control. 2014;42(6):586-90.

18. Hardy KJ, Gossain S, Henderson N, Drugan C, Oppenheim BA, Gao F, et al. Rapid recontamination with MRSA of the environment of an intensive care unit after decontamination with hydrogen peroxide vapour. Journal of Hospital Infection. 2007;66(4):360-8.

19. Horn K, Otter JA. Hydrogen peroxide vapor room disinfection and hand hygiene improvements reduce Clostridium difficile infection, methicillin-resistant Staphylococcus aureus, vancomycin-resistant enterococci, and extended-spectrum beta-lactamase. American Journal of Infection Control. 2015;43(12):1354-6.

20. Kitagawa H, Mori M, Kawano R, Hara T, Kashiyama S, Hayashi Y, et al. Combining pulsed xenon ultraviolet disinfection with terminal manual cleaning helps reduce the acquisition rate of methicillin-resistant Staphylococcus aureus. American Journal of Infection Control. 2021;49:1048-51.

21. Kovach CR, Taneli Y, Neiman T, Dyer EM, Arzaga AJA, Kelber ST. Evaluation of an ultraviolet room disinfection protocol to decrease nursing home microbial burden, infection and hospitalization rates. BMC Infectious Diseases. 2017;17(1):186.

22. Levin J, Riley LS, Parrish C, English D, Ahn S. The effect of portable pulsed xenon ultraviolet light after terminal cleaning on hospital-associated Clostridium difficile infection in a community hospital. American Journal of Infection Control. 2013;41(8):746-8.

23. Manian FA, Griesnauer S, Bryant A. Implementation of hospital-wide enhanced terminal cleaning of targeted patient rooms and its impact on endemic Clostridium difficile infection rates. American Journal of Infection Control. 2013;41(6):537-41.

24. McCord J, Prewitt M, Dyakova E, Mookerjee S, Otter JA. Reduction in Clostridium difficile infection associated with the introduction of hydrogen peroxide vapour automated room disinfection. Journal of Hospital Infection. 2016;94(2):185-7.

25. McMullen K, Guth RM, Wood H, Mueller C, Dunn G, Wade R, et al. Impact of no-touch ultraviolet light room disinfection systems on Clostridioides difficile infections. American Journal of Infection Control. 2020;49:646-8.

26. Miller R, Simmons S, Dale C, Stachowiak J, Stibich M. Utilization and impact of a pulsed-xenon ultraviolet room disinfection system and multidisciplinary care team on Clostridium difficile in a long-term acute care facility. American Journal of Infection Control. 2015;43(12):1350-3.

27. Mitchell BG, Digney W, Locket P, Dancer SJ. Controlling methicillin-resistant Staphylococcus aureus (MRSA) in a hospital and the role of hydrogen peroxide decontamination: An interrupted time series analysis. BMJ Open. 2014;4(4):e004522.

28. Morikane K, Suzuki S, Yoshioka J, Yakuwa J, Nakane M, Nemoto K. Clinical and microbiological effect of pulsed xenon ultraviolet disinfection to reduce multidrug-resistant organisms in the intensive care unit in a Japanese hospital: a before-after study. BMC Infectious Diseases. 2020;20(1):82.

29. Murphy P, Kang L, Fleming M, Atkinson C, Pryor R, Cooper K, et al. Effect of ultraviolet-C light disinfection at terminal patient discharge on hospital-acquired infections in bone marrow transplant and oncology units. American Journal of Infection Control. 2020;48(6):705-7.

30. Murrell LJ, Hamilton EK, Johnson HB, Spencer M. Influence of a visible-light continuous environmental disinfection system on microbial contamination and surgical site infections in an orthopedic operating room. American Journal of Infection Control. 2019;47(7):804-10.

31. Nagaraja A, Visintainer P, Haas JP, Menz J, Wormser GP, Montecalvo MA. Clostridium difficile infections before and during use of ultraviolet disinfection. American Journal of Infection Control. 2015;43(9):940-5.

32. Napolitano NA, Mahapatra T, Tang W. The effectiveness of UV-C radiation for facility-wide environmental disinfection to reduce health care-acquired infections. American Journal of Infection Control. 2015;43(12):1342-6.

33. Passaretti CL, Otter JA, Reich NG, Myers J, Shepard J, Ross T, et al. An evaluation of environmental decontamination with hydrogen peroxide vapor for reducing the risk of patient acquisition of multidrug-resistant organisms. Clinical infectious diseases : an official publication of the Infectious Diseases Society of America. 2013;56(1):27-35.

34. Pegues DA, Han J, Gilmar C, McDonnell B, Gaynes S. Impact of Ultraviolet Germicidal Irradiation for No-Touch Terminal Room Disinfection on Clostridium difficile Infection Incidence among Hematology-Oncology Patients. Infection Control & Hospital Epidemiology. 2017;38(1):39-44.

35. Raggi R, Archulet K, Haag CW, Tang W. Clinical, operational, and financial impact of an ultraviolet-C terminal disinfection intervention at a community hospital. American Journal of Infection Control. 2018;46(11):1224-9.

36. Rutala WA, Kanamori H, Gergen MF, Knelson LP, Sickbert-Bennett EE, Chen LF, et al. Enhanced disinfection leads to reduction of microbial contamination and a decrease in patient colonization and infection. Infection Control & Hospital Epidemiology. 2018;39(9):1118-21.

37. Sampathkumar P, Folkert C, Barth JE, Nation L, Benz M, Hesse A, et al. A trial of pulsed xenon ultraviolet disinfection to reduce Clostridioides difficile infection. American Journal of Infection Control. 2019;47(4):406-8.

38. Schaffzin JK, Wilhite AW, Li Z, Finney D, Ankrum AL, Moore R. Maximizing Efficiency in a High Occupancy Setting to Utilize Ultraviolet Disinfection for Isolation Rooms. American Journal of Infection Control. 2020.

39. Vianna PG, Dale CR, Simmons S, Stibich M, Licitra CM. Impact of pulsed xenon ultraviolet light on hospital-acquired infection rates in a community hospital. American Journal of Infection Control. 2016;44(3):299-303.

40. Barbut F, Menuet D, Verachten M, Girou E. Comparison of the efficacy of a hydrogen peroxide dry-mist disinfection system and sodium hypochlorite solution for eradication of clostridium difficile spores. Infection Control & Hospital Epidemiology. 2009;30(6):507-14.

41. Blazejewski C, Wallet F, Rouze A, Le Guern R, Ponthieux S, Salleron J, et al. Efficiency of hydrogen peroxide in improving disinfection of ICU rooms. Critical care (London, England). 2015;19:30.

42. French GL, Otter JA, Shannon KP, Adams NMT, Watling D, Parks MJ. Tackling contamination of the hospital environment by methicillin-resistant Staphylococcus aureus (MRSA): A comparison between conventional terminal cleaning and hydrogen peroxide vapour decontamination. Journal of Hospital Infection. 2004;57(1):31-7.

43. Ghantoji SS, Stibich M, Stachowiak J, Cantu S, Adachi JA, Raad II, et al. Non-inferiority of pulsed xenon UV light versus bleach for reducing environmental Clostridium difficile contamination on high-touch surfaces in Clostridium difficile infection isolation rooms. Journal of Medical Microbiology. 2015;64(2):191-4.

44. Jinadatha C, Quezada R, Huber TW, Williams JB, Zeber JE, Copeland LA. Evaluation of a pulsed-xenon ultraviolet room disinfection device for impact on contamination levels of methicillin-resistant Staphylococcus aureus. BMC Infectious Diseases. 2014;14(1):187.

45. Lerner AO, Abu-Hanna J, Carmeli Y, Schechner V. Environmental contamination by carbapenem-resistant Acinetobacter baumannii: The effects of room type and cleaning methods. Infection Control & Hospital Epidemiology. 2020;41(2):166-71.

46. Maclean M, MacGregor SJ, Anderson JG, Woolsey GA, Coia JE, Hamilton K, et al. Environmental decontamination of a hospital isolation room using high-intensity narrow-spectrum light. Journal of Hospital Infection. 2010;76(3):247-51.

47. Mosci D, Marmo GW, Sciolino L, Zaccaro C, Antonellini R, Accogli L, et al. Automatic environmental disinfection with hydrogen peroxide and silver ions versus manual environmental disinfection with sodium hypochlorite: a multicentre randomized before-and-after trial. Journal of Hospital Infection. 2017;97(2):175-9.

48. Sitzlar B, Deshpande A, Fertelli D, Kundrapu S, Sethi AK, Donskey CJ. An environmental disinfection odyssey: Evaluation of sequential interventions to improve disinfection of Clostridium difficile isolation rooms. Infection Control & Hospital Epidemiology. 2013;34(5 SPL):459-65.

49. Warren BG, Turner N, Smith B, Addison R, Marden S, Weber DJ, et al. Measuring the impact of continuous disinfection strategies on environmental burden in outpatient settings: A prospective randomized controlled trial. Open Forum Infectious Diseases. 2020;7(10).

50. Wong T, Woznow T, Petrie M, Murzello E, Muniak A, Kadora A, et al. Postdischarge decontamination of MRSA, VRE, and Clostridium difficile isolation rooms using 2 commercially available automated ultraviolet-C-emitting devices. American Journal of Infection Control. 2016;44(4):416-20.

51. Yui S, Ali S, Muzslay M, Jeanes A, Wilson APR. Identification of Clostridium difficile Reservoirs in the Patient Environment and Efficacy of Aerial Hydrogen Peroxide Decontamination. Infection Control & Hospital Epidemiology. 2017;38(12):1487-92.

52. Zeber JE, Pfeiffer C, Baddley JW, Cadena-Zuluaga J, Stock EM, Copeland LA, et al. Effect of pulsed xenon ultraviolet room disinfection devices on microbial counts for methicillin-resistant Staphylococcus aureus and aerobic bacterial colonies. American Journal of Infection Control. 2018;46(6):668-73.

53. Zeber JE, Coppin JD, Villamaria FC, Williams MD, Copeland LA, Chatterjee P, et al. Use of ultraviolet irradiation in addition to commonly used hospital disinfectants or cleaners further reduces the bioburden on high-touch surfaces. Open Forum Infectious Diseases. 2019;6(12):ofz529.

54. Ali S, Muzslay M, Bruce M, Jeanes A, Moore G, Wilson APR. Efficacy of two hydrogen peroxide vapour aerial decontamination systems for enhanced disinfection of meticillin-resistant Staphylococcus aureus, Klebsiella pneumoniae and Clostridium difficile in single isolation rooms. Journal of Hospital Infection. 2016;93(1):70-7.

55. Ali S, Yui S, Muzslay M, Wilson APR. Comparison of two whole-room ultraviolet irradiation systems for enhanced disinfection of contaminated hospital patient rooms. Journal of Hospital Infection. 2017;97(2):180-4.

56. Doan L, Forrest H, Fakis A, Craig J, Claxton L, Khare M. Clinical and cost effectiveness of eight disinfection methods for terminal disinfection of hospital isolation rooms contaminated with Clostridium difficile 027. Journal of Hospital Infection. 2012;82(2):114-21.

57. Havill NL, Moore BA, Boyce JM. Comparison of the microbiological efficacy of hydrogen peroxide vapor and ultraviolet light processes for room decontamination. Infection Control & Hospital Epidemiology. 2012;33(5):507-12.

58. Jelden KC, Gibbs SG, Smith PW, Hewlett AL, Iwen PC, Schmid KK, et al. Ultraviolet (UV)-reflective paint with ultraviolet germicidal irradiation (UVGI) improves decontamination of nosocomial bacteria on hospital room surfaces. Journal of Occupational and Environmental Hygiene. 2017;14(6):456-60.

59. Rutala WA, Gergen MF, Tande BM, Weber DJ. Rapid hospital room decontamination using ultraviolet (UV) light with a nanostructured UV-reflective wall coating. Infection Control & Hospital Epidemiology. 2013;34(5 SPL):527-9.

60. Rutala WA, Gergen MF, Tande BM, Weber DJ. Room decontamination using an ultraviolet-C device with short ultraviolet exposure time. Infection Control & Hospital Epidemiology. 2014;35(8):1070-2.

61. Weber DJ, Rutala WA, Anderson DJ, Chen LF, Sickbert-Bennett EE, Boyce JM. Effectiveness of ultraviolet devices and hydrogen peroxide systems for terminal room decontamination: Focus on clinical trials. American Journal of Infection Control. 2016;44(5 Supplement):e77-e84.

62. Dancer SJ, King M-F. Systematic review on use, cost and clinical efficacy of automated decontamination devices. Antimicrobial Resistance & Infection Control. 2021;10(1):34.

63. Dancer SJ. Controlling hospital-acquired infection: Focus on the role of the environment and new technologies for decontamination. Clinical Microbiology Reviews. 2014;27(4):665-90.

64. NHSE&NHSI. National Standards of Healthcare Cleanliness 2021: NHS England and NHS Improvement; 2021 [Available from: https://www.england.nhs.uk/wp-content/uploads/2021/04/B0271-national-standards-of-healthcare-cleanliness-2021.pdf; accessed 8 November 2021].

65. BSI. Specification for the planning, application, measurement and review of cleanliness services in hospitals, PAS 5748:2014. BSI Standards Limited; 2014.

66. Beswick AJ, Farrant J, Makison C, Gawn J, Frost G, Crook B, et al. Comparison of multiple systems for laboratory whole room fumigation. Applied Biosafety. 2011;16:139-57.

67. Otter JA, Mepham S, Athan B, Mack D, Smith R, Jacobs M, et al. Terminal decontamination of the Royal Free London's high-level isolation unit after a case of Ebola virus disease using hydrogen peroxide vapor. American Journal of Infection Control. 2016;44(2):233-5.

68. Pottage T, Richardson C, Parks S, Walker JT, Bennett AM. Evaluation of hydrogen peroxide gaseous disinfection systems to decontaminate viruses. Journal of Hospital Infection. 2010;74:55-61.

69. Pottage T, Macken S, Walker JT, Bennett AM. Meticillin-resistant Staphylococcus aureus is more resistant to vaporized hydrogen peroxide than commercial Geobacillus stearothermophilus biological indicators. Journal of Hospital Infection. 2012;80(1):41-5.

70. Ali S, Yui S, Muzslay M, Wilson APR. Response to letter of K. Singh, 'Role of silver nitrate in the efficacy of hydrogen peroxide aerial decontamination systems' regarding S. Ali et al. 'Efficacy of two hydrogen peroxide vapour aerial decontamination systems for enhanced disinfection of meticillin-resistant Staphylococcus aureus, Klebsiella pneumoniae and Clostridium difficile in single isolation rooms'. Journal of Hospital Infection. 2017;97(3):314-5.

71. PHE. Compendium of Chemical Hazards: Hydrogen Peroxide: Public Health England (PHE); 2018 [Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment\_data/file/732277/Hydrogen\_Peroxide\_PHE\_IM\_030818.pdf; accessed 8 November 2021].

72. Murdoch LE, Bailey L, Banham E, Watson F, Adams NMT, Chewins J. Evaluating different concentrations of hydrogen peroxide in an automated room disinfection system. Letters in Applied Microbiology. 2016;63(3):178-82.

73. Anderson DJ, Knelson LP, Lewis SS, Chen LF, Sexton DJ, Weber DJ, et al. Implementation Lessons Learned from the Benefits of Enhanced Terminal Room (BETR) Disinfection Study: Process and Perceptions of Enhanced Disinfection with Ultraviolet Disinfection Devices. Infection Control & Hospital Epidemiology. 2018;39(2):157-63.

74. Masse V, Hartley MJ, Edmond MB, Diekema DJ. Comparing and optimizing ultraviolet germicidal irradiation systems use for patient room terminal disinfection: an exploratory study using radiometry and commercial test cards. Antimicrobial Resistance & Infection Control. 2018;7:29.

75. HSE. Manual cleaning and disinfecting surfaces: Harm via skin or eye contact, SR4, COSHH essentials for service and retail: Health and Safety Executive (HSE); 2006 [Available from: http://coshh-tool.hse.gov.uk/assets/live/sr04.pdf, accessed 8 November 2021].

76. Wilson APR, Smyth D, Moore G, Singleton J, Jackson R, Gant V, et al. The impact of enhanced cleaning within the intensive care unit on contamination of the near-patient environment with hospital pathogens: A randomized crossover study in critical care units in two hospitals. Critical Care Medicine. 2011;39(4):651-8.

77. Beal A, Mahida N, Staniforth K, Vaughan N, Clarke M, Boswell T. First UK trial of Xenex PX-UV, an automated ultraviolet room decontamination device in a clinical haematology and bone marrow transplantation unit. Journal of Hospital Infection. 2016;93(2):164-8.

78. Andersen BM, Rasch M, Hochlin K, Jensen FH, Wismar P, Fredriksen JE. Decontamination of rooms, medical equipment and ambulances using an aerosol of hydrogen peroxide disinfectant. Journal of Hospital Infection. 2006;62(2):149-55.

79. Poppendieck D, Hubbard H, Corsi RL. Hydrogen Peroxide Vapor as an Indoor Disinfectant: Removal to Indoor Materials and Associated Emissions of Organic Compounds. Environmental Science & Technology Letters. 2021;8(4):320-5.

80. Nerandzic MM, Cadnum JL, Pultz MJ, Donskey CJ. Evaluation of an automated ultraviolet radiation device for decontamination of Clostridium difficile and other healthcare-associated pathogens in hospital rooms. BMC Infectious Diseases. 2010;10:197.

81. Nottingham M, Peterson G, Doern C, Doll M, Masroor N, Sanogo K, et al. Ultraviolet-C light as a means of disinfecting anesthesia workstations. American Journal of Infection Control. 2017;45(9):1011-3.

82. Kimura T, Yahata H, Uchiyama Y. Examination of Material Compatibilities with Ionized and Vaporized Hydrogen Peroxide Decontamination. Journal of the American Association for Laboratory Animal Science : JAALAS. 2020;59(6):703-11.

83. Derkits GE, Mandich ML, Reents WD, Franey JP, Xu C, Fleming D, et al., editors. Reliability of electronic equipment exposed to chlorine dioxide used for biological decontamination. 2010 IEEE International Reliability Physics Symposium; 2010 2-6 May 2010.

84. Girouard DJ, Czarneski MA. Room, Suite Scale, Class III Biological Safety Cabinet, and Sensitive Equipment Decontamination and Validation Using Gaseous Chlorine Dioxide. Applied Biosafety. 2016;21:34-44.

85. Hall L, Otter JA, Chewins J, Wengenack NL. Use of hydrogen peroxide vapor for deactivation of Mycobacterium tuberculosis in a biological safety cabinet and a room. Journal of Clinical Microbiology. 2007;45(3):810-5.

86. Krause J, McDonnell G, Riedesel H. Biodecontamination of animal rooms and heat-sensitive equipment with vaporized hydrogen peroxide. Contemporary topics in laboratory animal science / American Association for Laboratory Animal Science. 2001;40(6):18-21.

87. Pottage T, Lewis S, Lansley A, Fraser S, Hendon-Dunn C, Bacon J, et al. Hazard Group 3 agent decontamination using hydrogen peroxide vapour in a class III microbiological safety cabinet. Journal of Applied Microbiology. 2020;128(1):116-23.

88. Irving D, Lamprou DA, Maclean M, MacGregor SJ, Anderson JG, Grant MH. A comparison study of the degradative effects and safety implications of UVC and 405 nm germicidal light sources for endoscope storage. Polymer Degradation and Stability. 2016;133:249-54.

89. Kauffman R, Wolf J. Study of the degradation of typical HVAC materials, filters, and components irradiated by UVC energy – Part II: Polymers (RP-1509). ASHRAE Transactions. 2012;118:648-59.

90. Byrns G, Fuller TP. The risks and benefits of chemical fumigation in the health care environment. Journal of Occupational and Environmental Hygiene. 2011;8(2):104-12.

91. Doll M, Morgan DJ, Anderson D, Bearman G. Touchless Technologies for Decontamination in the Hospital: a Review of Hydrogen Peroxide and UV Devices. Current Infectious Disease Reports. 2015;17(9):44.

92. HSE. EH40/2005 Workplace exposure limits: Health and Safety Executive (HSE); 2020 [4th edition:[Available from: https://www.hse.gov.uk/pubns/priced/eh40.pdf; accessed 8 November 2021].

93. Rutala WA, Weber DJ. Disinfectants used for environmental disinfection and new room decontamination technology. American Journal of Infection Control. 2013;41(5 SUPPL.):S36-S41.

94. Davies A, Pottage T, Bennett A, Walker J. Gaseous and air decontamination technologies for Clostridium difficile in the healthcare environment. Journal of Hospital Infection. 2011;77(3):199-203.

95. Otter JA, Yezli S, Perl TM, Barbut F, French GL. The role of 'no-touch' automated room disinfection systems in infection prevention and control. Journal of Hospital Infection. 2013;83(1):1-13.

96. Rutala WA, Gergen MF, Weber DJ. Room decontamination with UV radiation. Infection Control & Hospital Epidemiology. 2010;31(10):1025-9.

97. Shapey S, Machin K, Levi K, Boswell TC. Activity of a dry mist hydrogen peroxide system against environmental Clostridium difficile contamination in elderly care wards. Journal of Hospital Infection. 2008;70(2):136-41.

98. Ali S, Yui S, Muzslay M, Wilson APR. Test parameters for efficacy evaluations of aerial hydrogen peroxide decontamination systems. Journal of Hospital Infection. 2018;98(4):438-9.

99. Otter JA, Yezli S. Are commercially available Geobacillus stearothermophilus biological indicators an appropriate standard for hydrogen peroxide vapour systems in hospitals? Journal of Hospital Infection. 2012;80:272-3.

100. Ali S, Muzslay M, Wilson P. A novel quantitative sampling technique for detection and monitoring of clostridium difficile contamination in the clinical environment. Journal of Clinical Microbiology. 2015;53(8):2570-4.

101. Otter JA, Yezli S, French GL. Impact of the suspending medium on susceptibility of meticillin-resistant Staphylococcus aureus to hydrogen peroxide vapour decontamination. Journal of Hospital Infection. 2012;82(3):213-5.

102. Tano E, Lindahl C, Lindblad M, Huss F. Ultraviolet-C decontamination of a hospital room: Amount of UV light needed. Burns. 2020;46(4):842-9.

103. Butts CT. network: a Package for Managing Relational Data in R. Journal of Statistical Software. 2008;24(2):https://www.jstatsoft.org/v24/i02/paper.

104. Butts CT. network: Classes for Relational Data: The Statnet Project (http://www.statnet.org/); 2015 [R package version 1.13.0.1]. Available from: https://CRAN.R-project.org/package=network; accessed 8 November 2021].

# Appendices

## Appendix A – Glossary

## Appendix B – Continuing professional development questions and answers

## Appendix C – Search strategies and results

## Appendix D – Study selection flow chart

## Appendix E – Excluded studies

## Appendix F – Included studies

## Appendix G – Methodological quality of studies reporting clinical outcomes

## Appendix H – Network meta-analysis for the clinical outcomes of infection or acquisition

## Appendix I – GRADE tables

## Appendix J – Consultation

# Appendix A – Glossary

Cycle time: time required for an automated decontamination device to go from start to finish of its treatment, at the point where staff and patients can safely re-enter the treated area.

Fumigation: process of gaseous sterilization used for killing micro-organisms in air and surfaces.

Fumigant: volatile chemical compound used as a disinfectant.

Hydrogen peroxide vapour (HPV): vapour form of hydrogen peroxide used to decontaminate enclosed and sealed areas; 30–35% hydrogen peroxide.

Aerosolized hydrogen peroxide (AHP): mist produced by nebulizing a solution containing a low concentration of hydrogen peroxide; 5–6% hydrogen peroxide.

Luminometer: sensitive instrument that measures visible light.

Network meta-analysis (NMA): statistical technique for combining results of studies involving different interventions or comparators.

Off-gas: giving off a chemical in the form of a gas.

Pulsed-xenon ultraviolet light (PX-UV): short pulses of ultraviolet and visible light emitted by xenon gas bulbs.

Ultraviolet C light (UV-C): one of three types of ultraviolet light.

Workplace exposure limit (WEL): recommended limit for any toxin or substance that might have adverse health effects.

# Appendix B – Continuing professional development questions and answers

### Questions

1. Which of the following statements are true?

1. Consider using an automated decontamination device instead of manual cleaning
2. Consider using an automated decontamination device as a supplement to manual cleaning
3. Consider using an automated decontamination device as a supplement to manual cleaning if there is a rising or high prevalence of nosocomial infection
4. Consider using an automated decontamination device only during an outbreak
5. Use standard manual cleaning only

2. Which of the following statements are true?

1. Using an ultraviolet-light or hydrogen peroxide system to supplement manual cleaning is generally more effective than using manual cleaning alone
2. Hydrogen peroxide vapour (30–35% hydrogen peroxide) is generally more effective than ultraviolet-light systems when used to supplement manual cleaning
3. Pulsed-xenon ultraviolet light is generally less effective than ultraviolet light C for targeting *Clostridioides difficile* and meticillin-resistant *Staphylococcus aureus*
4. Manual cleaning should be completed to the same high standard regardless of the subsequent use of automated decontamination devices
5. Repeated manual cleaning may be required in areas where automated decontamination devices cannot be used

3. Which of the following statements are true?

1. When an area to be treated can be sealed, choose between ultraviolet light or fumigation based on the dimensions of the area
2. When using an ultraviolet-light system, tailor the duration and dosage of irradiation to the complexity of the room design
3. Before using fumigation, ensure that covers are removed from foam materials
4. It is safe to initiate fumigation from inside the room to be treated
5. When first using ultraviolet light or fumigation in a specific room design, monitor the effectiveness of sealing throughout the treatment

4. Which of the following statements are true?

1. Prioritize different cleaning systems to the type of infection of the most recent room occupant using a red/amber/green rating based on local nosocomial infection rates
2. When using fumigation, refer to local microbiological tests and required operational requirements (such as machine settings) to deliver adequate dosage
3. When adopting a new automated system or disinfecting a new room design, conduct microbiological culture tests (if permitted in the hospital) or take in-use environmental swab tests before and after disinfection to confirm efficacy
4. When using ultraviolet light or fumigation, the room should ideally be locked, and motion sensors and interlocks should be used to switch the system off in the event of unauthorized entry
5. When using fumigation, signage warning against entry to the area being treated is not required

### Answers

1. Statement C is true; statements A, D and E are false; statement B does not capture the full sense of the Working Party’s recommendations

2. Statements A, B, D and E are true; statement C expresses the reverse of the relative effectiveness of pulsed-xenon ultraviolet light and ultraviolet light C for targeting *Clostridioides difficile* and meticillin-resistant *Staphylococcus aureus*

3. Statements B and E are true; statement A should reflect the choice between ultraviolet light and fumigation in an area that can be sealed airtight being based on the infection prevention and control team’s prioritization of pathogens; statement C is false because foam materials should be removed from the room before fumigation unless sealed in an impervious cover; statement D is false because the process of fumigation should be initiated from outside the area to be treated

4. Statements A, B, C and D are true; statement E is false because signage should be used to prevent inadvertent entry to the room being treated when using fumigation

# Appendix C – Search strategies and results

Any studies added to the databases after February 2021 (including those published before February 2021, but not yet indexed) were not considered for inclusion.

## Table C.1: Embase and MEDLINE search strategy

Database: Embase <1974 to 2021 February 15>, Ovid MEDLINE(R) ALL <1946 to February 15, 2021>

Search Strategy:

--------------------------------------------------------------------------------

1 decontamination/ or decontamination.mp. (30721)

2 disinfection system/ or disinfection/ (43096)

3 fumigation/ or fumigation.mp. (5512)

4 sterilisation.mp. (7105)

5 or/1-4 (82901)

6 ultraviolet.mp. or ultraviolet radiation/ (427135)

7 UV.mp. (361458)

8 UVC.mp. or ultraviolet C radiation/ (5703)

9 UV-C.mp. (3363)

10 ultraviolet irradiation/ or UVGI.mp. (15934)

11 xenon.mp. (26482)

12 xenex.mp. (17)

13 tru-d.mp. (25)

14 visible light.mp. (46504)

15 high-intensity narrow-spectrum.mp. (27)

16 HINS.mp. (139)

17 hydrogen peroxide.mp. or hydrogen peroxide/ (201863)

18 HPV.mp. (105527)

19 VHP.mp. (563)

20 HPM.mp. (1439)

21 steam.mp. (22210)

22 vapo$r.mp. or vapor/ (88256)

23 peracetic acid.mp. or peracetic acid/ (4221)

24 automated.mp. (337656)

25 non-manual.mp. (1582)

26 disinfection system/ or no-touch system.mp. (347)

27 automated dispersal system.mp. (0)

28 automated room decontamination device.mp. (5)

29 ARDD.mp. (30)

30 fumiga$ system.mp. (86)

31 or/6-30 (1390242)

32 candida.mp. or Candida/ (180775)

33 clostrid$ difficile.mp. (47863)

34 C diff$.mp. (22595)

35 CDI.mp. (18359)

36 methicillin-resistant Staphylococcus aureus.mp. or Staphylococcus aureus/ or methicillin resistant Staphylococcus aureus/ (265629)

37 meticillin-resistant Staphylococcus aureus.mp. (2392)

38 MRSA.mp. (61094)

39 vancomycin-resistant enterococcus.mp. or vancomycin resistant Enterococcus/ (9783)

40 VRE.mp. (8326)

41 Enterococcus/ or enterococci.mp. (41550)

42 Acinetobacter baumannii.mp. or Acinetobacter baumannii/ (28069)

43 A baumannii.mp. (11897)

44 Enterobacter/ or Enterobacter.mp. (51374)

45 E cloacae.mp. (3553)

46 Serratia/ or serratia.mp. (29078)

47 Gram-negative rods.mp. or Gram negative bacterium/ (57150)

48 norovirus.mp. or Norovirus/ (14225)

49 severe acute respiratory syndrome coronavirus 2.mp. (67633)

50 SARS-CoV-2.mp. (72767)

51 pathogen.mp. or infectious agent/ (424730)

52 bacteria.mp. or bacterium/ (1038076)

53 multi-drug resistant.mp. (17385)

54 MDR.mp. (57808)

55 spore.mp. or bacterial spore/ (64435)

56 Viruses/ (61889)

57 or/32-56 (2109216)

58 infection/ or infection.mp. (3702716)

59 bacterial colonization/ or colonisation.mp. (56788)

60 colony forming unit/ or bacterial count/ or colony count.mp. (169789)

61 cfu.mp. (106953)

62 or/58-61 (3925535)

63 healthcare.mp. (698474)

64 hospital.mp. or hospital/ (3628276)

65 nosocomial.mp. (76625)

66 patient/ or patient.mp. (8895919)

67 unit.mp. (1138592)

68 ward/ or ward.mp. (276488)

69 or/63-68 (11988816)

70 5 and 31 and 57 and 62 and 69 (1205)

## Table C.2: CINAHL search strategy

|  |  |  |
| --- | --- | --- |
| **Search terms** | **Search options** | **Actions** |
| ( Decontamination OR Disinfection OR Fumigation OR Sterilisation ) AND ( Ultraviolet OR UV OR UV-C OR UVC OR UVGI OR xenon OR Xenex OR TRU-D OR Visible OR light high-intensity narrow-spectrum OR HINS OR hydrogen peroxide OR HPV OR VHP OR HPM OR steam OR vapor OR peracetic acid OR automated OR non-manual OR no-touch system OR automated dispersal system OR Automated Room Decontamination Devices OR ARDD OR Fumigation system ) AND ( Candida OR Clostridium difficile OR C. difficile OR CDI OR methicillin-resistant Staphylococcus aureus OR Meticillin-Resistant Staphylococcus aureus OR MRSA OR Vancomycin-resistant enterococcus OR VRE OR enterococci OR Acinetobacter baumannii OR A. baumannii OR Enterobacter OR E. cloacae OR Norovirus OR Serratia OR gram-negative rods OR pathogen OR bacteriA OR bacterium OR multi-drug resistant OR MDR OR Spore OR virus OR SARS-CoV-2 OR COVID-19 ) AND ( Infection OR Colonisation OR Colony count OR Cfu OR contamination OR presence ) AND ( Healthcare OR Hospital OR Nosocomial OR Patient OR Unit OR ward ) | **Expanders** - Apply equivalent subjects**Search modes** - Boolean/Phrase | **View results** (294) |

# Appendix D – Study selection flow chart

## Figure D.1: Study selection flow chart



# Appendix E – Excluded studies

## Table E.1: Excluded studies

| **Citation** | **Reason for exclusion** |
| --- | --- |
| Abreu, A.C., et al., Current and emergent strategies for disinfection of hospital environments. Journal of Antimicrobial Chemotherapy, 2013. 68(12): p. 2718-2732. | Narrative review - references checked for relevant articles |
| AHC Media, Continuous Visible Lighting Disinfection May Offer Benefits. Hospital Employee Health, 2020. 39(3): p. N.PAG-N.PAG. | Editorial |
| Al Bshabshe, A., et al., A multimodality approach to decreasing ICU infections by hydrogen peroxide, silver cations, and compartmentalization. Journal of Infection and Public Health, 2020. 13(8): p. 1172-1175. | Automated decontamination applied as part of a bundle of infection prevention and control interventions |
| Alfandari, S., et al., Management and control of a carbapenem-resistant Acinetobacter baumannii outbreak in an intensive care unit. Medecine et Maladies Infectieuses, 2014. 44(5): p. 229-231. | Not a comparative clinical study |
| Ali, S., et al., Test parameters for efficacy evaluations of aerial hydrogen peroxide decontamination systems. Journal of Hospital Infection, 2018. 98(4): p. 438-439. | Commentary - references checked for relevant articles |
| Allen, O., et al., Microbiological evaluation of UV disinfection effectiveness in a specialist cystic fibrosis clinic. Journal of Cystic Fibrosis, 2019. 18(4): p. e37-e39. | Not a comparative clinical study |
| Allenby, M., G. Jones, and L. Jadkauskaite, UV-C decontamination reduces cystic fibrosis clinic room bacterial counts over existing infection control measures. Journal of Cystic Fibrosis, 2020. 19(Supplement 2): p. S102. | Conference abstract |
| Amaeze, N.J., et al., Influence of delivery system on the efficacy of low concentrations of hydrogen peroxide in the disinfection of common healthcare-associated infection pathogens. Journal of Hospital Infection, 2020. 106(1): p. 189-195. | Not clinical setting |
| Andersen, B.M., et al., Comparison of UV C light and chemicals for disinfection of surfaces in hospital isolation units. Infection Control & Hospital Epidemiology, 2006. 27(7): p. 729-734. | Not a comparative clinical study |
| Andersen, B.M., et al., Decontamination of rooms, medical equipment and ambulances using an aerosol of hydrogen peroxide disinfectant. Journal of Hospital Infection, 2006. 62(2): p. 149-155. | Not a comparative clinical study |
| Anderson, D.J., et al., Decontamination of targeted pathogens from patient rooms using an automated ultraviolet-C-emitting device. Infection Control & Hospital Epidemiology, 2013. 34(5 SPL): p. 466-471. | Not a comparative clinical study |
| Armellino, D., et al., Assessment of focused multivector ultraviolet disinfection with shadowless delivery using 5-point multisided sampling of patient care equipment without manual-chemical disinfection. American Journal of Infection Control, 2019. 47(4): p. 409-414. | Not a comparative clinical study |
| Armellino, D., et al., Comparative evaluation of operating room terminal cleaning by two methods: Focused multivector ultraviolet (FMUV) versus manual-chemical disinfection. American Journal of Infection Control, 2020. 48(2): p. 147-152. | Outcomes reported as total counts rather than counts for specific microoganisms |
| Bache, S.E., et al., Clinical studies of the High-Intensity Narrow-Spectrum light Environmental Decontamination System (HINS-light EDS), for continuous disinfection in the burn unit inpatient and outpatient settings. Burns, 2012. 38: p. 69-76. | Outcomes reported as total counts rather than counts for specific microoganisms |
| Bache, S.E., et al., Universal decontamination of hospital surfaces in an occupied inpatient room with a continuous 405 nm light source. Journal of Hospital Infection, 2018. 98(1): p. 67-73. | Not a comparative clinical study |
| Barbut, F., et al., Reducing the spread of Acinetobacter baumannii and methicillin-resistant Staphylococcus aureus on a burns unit through the intervention of an infection control bundle. Burns, 2013. 39(3): p. 395-403.A16 | Automated decontamination applied as part of a bundle of infection prevention and control interventions |
| Barbut, F., How to eradicate Clostridium difficile from the environment. Journal of Hospital Infection, 2015. 89(4): p. 287-295. | Narrative review - references checked for relevant articles |
| Bartels, M.D., et al., Environmental meticillin-resistant Staphylococcus aureus (MRSA) disinfection using dry-mist-generated hydrogen peroxide. Journal of Hospital Infection, 2008. 70(1): p. 35-41. | Not a comparative clinical study |
| Beal, A., et al., First UK trial of Xenex PX-UV, an automated ultraviolet room decontamination device in a clinical haematology and bone marrow transplantation unit. Journal of Hospital Infection, 2016. 93(2): p. 164-8. | Not a comparative clinical study |
| Bedell, K., A.H. Buchaklian, and S. Perlman, Efficacy of an automated multiple emitter whole-room Ultraviolet-C disinfection system against coronaviruses MHV and MERS-CoV. Infection Control & Hospital Epidemiology, 2016. 37(5): p. 598-599. | Not clinical setting |
| Best, E.L., et al., Effectiveness of deep cleaning followed by hydrogen peroxide decontamination during high Clostridium difficile infection incidence. Journal of Hospital Infection, 2014. 87(1): p. 25-33. | Not a comparative clinical study |
| Blazejewski, C., et al., New methods to clean ICU rooms. Infectious Disorders - Drug Targets, 2011. 11(4): p. 365-375. | Narrative review - references checked for relevant articles |
| Blazejewski, C., F. Wallet, and S. Nseir, What's new in room decontamination in the intensive care unit? Reanimation, 2014. 23(3): p. 256-262. | Narrative review - references checked for relevant articles |
| Boyce, J.M. and C.J. Donskey, Understanding ultraviolet light surface decontamination in hospital rooms: A primer. Infection Control & Hospital Epidemiology, 2019. 40(9): p. 1030-1035. | Narrative review - references checked for relevant articles |
| Boyce, J.M., N.L. Havill, and B.A. Moore, Terminal decontamination of patient rooms using an automated mobile UV light unit. Infection Control & Hospital Epidemiology, 2011. 32(8): p. 737-742. | Not a comparative clinical study |
| Boyce, J.M., New approaches to decontamination of rooms after patients are discharged. Infection Control & Hospital Epidemiology, 2009. 30(6): p. 515-517. | Commentary - references checked for relevant articles |
| Brons, J.A., R. White, and M.S. Rea, UV-A in the NICU: New Technology for an Old Challenge. Neonatology Today, 2020: p. 17-24. | Not a comparative clinical study |
| Browne, K., et al., Reduction of bacterial load with the addition of ultraviolet-C disinfection inside the hyperbaric chamber. Diving and hyperbaric medicine, 2020. 50(4): p. 332-337. | British Library On Demand unable to supply full text of article |
| Cabral, J. and A.G. Rodrigues, Blue light disinfection in hospital infection control: Advantages, drawbacks, and pitfalls. Antibiotics, 2019. 8(2): p. 58. | Narrative review - references checked for relevant articles |
| Cadnum, J.L., et al., A comparison of the efficacy of multiple ultraviolet light room decontamination devices in a radiology procedure room. Infection Control & Hospital Epidemiology, 2019. 40(2): p. 158-163. | Not a comparative clinical study |
| Cadnum, J.L., et al., Effectiveness of a hydrogen peroxide spray for decontamination of soft surfaces in hospitals. American Journal of Infection Control, 2015. 43(12): p. 1357-1359. | Not a comparative clinical study |
| Carling, P., et al., Mitigating Hospital-Onset Clostridioides difficile : Evaluation of a Standardized Environmental Hygiene Program in Eight Hospitals...Sixth Decennial International Conference on Healthcare-Associated Infections. Infection Control & Hospital Epidemiology, 2020. 41(S1): p. s43-s43. | Conference abstract |
| Casini, B., et al., Evaluation of an ultraviolet C (UVC) light-emitting device for disinfection of high touch surfaces in hospital critical areas. International Journal of Environmental Research and Public Health, 2019. 16(19): p. 3572. | Not a comparative clinical study |
| Chan, H.T., et al., Evaluation of the biological efficacy of hydrogen peroxide vapour decontamination in wards of an Australian hospital. Journal of Hospital Infection, 2011. 79(2): p. 125-128. | Not a comparative clinical study |
| Chen, L.H., et al., Evaluation of a pulsed xenon ultraviolet light device for reduction of pathogens with biofilm-forming ability and impact on environmental bioburden in clinical laboratories. Photodiagnosis and Photodynamic Therapy, 2020. 29: p. 101544. | Not a comparative clinical study |
| Chirca, I. and C.D. Salgado, What strategies are in place to control microbial burden in hospital environments and how could these change in the future? Future Microbiology, 2013. 8(9): p. 1051-1054. | Editorial - references checked for relevant articles |
| Chirca, I., The hospital environment and its microbial burden: Challenges and solutions. Future Microbiology, 2019. 14(12): p. 1007-1010. | Editorial - references checked for relevant articles |
| Chmielarczyk, A., et al., Control of an outbreak of Acinetobacter baumannii infections using vaporized hydrogen peroxide. Journal of Hospital Infection, 2012. 81(4): p. 239-245. | Automated decontamination applied as part of a bundle of infection prevention and control interventions |
| Cobb, T.C., Methicillin-resistant Staphylococcus aureus decontamination: Is ultraviolet radiation more effective than vapor-phase hydrogen peroxide? Reviews in Medical Microbiology, 2017. 28(2): p. 69-74. | Systematic review - references checked for relevant articles |
| Cobrado, L., et al., Effective Disinfection of a Burn Unit after Two Cases of Sepsis Caused by Multi-Drug-Resistant Acinetobacter baumannii. Surgical Infections, 2018. 19(5): p. 541-543. | Not a comparative clinical study |
| Cooper, J., et al., Efficacy of an automated ultraviolet C device in a shared hospital bathroom. American Journal of Infection Control, 2016. 44(12): p. 1692-1694. | Outcomes reported as total counts rather than counts for specific microoganisms |
| Cooper, T., et al., Impact of environmental decontamination using hydrogen peroxide vapour on the incidence of Clostridium difficile infection in one hospital Trust. Journal of Hospital Infection, 2011. 78(3): p. 238-240. | Automated decontamination applied as part of a bundle of infection prevention and control interventions |
| Cotoia, A., et al., Pathogenesis-Targeted Preventive Strategies for Multidrug Resistant Ventilator-Associated Pneumonia: A Narrative Review. Microorganisms, 2020. 8(6). | Narrative review - references checked for relevant articles |
| Crotty, M.P. and P.J. Jackson, Terminal room disinfection: how much BETR can it get? The Lancet, 2017. 389(10071): p. 765-766. | Commentary - references checked for relevant articles |
| Dancer, S.J. and M.-F. King, Systematic review on use, cost and clinical efficacy of automated decontamination devices. Antimicrobial Resistance & Infection Control, 2021. 10(1): p. 34. | Systematic review - references checked for relevant articles |
| Dancer, S.J., Controlling hospital-acquired infection: Focus on the role of the environment and new technologies for decontamination. Clinical Microbiology Reviews, 2014. 27(4): p. 665-690. | Narrative review - references checked for relevant articles |
| Davies, A., et al., Gaseous and air decontamination technologies for Clostridium difficile in the healthcare environment. Journal of Hospital Infection, 2011. 77(3): p. 199-203. | Narrative review - references checked for relevant articles |
| De Giglio, O., et al., Pilot study on the antibacterial activity of hydrogen peroxide and silver ions in the hospital environment. Annali di igiene : medicina preventiva e di comunita, 2014. 26(2): p. 181-185. | Not a comparative clinical study |
| Diamond, F., Ultraviolet Irradiation Boosts Cleansers' Effect, but Much Hinges on How Well EVS Teams Function. Infection Control Today, 2020. 24(2): p. 9-9. | Editorial - references checked for relevant articles |
| Dippenaar, R. and J. Smith, Impact of pulsed xenon ultraviolet disinfection on surface contamination in a hospital facility's expressed human milk feed preparation area. BMC Infectious Diseases, 2018. 18(1): p. 91. | Not a comparative clinical study |
| Doll, M., et al., Touchless Technologies for Decontamination in the Hospital: a Review of Hydrogen Peroxide and UV Devices. Current Infectious Disease Reports, 2015. 17(9): p. 44. | Systematic review - references checked for relevant articles |
| Dong, Z., et al., Role of pulsed-xenon ultraviolet light in reducing healthcare-associated infections: A systematic review and meta-analysis. Epidemiology & Infection, 2020. | Systematic review - references checked for relevant articles |
| El Haddad, L., et al., Evaluation of a pulsed xenon ultraviolet disinfection system to decrease bacterial contamination in operating rooms. BMC Infectious Diseases, 2017. 17(1): p. 672. | Not a comparative clinical study |
| Ethington, T., et al., Cleaning the air with ultraviolet germicidal irradiation lessened contact infections in a long-term acute care hospital. American Journal of Infection Control, 2018. 46(5): p. 482-486. | Focus is on decontamination of air (clinical outcomes do not distinguish between different microorganisms and environmental sampling is from the air) |
| Falagas, M.E., et al., Airborne hydrogen peroxide for disinfection of the hospital environment and infection control: A systematic review. Journal of Hospital Infection, 2011. 78(3): p. 171-177. | Systematic review - references checked for relevant articles |
| Frakking, F.N.J., et al., Recommendations for the successful control of a large outbreak of vancomycin-resistant Enterococcus faecium in a non-endemic hospital setting. Journal of Hospital Infection, 2018. 100(4): p. e216-e225. | Automated decontamination applied as part of a bundle of infection prevention and control interventions |
| Fu, T.Y., P. Gent, and V. Kumar, Efficacy, efficiency and safety aspects of hydrogen peroxide vapour and aerosolized hydrogen peroxide room disinfection systems. Journal of Hospital Infection, 2012. 80(3): p. 199-205. | Not clinical setting |
| Galvin, S., et al., Evaluation of vaporized hydrogen peroxide, Citrox and pH neutral Ecasol for decontamination of an enclosed area: A pilot study. Journal of Hospital Infection, 2012. 80(1): p. 67-70. | Not clinical setting |
| Garcia, R., Evaluation of Environmental Decontamination of Surfaces Using Continuous Application of Low-Level Hydrogen Peroxide...Sixth Decennial International Conference on Healthcare-Associated Infections. Infection Control & Hospital Epidemiology, 2020. 41(S1): p. s227-s228. | Conference abstract |
| Garcia-Arenzana, N., et al., Carbapenem-Resistant Enterobacteriaceae Outbreak in a Medical Ward in Spain: Epidemiology, Control Strategy, and Importance of Environmental Disinfection. Microbial Drug Resistance, 2020. 26(1): p. 54-59. | Not a comparative clinical study |
| Garvey, M., J.P. Andrade Fernandes, and N. Rowan, Pulsed light for the inactivation of fungal biofilms of clinically important pathogenic Candida species. Yeast, 2015. 32(7): p. 533-540. | Not clinical setting |
| Garvey, M.I., C.W. Bradley, and P. Jumaa, Environmental decontamination following occupancy of a burns patient with multiple carbapenemase-producing organisms. The Journal of hospital infection, 2016. 93(2): p. 136-40. | Not a comparative clinical study |
| Gray, J. and P. Orton, The healthcare environment and infection. Journal of Hospital Infection, 2019. 103(1): p. 112-113. | Editorial - references checked for relevant articles |
| Guimera, D., et al., Effectiveness of a shielded ultraviolet C air disinfection system in an inpatient pharmacy of a tertiary care children's hospital. American Journal of Infection Control, 2018. 46(2): p. 223-225. | Focus is on decontamination of air |
| Guridi, A., et al., Disinfectant activity of a portable ultraviolet c equipment. International Journal of Environmental Research and Public Health, 2019. 16(23): p. 4747. | Not clinical setting |
| Häring, A., et al., Impact of surface disinfection with hydrogen peroxide on the prevalence of vancomycin-resistant enterococci (VRE) in hospital wards. GMS hygiene and infection control, 2020. 15: p. Doc13. | Comparison of manual cleaning methods |
| Health Quality Ontario, Portable Ultraviolet Light Surface-Disinfecting Devices for Prevention of Hospital-Acquired Infections: A Health Technology Assessment. Ontario health technology assessment series, 2018. 18(1): p. 1-73. | Health technology assessment - references checked for relevant articles |
| Heilingloh, C.S., et al., Susceptibility of SARS-CoV-2 to UV irradiation. American Journal of Infection Control, 2020. 48(10): p. 1273-1275. | Not clinical setting |
| Holmdahl, T., et al., A head-to-head comparison of hydrogen peroxide vapor and aerosol room decontamination systems. Infection Control & Hospital Epidemiology, 2011. 32(9): p. 831-6. | Not clinical setting |
| Hosein, I., et al., Evaluation of a pulsed xenon ultraviolet light device for isolation room disinfection in a United Kingdom hospital. American Journal of Infection Control, 2016. 44(9): p. e157-e161. | Not a comparative clinical study |
| Huttner, B.D. and S. Harbarth, Hydrogen peroxide room disinfection - ready for prime time? Critical Care, 2015. 19(1): p. 216. | Commentary - references checked for relevant articles |
| Inman, T. and D. Chansolme, Evaluation of a Continuous Decontamination Technology in an Intensive Care Unit...Sixth Decennial International Conference on Healthcare-Associated Infections. Infection Control & Hospital Epidemiology, 2020. 41(S1): p. s519-s519. | Conference abstract |
| Jelden, K.C., et al., Comparison of hospital room surface disinfection using a novel ultraviolet germicidal irradiation (UVGI) generator. Journal of Occupational and Environmental Hygiene, 2016. 13(9): p. 690-698. | Not a comparative clinical study |
| Jinadatha, C., et al., Can pulsed xenon ultraviolet light systems disinfect aerobic bacteria in the absence of manual disinfection? American Journal of Infection Control, 2015. 43(4): p. 415-417. | Not a comparative clinical study |
| Jinadatha, C., et al., Is the pulsed xenon ultraviolet light no-touch disinfection system effective on methicillin-resistant Staphylococcus aureus in the absence of manual cleaning? American Journal of Infection Control, 2015. 43(8): p. 878-881. | Not a comparative clinical study |
| Kanamori, H., et al., Patient Room Decontamination against Carbapenem-Resistant Enterobacteriaceae and Methicillin-Resistant Staphylococcus aureus Using a Fixed Cycle-Time Ultraviolet-C Device and Two Different Radiation Designs. Infection Control & Hospital Epidemiology, 2016. 37(8): p. 994-996. | Not a comparative clinical study |
| Kitagawa, H., et al., Effect of pulsed xenon ultraviolet disinfection on methicillin-resistant Staphylococcus aureus contamination of high-touch surfaces in a Japanese hospital. American Journal of Infection Control, 2020. 48(2): p. 139-142. | Not a comparative clinical study |
| Kitagawa, H., et al., Efficacy of pulsed xenon ultraviolet disinfection of multidrug-resistant bacteria and Clostridioides difficile spores. Infection, Disease & Health, 2020. 25(3): p. 181-185. | Not clinical setting |
| Ku, T.S.N., C.J. Walraven, and S.A. Lee, Candida auris: Disinfectants and implications for infection control. Frontiers in Microbiology, 2018. 9(APR): p. 726. | Narrative review - references checked for relevant articles |
| Lemmen, S., et al., Evaluation of hydrogen peroxide vapor for the inactivation of nosocomial pathogens on porous and nonporous surfaces. American Journal of Infection Control, 2015. 43(1): p. 82-85. | Not a comparative clinical study |
| Li, J.J., et al., Portable pulsed xenon ultraviolet light disinfection in a teaching hospital animal laboratory in China. Journal of Photochemistry and Photobiology B: Biology, 2020. 207: p. 111869. | Not clinical setting |
| Lindsley, W.G., et al., Ambulance disinfection using Ultraviolet Germicidal Irradiation (UVGI): Effects of fixture location and surface reflectivity. Journal of Occupational and Environmental Hygiene, 2018. 15(1): p. 1-12. | Not a comparative clinical study |
| Liscynesky, C., et al., The Effect of Ultraviolet Light on Clostridium difficile Spore Recovery Versus Bleach Alone. Infection Control & Hospital Epidemiology, 2017. 38(9): p. 1116-1117. | Not a comparative clinical study |
| Livingston, S.H., et al., Efficacy of an ultraviolet-A lighting system for continuous decontamination of health care-associated pathogens on surfaces. American Journal of Infection control, 2020. 48(3): p. 337-339. | Not clinical setting |
| Lugo, V., A.M. Wilson, and K.A. Reynolds, Evaluating the Use of Ultraviolet Light to Reduce Transmission of Methicillin-resistant Staphylococcus Aureus in Emergency Medical Service Vehicles. American Journal of Infection Control, 2020. 48(8 Supplement): p. S18-S19. | Conference abstract |
| Maclean, M., et al., 405 nm light technology for the inactivation of pathogens and its potential role for environmental disinfection and infection control. Journal of Hospital Infection, 2014. 88(1): p. 1-11. | Narrative review - references checked for relevant articles |
| Mahida, N., N. Vaughan, and T. Boswell, First UK evaluation of an automated ultraviolet-C room decontamination device (Tru-DTM). Journal of Hospital Infection, 2013. 84(4): p. 332-335. | Not a comparative clinical study |
| Mana, T.S.C., et al., Evaluation of an automated room decontamination device using aerosolized peracetic acid. American Journal of Infection Control, 2017. 45(3): p. 327-329. | Not a comparative clinical study |
| Manian, F.A., et al., Isolation of Acinetobacter baumannii complex and methicillin-resistant Staphylococcus aureus from hospital rooms following terminal cleaning and disinfection: Can we do better? Infection Control & Hospital Epidemiology, 2011. 32(7): p. 667-672. | Outcomes reported as total counts rather than counts for specific microoganisms |
| Marra, A.R., M.L. Schweizer, and M.B. Edmond, No-touch disinfection methods to decrease multidrug-resistant organism infections: A systematic review and meta-analysis. Infection Control & Hospital Epidemiology, 2018. 39(1): p. 20-31. | Systematic review - references checked for relevant articles |
| Masse, V., et al., Comparing and optimizing ultraviolet germicidal irradiation systems use for patient room terminal disinfection: an exploratory study using radiometry and commercial test cards. Antimicrobial Resistance & Infection Control, 2018. 7: p. 29. | Decontamination evaluated using a surrogate outcome (equivalent dose to kill specified microorganisms) |
| Melgar, M., et al., Effectiveness of Dry Hydrogen Peroxide on Reducing Environmental Microbial Bioburden Risk in a Pediatric Intensive Care Unit...Sixth Decennial International Conference on Healthcare-Associated Infections. Infection Control & Hospital Epidemiology, 2020. 41(S1): p. s516-s517. | Conference abstract |
| Mistry, D.M., Impact of H2O2 decontamination technology over high heat sterilization: Increased efficiency and efficacy with significantly reduced downtime. BioTechniques, 2013. 54(3): p. 172. | Not clinical setting |
| Moghnieh, R., et al., The effect of temporary closure and enhanced terminal disinfection using aerosolized hydrogen peroxide of an open-bay intensive care unit on the acquisition of extensively drug-resistant Acinetobacter baumannii. Antimicrobial Resistance & Infection Control, 2020. 9(1): p. 108. | Focus is on clinical outcomes in relation to time elapsed since the previous application of automated disinfection, rather than comparing outcomes for automated decontamination and manual cleaning/disinfection |
| Mustapha, A., et al., Efficacy of manual cleaning and an ultraviolet C room decontamination device in reducing health care-associated pathogens on hospital floors. American Journal of Infection Control, 2018. 46(5): p. 584-586. | Not a comparative clinical study |
| Naidoo, S., A review of nosocomial infections: Epidemiology, transmission and control measures. SA Pharmaceutical Journal, 2017. 84(5): p. 60-64. | Narrative review - references checked for relevant articles |
| Neptune, N. and D. Anderson, Cost-effectiveness analysis of uv-c disinfection to prevent hospital-onset clostridioides difficile infections in acute-care hospitals. Journal of Investigative Medicine, 2020. 68(5): p. 1095-1097. | Conference abstract |
| Nerandzic, M.M., C.W. Fisher, and C.J. Donskey, Sorting through the wealth of options: Comparative evaluation of two ultraviolet disinfection systems. PLoS ONE, 2014. 9(9): p. e107444. | Not clinical setting |
| Nerandzic, M.M., et al., Evaluation of a pulsed xenon ultraviolet disinfection system for reduction of healthcare-associated pathogens in hospital rooms. Infection Control & Hospital Epidemiology, 2015. 36(2): p. 192-197. | Not a comparative clinical study |
| Nerandzic, M.M., et al., Evaluation of an automated ultraviolet radiation device for decontamination of Clostridium difficile and other healthcare-associated pathogens in hospital rooms. BMC Infectious Diseases, 2010. 10: p. 197. | Not a comparative clinical study |
| Nottingham, M., et al., Ultraviolet-C light as a means of disinfecting anesthesia workstations. American Journal of Infection Control, 2017. 45(9): p. 1011-1013. | Not a comparative clinical study |
| Otter, J.A., et al., Assessing the biological efficacy and rate of recontamination following hydrogen peroxide vapour decontamination. Journal of Hospital Infection, 2007. 67(2): p. 182-188. | Not a comparative clinical study |
| Otter, J.A., et al., Evidence that contaminated surfaces contribute to the transmission of hospital pathogens and an overview of strategies to address contaminated surfaces in hospital settings. American Journal of Infection Control, 2013. 41(5 SUPPL.): p. S6-S11. | Narrative review - references checked for relevant articles |
| Otter, J.A., et al., Feasibility of routinely using hydrogen peroxide vapor to decontaminate rooms in a busy United States hospital. Infection Control & Hospital Epidemiology, 2009. 30(6): p. 574-7. | Focus is on time needed for disinfection |
| Otter, J.A., et al., Hydrogen peroxide vapor decontamination of an intensive care unit to remove environmental reservoirs of multidrug-resistant gram-negative rods during an outbreak. American Journal of Infection Control, 2010. 38(9): p. 754-756. | Not a comparative clinical study |
| Otter, J.A., et al., The role of 'no-touch' automated room disinfection systems in infection prevention and control. Journal of Hospital Infection, 2013. 83(1): p. 1-13. | Narrative review - references checked for relevant articles |
| Patrick, A., et al., Daily Disinfection of the Hospital Room and Non-critical Items: Barriers and Practical Approaches. Current Infectious Disease Reports, 2020. 22(12): p. 33. | Narrative review - references checked for relevant articles |
| Penno, K., R.A. Jandarov, and M.M. Sopirala, Effect of automated ultraviolet C-emitting device on decontamination of hospital rooms with and without real-time observation of terminal room disinfection. American Journal of Infection Control, 2017. 45(11): p. 1208-1213. | Outcomes reported as total counts rather than counts for specific microoganisms |
| Piskin, N., et al., Activity of a dry mist-generated hydrogen peroxide disinfection system against methicillin-resistant Staphylococcus aureus and Acinetobacter baumannii. American Journal of Infection Control, 2011. 39(9): p. 757-762. | Not a comparative clinical study |
| Polarine, J., Evaluation of a quaternary ammonium ready-to-use (RTU) disinfectant and hydrogen peroxide/peracetic ready to use (RTU) combination sanitization regimen for cleanroom start-up. American Pharmaceutical Review, 2020. 23(4). | Not clinical setting |
| Pottage, T., et al., Evaluation of hydrogen peroxide gaseous disinfection systems to decontaminate viruses. Journal of Hospital Infection, 2010. 74: p. 55-61. | Not clinical setting |
| Qureshi, Z. and M.H. Yassin, Role of ultraviolet (UV) disinfection in infection control and environmental cleaning. Infectious Disorders Drug Targets, 2013. 13(3): p. 191-5. | Narrative review - references checked for relevant articles |
| Rashid, T., et al., Evaluation of a shoe sole UVC device to reduce pathogen colonization on floors, surfaces and patients. Journal of Hospital Infection, 2018. 98(1): p. 96-101. | Focus is on device for decontaminating the soles of shoes |
| Rastogi, N., et al., Epidemiological investigation and successful management of a Burkholderia cepacia outbreak in a neurotrauma intensive care unit. International Journal of Infectious Diseases, 2019. 79: p. 4-11. | Not a comparative clinical study |
| Ray, A., et al., Use of vaporized hydrogen peroxide decontamination during an outbreak of multidrug-resistant Acinetobacter baumannii infection at a long-term acute care hospital. Infection Control & Hospital Epidemiology, 2010. 31(12): p. 1236-1241. | Not a comparative clinical study |
| Robustillo-Rodela, A., et al., Successful control of 2 simultaneous outbreaks of OXA-48 carbapenemase-producing Enterobacteriaceae and multidrug-resistant Acinetobacter baumannii in an intensive care unit. American Journal of Infection Control, 2017. 45(12): p. 1356-1362. | Not a comparative clinical study |
| Rock, C., et al., Patient and health care worker perceptions of daily use of ultraviolet-C technology as an adjunct to daily cleaning in an academic hospital: Secondary study of Ultra Violet-C Light Evaluation as an Adjunct to Removing Multi-Drug Resistant Organisms. American Journal of Infection Control, 2018. 46(3): p. 348-349. | Outcomes related to patients' and healthcare workers' perceptions, rather than patient infection/colonization or counts of microorganisms in the environment |
| Roques, C., L. Pineau, and A. Florentin, Automated room surface disinfection - Proposals for an international standard. European Infectious Disease, 2012. 6(2): p. 94-97. | Proposal for an international standard - references checked for relevant articles |
| Rutala, W.A. and D.J. Weber, Are room decontamination units needed to prevent transmission of environmental pathogens? Infection Control & Hospital Epidemiology, 2011. 32(8): p. 743-747. | Commentary - references checked for relevant articles |
| Rutala, W.A. and D.J. Weber, Best practices for disinfection of noncritical environmental surfaces and equipment in health care facilities: A bundle approach. American Journal of Infection Control, 2019. 47(Supplement): p. A96-A105. | Narrative review - references checked for relevant articles |
| Rutala, W.A. and D.J. Weber, Disinfection and Sterilization in Health Care Facilities: An Overview and Current Issues. Infectious Disease Clinics of North America, 2016. 30(3): p. 609-637. | Narrative review - references checked for relevant articles |
| Rutala, W.A., et al., Antimicrobial activity of a continuous visible light disinfection system. Infection Control & Hospital Epidemiology, 2018. 39(10): p. 1250-1253. | Not clinical setting |
| Rutala, W.A., M.F. Gergen, and D.J. Weber, Room decontamination with UV radiation. Infection Control & Hospital Epidemiology, 2010. 31(10): p. 1025-1029. | Not a comparative clinical study |
| Scarano, A., F. Inchingolo, and F. Lorusso, Environmental disinfection of a dental clinic during the Covid-19 pandemic: A narrative insight. BioMed Research International, 2020. 2020: p. 8896812. | Systematic review - references checked for relevant articles |
| Schlote, E., Re: Evaluation of dilute hydrogen peroxide technology for continuous room decontamination of multidrug-resistant organisms...Evaluation of dilute hydrogen peroxide technology for continuous room decontamination of multidrugresistant organisms. 2020, Cambridge University Press. p. 737-737. | Commentary - references checked for relevant articles |
| Schoyer, E. and K. Hall, Environmental Cleaning and Decontamination to Prevent Clostridioides difficile Infection in Health Care Settings: A Systematic Review. Journal of Patient Safety, 2020. 16(3S Suppl 1): p. S12-S15. | Systematic review - references checked for relevant articles |
| Sexton, J.D., et al., Reduction in the microbial load on high-touch surfaces in hospital rooms by treatment with a portable saturated steam vapor disinfection system. American Journal of Infection Control, 2011. 39(8): p. 655-662. | Not a comparative clinical study |
| Shapey, S., et al., Activity of a dry mist hydrogen peroxide system against environmental Clostridium difficile contamination in elderly care wards. Journal of Hospital Infection, 2008. 70(2): p. 136-141. | Not a comparative clinical study |
| Sharma, M. and J.B. Hudson, Ozone gas is an effective and practical antibacterial agent. American Journal of Infection Control, 2008. 36(8): p. 559-563. | Not clinical setting |
| Simmons, S., et al., Impact of a multi-hospital intervention utilising screening, hand hygiene education and pulsed xenon ultraviolet (PX-UV) on the rate of hospital associated meticillin resistant Staphylococcus aureus infection. Journal of Infection Prevention, 2013. 14: p. 172-174. | Automated decontamination applied as part of a bundle of infection prevention and control interventions |
| Simmons, S.E., et al., Deactivation of SARS-CoV-2 with pulsed-xenon ultraviolet light: Implications for environmental COVID-19 control. Infection Control & Hospital Epidemiology, 2021. 42(2): p. 127-130. | Not clinical setting |
| Sitzlar, B., et al., Environmental decontamination with ultraviolet radiation to prevent recurrent Clostridium difficile infection in 2 roommates in a long-term care facility. Infection Control & Hospital Epidemiology, 2012. 33(5): p. 535-536. | Not a comparative clinical study |
| Smith, E., Wiping out pathogens with multi-area cleaning. Healthcare Purchasing News, 2020. 44(9): p. 20-26. | Narrative review - references checked for relevant articles |
| Song, L., et al., Development of a Pulsed Xenon Ultraviolet Disinfection Device for Real-Time Air Disinfection in Ambulances. Journal of Healthcare Engineering, 2020. 2020: p. 6053065. | Focus is on decontamination of air |
| Stibich, M. and J. Stachowiak, The microbiological impact of Pulsed xenon ultraviolet disinfection on resistant bacteria, bacterial spore and fungi and viruses. Southern African Journal of Epidemiology & Infection, 2016. 31(1): p. 12-15. | Not clinical setting |
| Stibich, M., et al., Evaluation of a pulsed-xenon ultraviolet room disinfection device for impact on hospital operations and microbial reduction. Infection Control & Hospital Epidemiology, 2011. 32(3): p. 286-8. | Not a comparative clinical study |
| Stibich, M., S. Simmons, and D. Passey, 10 Years of Pulsed-Xenon Ultraviolet Disinfection...Sixth Decennial International Conference on Healthcare-Associated Infections. Infection Control & Hospital Epidemiology, 2020. 41(S1): p. s438-s438. | Conference abstract |
| Taneja, N., et al., Hydrogen peroxide vapour for decontaminating air-conditioning ducts and rooms of an emergency complex in northern India: Time to move on. Journal of Hospital Infection, 2011. 78(3): p. 200-203. | Automated decontamination applied as part of a bundle of infection prevention and control interventions |
| Tarka, P., et al., No-touch automated room disinfection after autopsies of exhumed corpses. Pathogens, 2020. 9(8): p. 1-8. | Not clinical setting |
| Totaro, M., et al., Role of hydrogen peroxide vapor (HPV) for the disinfection of hospital surfaces contaminated by multiresistant bacteria. Pathogens, 2020. 9(5): p. 408. | Narrative review - references checked for relevant articles |
| Umezawa, K., et al., A comparative study of the bactericidal activity and daily disinfection housekeeping surfaces by a new portable pulsed UV radiation device. Current Microbiology, 2012. 64(6): p. 581-587. | Not a comparative clinical study |
| Villacis, J.E., et al., Efficacy of pulsed-xenon ultraviolet light for disinfection of high-touch surfaces in an Ecuadorian hospital. BMC Infectious Diseases, 2019. 19(1): p. 575. | Not a comparative clinical study |
| Wang, S.N., et al., Pulsed xenon ultraviolet and non-thermal atmospheric plasma treatments are effective for the disinfection of air in hospital blood sampling rooms. Photodiagnosis and Photodynamic Therapy, 2019. 27: p. 137-140. | Focus is on decontamination of air |
| Warren, B., et al., Efficacy of UV-C Disinfection in Hyperbaric Chambers...Decennial 2020 6th International Conference on Healthcare Associated Infections. Infection Control & Hospital Epidemiology, 2020. 41(S1): p. s210-s211. | Conference abstract |
| Watson, F., Evaluation of Hydrogen Peroxide Vapour Biodecontamination Against Clinically Relevant Presentations of Multi-drug Resistant Biofilms. American Journal of Infection Control, 2020. 48(8 Supplement): p. S19. | Conference abstract |
| Wawrzyk, A., et al., Decontamination of microbiologically contaminated abiotic porous surfaces in an oral surgery clinic using vaporised hydrogen peroxide (VHP). Journal of Environmental Health Science and Engineering, 2020. 18(2): p. 639-653. | Not a comparative clinical study |
| Weber, D.J., et al., Continuous room decontamination technologies. American Journal of Infection Control, 2019. 47(Supplement): p. A72-A78. | Narrative review - references checked for relevant articles |
| Weber, D.J., et al., Effectiveness of ultraviolet devices and hydrogen peroxide systems for terminal room decontamination: Focus on clinical trials. American Journal of Infection Control, 2016. 44(5 Supplement): p. e77-e84. | Narrative review - references checked for relevant articles |
| Weber, D.J., H. Kanamori, and W.A. Rutala, 'No touch' technologies for environmental decontamination: Focus on ultraviolet devices and hydrogen peroxide systems. Current Opinion in Infectious Diseases, 2016. 29(4): p. 424-431. | Narrative review - references checked for relevant articles |
| Weppner, J., et al., Clostridium difficile Infection Reservoirs Within an Acute Rehabilitation Environment. American Journal of Physical Medicine & Rehabilitation, 2021. 100(1): p. 44-47. | Automated decontamination applied as part of a bundle of infection prevention and control interventions |
| Wong, V., K. Staniforth, and T.C. Boswell, Environmental contamination and airborne microbial counts: A role for hydroxyl radical disinfection units? Journal of Hospital Infection, 2011. 78(3): p. 194-199. | Focus is on decontamination of air (and outcomes reported as total counts rather than counts for specific microorganisms) |
| Yang, J.H., et al., Effectiveness of an ultraviolet-C disinfection system for reduction of healthcare-associated pathogens. Journal of Microbiology, Immunology and Infection, 2019. 52(3): p. 487-493. | Not a comparative clinical study |
| Zargar, B., et al., A quantitative method to assess the role of indoor air decontamination to simultaneously reduce contamination of environmental surfaces: testing with vegetative and spore-forming bacteria. Letters in Applied Microbiology, 2019. 68(3): p. 206-211. | Focus is on decontamination of air |
| Zhang, A., et al., Does organic material on hospital surfaces reduce the effectiveness of hypochlorite and UV radiation for disinfection of clostridium difficile? Infection Control & Hospital Epidemiology, 2013. 34(10): p. 1106-1108. | Not clinical setting |
| Ziegler, M., et al., Enhanced Environmental Cleaning to Reduce Rates of Clostridioides difficile Infection on Oncology Units. Infection Control & Hospital Epidemiology, 2020. 41(S1): p. s213-s213. | Conference abstract |

# Appendix F – Included studies

The incidence rate in any treatment arm is given by the observed number of events (infections/colonizations/acquisitions) divided by the exposure period in that treatment arm. The exposure period is typically measured in person days or, in the case of device-associated infection such as catheter-associated urinary tract infection (CAUTI) or central line-associated bloodstream infection (CLABSI)), device-utilization days. Where incidence rates, numbers of events and exposure periods were reported in published articles these were extracted directly and presented in the evidence tables. Presentation of incidence rates in the evidence tables mirrors that in the source articles, for example, events per 1,000 patient days or events per 10,000 patient days. However, in the corresponding Grading of Recommendations Assessment, Development and Evaluation (GRADE) tables (see Appendix I), presentation of incidence rates was standardized to events per 1,000 patient days, events per 100 surgical procedures, or events per 1,000 device-utilization days to aid comparability between studies.

An incidence rate ratio (IRR) is obtained by dividing the incidence rate in an intervention arm by the incidence rate in a comparator (reference) arm. Taking the log transformation of the IRR allows calculation of its standard error (SE). The log-IRR and its SE for each intervention-comparator pair formed the data inputs for all network meta-analyses (NMAs; see Appendix H). Where the incidence rate, number of events or exposure period was not reported in a particular article, back calculation was used to impute missing values where possible. The log-IRR and its SE was then calculated. Where an article reported an adjusted IRR (allowing for possible confounding factors) and its 95% confidence interval (CI), these were extracted and used to calculate the adjusted log-IRR and its SE. For outcomes that were not included in any NMA, a 95% CI for the log-IRR was calculated and back-transformed to obtain a 95% CI for the IRR where possible.

Unless otherwise stated, automated decontamination as presented in the evidence tables is additional to the manual cleaning/disinfection presented in the tables. Most studies compared automated decontamination with manual cleaning/disinfection during terminal cleaning/disinfection of patient rooms or other clinical areas. Studies that reported both clinical and environmental sampling outcomes are indicated by shading in Table F.1. Studies that reported only environmental sampling outcomes are presented in Table F.2.

All but one study that focused on clinical outcomes reported infection or acquisition (the latter referring to infection or colonization that was indistinguishable in the available evidence). The one exception to this was an article reporting specifically on colonization (see Table F.1).[18]

## Table F.1: Studies reporting clinical outcomes of infection or acquisition\*

| **Citation, country and study dates** | **Study design** | **Setting** | **Automated decontamination** | **Manual cleaning/disinfection** | **Clinical outcomes\*** | **Reviewer comments** |
| --- | --- | --- | --- | --- | --- | --- |
| Anderson 2017;[8]Anderson 2018;[9]Rutala 2018[36]USAApril 2012 to July 2014 | Multicentre cluster randomized controlled crossover trial | Patient rooms in tertiary, community and Veterans Affairs hospitals | UV-C (after standard terminal cleaning/disinfection or bleach disinfection) | Standard terminal cleaning/disinfection or bleach disinfection | Multidrug-resistant *Acinetobacter* acquisitions per 10,000 patient days: 0.0 with UV-C after bleach disinfection (0 events and 244 patient days); 0.0 with UV-C after standard/cleaning disinfection (0 events and 199 patient days); 102.4 with bleach disinfection (1 events and 98 patient days); 0.0 with standard/cleaning disinfection (0 events and 156 patient days)*C. difficile* infections per 10,000 patient days: 30·4 with UV-C after bleach disinfection (38 events and 12,509 patient days); 31·6 with bleach disinfection (36 events and 11,385 patient days)MRSA acquisitions per 10,000 patient days: 46.9 with UV-C after bleach disinfection (89 events and 18,960 patient days); 36.5 with UV-C after standard/cleaning disinfection (54 events and 14,780 patient days); 48·2 with bleach disinfection (74 events and 15,343 patient days); 50·3 with standard/cleaning disinfection (73 events and 14,524 patient days)VRE acquisitions per 10,000 patient days: 39.0 with UV-C after bleach disinfection (37 events and 9,488 patient days); 29.4 with UV-C after standard/cleaning disinfection (17 events and 5,780 patient days); 31·9 with bleach disinfection (24 events and 7,522 patient days); 63·4 with standard/cleaning disinfection (37 events and 5,838 patient days) | Intention-to-treat results extracted from Anderson 2017;[8] all target microorganisms also reported, but not extracted to avoid duplication of data; adjusted IRRs for all but *Acinetobacter* extracted for NMAAnderson 2018[9] reported hospital-wide infection/acquisition using a retrospective cohort study; data not extractedRutala 2018[36] reported environmental sampling results using a prospective cohort study; data not extracted |
| Attia 2020[10]USAJanuary 2016 to September 2017 | Uncontrolled before–after study | Patient rooms in an academic tertiary care hospital | PX-UV | Standard cleaning/disinfection | *C. difficile* infections per 1,000 patient days: 1.61 with PX-UV (number of events not reported; 33,542 patient days); 1.57 with standard cleaning/disinfection (number of events not reported; 33,809 patient days) |  |
| Boyce 2008[11]USAJune 2004 to March 2006 | Uncontrolled before–after study | Patient rooms in an academic hospital | HPV | Standard cleaning/disinfection | *C. difficile* infections per 1,000 patient days: 0.88 with HPV (numbers of events and patient days not reported); 1.89 with standard cleaning/disinfection (numbers of events and patient days not reported) |  |
| Boyce 2017[12]USAStudy dates not reported (study duration 12 months) | Multicentre cluster randomized controlled crossover trial | Patient rooms in a medical ICU, its step-down unit, and two general medical wards in an academic hospital | Not applicable | Standard cleaning/disinfection or improved hydrogen peroxide cleaning/disinfection | *C. difficile* infections per 1,000 patient days: 0.56 with improved hydrogen peroxide (6 events and 10,741 patient days); 1.0 with standard cleaning/disinfection (12 events and 11,490 patient days)MRSA acquisitions per 1,000 patient days: 1.96 with improved hydrogen peroxide (21 events and 10,741 patient days); 2.79 with standard cleaning/disinfection (32 events and 11,490 patient days)VRE acquisitions per 1,000 patient days: 5.49 with improved hydrogen peroxide (59 events and 10,741 patient days); 6.6 with standard cleaning/disinfection (76 events and 11,490 patient days) | Study compared different approaches to manual cleaning/disinfection; included only to strengthen estimation of between-study SD in NMA; MRSA acquisitions with standard cleaning/disinfection reported as 332 events in the article; all target microorganisms also reported, but not extracted to avoid duplication of data |
| Brite 2018[13]USAApril 2015 to November 2016 | Interrupted time series | Patient rooms in the bone marrow transplant unit of a tertiary-care cancercentre | PX-UV | Standard cleaning/disinfection | *C. difficile* infections per 1,000 patient days: 1.114 with PX-UV (number of events and patient days not reported); 1.411 with standard cleaning/disinfection (numbers of events and patient days not reported)*C. difficile* infections per 1,000 patient days, segmented regression: change in intercept, 0.51 (95% CI 0.13 to 2.11); change in slope, 1.08 (95% CI 0.89 to 1.31)VRE infections per 1,000 patient days: 3.6588 with PX-UV (numbers of events and patient days not reported); 3.0236 with standard cleaning/disinfection (numbers of events and patient days not reported)VRE infections per 1,000 patient days, segmented regression: change in intercept, 1.34 (95% CI 0.37 to 4.80); change in slope, 0.96 (95% CI 0.81 to 1.14) | Article also reported interrupted time series results for segmented regression of acquisitions – data not extracted |
| Catalanotti 2016[14]USAJanuary 2012 to December 2014 | Uncontrolled before–after study | Operating theatres in a not-for-profit community hospital | PX-UV | Standard cleaning/disinfection | Surgical site infections per 100 class 1 (clean wound) procedures: 0.26 with PX-UV (29 events and 10,883 procedures); 0.48 with standard cleaning/disinfection (31 events and 6,439 procedures)Surgical site infections per 100 class 2 (clean-contaminated wound) procedures: 0.33 with PX-UV (26 events and 7,825 procedures); 0.27 with standard cleaning/disinfection (13 events and 4,811 procedures) | Classes were assigned to wounds postoperatively; infection rates were compared in the article using one-sided t tests – data not extracted |
| Doll 2020[15]USAJanuary 2013 to January 2019 | Interrupted time series | Patient rooms in a tertiary-care, academic medicalcentre | UV-C | Standard cleaning/disinfection | *C. difficile* infections per 10,000 patient days, segmented regression: change in intercept, 0.095 (95% CI 4.294 to 4.483); change in slope, -0.149 (95% CI 0.787 to 0.489) | Unclear whether UV-C was additional to or instead of standard cleaning/disinfection |
| Green 2017[16]USADecember 2013 to May 2015 | Uncontrolled before–after study | Patient rooms, operating theatres, shower rooms and ancillary areas in a burns unit in a military hospital | PX-UV | Standard cleaning/disinfection | *C. difficile* infections per 1,000 patient days: 0.0 with PX-UV (0 events and 653 patient days); 1.83 with standard cleaning/disinfection (4 events and 2,186 patient days)Multidrug-resistant *P. aeruginosa* acquisitions per 1,000 patient days: 0.0 with PX-UV (0 events and 653 patient days); 0.91 with standard cleaning/disinfection (2 events and 2,186 patient days)MRSA acquisitions per 1,000 patient days: 4.6 with PX-UV (3 events and 653 patient days); 3.66 with standard cleaning/disinfection (8 events and 2,186 patient days)*S. maltophilia* acquisitions per 1,000 patient days: 4.6 with PX-UV (3 events and 653 patient days); 1.83 with standard cleaning/disinfection (4 events and 2,186 patient days)ESBL Enterobacteriaceae acquisitions per 1,000 patient days: 1.5 with PX-UV (1 event and 653 patient days); 0.91 with standard cleaning/disinfection (2 events and 2,186 patient days)Any MDR-GNR acquisitions per 1,000 patient days: 6.1 with PX-UV (4 events and 653 patient days); 3.66 with standard cleaning/disinfection (8 events and 2,186 patient days)CAUTIs per 1,000 device-utilization days: 1.79 with PX-UV (number of events not reported; 558 device-utilization days); rate with standard cleaning/disinfection not reported (number of events not reported; 1,956 device-utilization days); p=0.23CLABSIs per 1,000 device-utilization days: 1.85 with PX-UV (number of events not reported; 542 device-utilization days); rate with standard cleaning/disinfection not reported (number of events not reported; 1,899 device-utilization days); p=0.20Ventilator-associated pneumonias per 1,000 device-utilization days: 7.87 with PX-UV (number of events not reported; 381 device-utilization days); rate with standard cleaning/disinfection not reported (number of events not reported; 1,466 device-utilization days); p=0.12 | Unclear whether results reported in article were infection or acquisition – taken as infection for consistency with article text; all multidrug-resistant microorganisms also reported – not extracted to avoid duplication of data |
| Haas 2014;[17]Nagaraja 2015[31]USAJanuary 2009 to April 2013 | Uncontrolled before–after study | Patient rooms, operating theatres and a dialysis unit in a tertiary care hospital | PX-UV | Standard cleaning/disinfection | *C. difficile* infections per 1,000 patient days: 0.65 with PX-UV (228 events; patient days not reported); 0.79 with standard cleaning/disinfection (390 events; patient days not reported)MRSA acquisitions per 1,000 patient days: 0.33 with PX-UV (116 events; patient days not reported); 0.45 with standard cleaning/disinfection (224 events; patient days not reported)VRE acquisitions per 1,000 patient days: 0.73 with PX-UV (257 events; patient days not reported); 0.90 with standard cleaning/disinfection (443 events; patient days not reported)MDR-GNB acquisitions per 1,000 patient days: 0.42 with PX-UV (148 events; patient days not reported); 0.52 with standard cleaning/disinfection (260 events; patient days not reported); IRR=0.81 (95% CI 0.66 to 0.98) | Results extracted from Haas 2014;[17] further analysis of *C. difficile* data reported for a portion of the study period (May 2010 to June 2012) – data not extracted; total infections/acquisitions also reported – not extracted to avoid duplication of dataNagaraja 2015[31] reported an alternative analysis of the same data – not extracted to avoid duplication of data |
| Hardy 2007[18]UKStudy dates not reported | Uncontrolled before–after study | Open-plan ICU | HPV | Standard cleaning/disinfection | MRSA colonizations: 12 patients after one-off HPV application (of whom 7 acquired MRSA during their ICU stay); 10 patients in the 3 months preceding the one-off HPV application (of whom 3 acquired MRSA during their ICU stay) | One-off use of HPV – the study showed how rapidly the environment was recontaminated in such circumstances; only study that reported the clinical outcome of colonization; not included in NMA |
| Horn 2015[19]UKOctober 2010 to September 2013 | Uncontrolled before–after study | Patient rooms in a hospital | HPV | Standard cleaning/disinfection | *C. difficile* infections per 1,000 patient days: 0.90 with HPV (99 events; patient days not reported); 1.38 with standard cleaning/disinfection (96 events; patient days not reported)MRSA acquisitions per 1,000 patient days: 0.13 with HPV (12 events; patient days not reported); 0.23 with standard cleaning/disinfection (11 events; patient days not reported)VRE acquisitions per 1,000 patient days: 0.01 with HPV (1 event; patient days not reported); 0.21 with standard cleaning/disinfection (10 events; patient days not reported)ESBL-GNB acquisitions per 1,000 patient days: 0.01 with HPV (1 event; patient days not reported); 0.16 with standard cleaning/disinfection (8 events; patient days not reported) | Unclear whether HPV was additional to or instead of standard cleaning/disinfection; total infections/acquisitions also reported – not extracted to avoid duplication of data |
| Kitagawa 2021[20]JapanMarch 2018 to February 2020 | Controlled before–after study | Patient rooms in ICUs and a high care room in a tertiary care hospital | PX-UV | Standard cleaning/disinfection | MRSA acquisitions per 1,000 patient days: 2.21 with PX-UV (17 events and 7,709 patient days); 3.56 with standard cleaning/disinfection (29 events and 8,139 patient days) | Data extracted are for before–after comparison in intervention units only; adjusted IRR extracted for meta-analysis |
| Kovach 2017[21]USAJanuary 2012 to December 2015 | Uncontrolled before–after study | Patient rooms and communal areas in a long-term care facility (nursing home) | PX-UV | Standard cleaning/disinfection | Enteric infections in nursing home per 1,000 patient days: 0.00 with PX-UV (numbers of events and patient days not reported); rate with standard cleaning/disinfection not reported (numbers of events and patient days not reported)Respiratory system infections in nursing home per 1,000 patient days: 0.04 with PX-UV (numbers of events and patient days not reported); rate with standard cleaning/disinfection not reported (numbers of events and patient days not reported); ANOVA of change in ratio of hospital-acquired to nursing-home acquired infections before and after introduction of PX-UV, p=0.017Skin and soft tissue infections in nursing home per 1,000 patient days: 0.03 with PX-UV (numbers of events and patient days not reported); rate with standard cleaning/disinfection not reported (numbers of events and patient days not reported); ANOVA of change in ratio of hospital-acquired to nursing-home acquired infections before and after introduction of PX-UV, p=0.014UTIs in nursing home per 1,000 patient days: 0.05 with PX-UV (numbers of events and patient days not reported); rate with standard cleaning/disinfection not reported (numbers of events and patient days not reported); ANOVA of change in ratio of hospital-acquired to nursing-home acquired infections before and after introduction of PX-UV, p=0.014 | No inferential analyses reported for enteric infection |
| Levin 2013[22]USA2008 to 2011 (automated disinfection introduced in January 2011; no further details reported) | Uncontrolled before–after study | Patient rooms, operating suites, emergency department, and other clinical areas as available, in an acute care community hospital  | PX-UV | Standard cleaning/disinfection | *C. difficile* infections per 10,000 patient days: 4.45 with PX-UV (15 events and 33,687 patient days); 9.46 with standard cleaning/disinfection (33 events and 34,870 patient days) | Comparison of 2011 and 2010 rates extracted |
| Manian 2013[23]USAJanuary 2007 to December 2009 | Uncontrolled before–after study | Patient rooms in a community teaching hospital | HPV | Standard cleaning/disinfection | *C. difficile* infections per 1,000 patient days: 0.55 with HPV (109 events and 196,313 patient days); 0.88 with standard cleaning/disinfection (322 events and 365,926 patient days) |  |
| McCord 2016[24]USAJanuary 2010 to December 2013 | Interrupted time series | Patient rooms (no further details reported) | HPV | Standard cleaning/disinfection | *C. difficile* infections per 1,000 patient days: 0.4 with HPV (123 events; patient days not reported); 1.0 with standard cleaning/disinfection (258 events; patient days not reported)  |  |
| McMullen 2020[25]USAJanuary 2013 to August 2014 (hospital A)June 2013 to April 2016 (hospital B)October 2013 to June 2015 (hospital C) | Uncontrolled before–after studies | Patient rooms in an academic medical centre (hospital A) or an acute care community hospital (hospitals B and C) | PX-UV (hospitals A and C) or UV-C (hospital B) | Standard cleaning/disinfection | *C. difficile* infections per 1,000 patient days, hospital A: 0.64 with PX-UV (135 events and 209,417 patient days); 0.69 with standard cleaning/disinfection (218 events and 315,815 patient days)*C. difficile* infections per 1,000 patient days, hospital B: 0.46 with UV-C (55 events and 120,152 patient days); 0.34 with standard cleaning/disinfection (25 events and 73,223 patient days)*C. difficile* infections per 1,000 patient days, hospital C: 1.18 with PX-UV (56 events and 47,565 patient days); 0.96 with standard cleaning/disinfection (110 events and 114,322 patient days) |  |
| Miller 2015[26]USAJuly 2010 to September 2014 | Uncontrolled before–after study | Patient rooms and communal living areas in a long-term acute care hospital | PX-UV | Standard cleaning/disinfection | *C. difficile* infections per 10,000 patient days: 8.3 with PX-UV (22 events; patient days not reported); 19.3 with standard cleaning/disinfection (23 events; patient days not reported) |  |
| Mitchell 2014[27]AustraliaJanuary 2006 to December 2012 | Interrupted time series | Patient rooms in an acute care hospital | AHP in single-occupancy rooms (and manually applied hydrogen peroxide in shared rooms) | Standard cleaning/disinfection | MRSA bacteraemias per 10,000 patient days: 0.11 with aerosolized hydrogen peroxide (numbers of events and patient days not reported); 0.16 with standard cleaning/disinfection (numbers of events and patient days not reported)MRSA acquisitions per 10,000 patient days: 5.3 with aerosolized hydrogen peroxide (186 events; patient days not reported); 9.0 with standard cleaning/disinfection (334 events; patient days not reported) | Unlike other interrupted time series studies, no segmented regression analysis was reported |
| Morikane 2020[28]JapanAugust 2016 to February 2019 | Controlled before–after study | ICU in an academic tertiary referral hospital | PX-UV | Standard cleaning/disinfection | Two-drug resistant *A. baumannii* infections per 10,000 patient days: 18.10 with PX-UV (4 events and 2102 patient days); 48.5 with standard cleaning/disinfection (14 events and 2852 patient days)MRSA infections per 10,000 patient days: 9.89 with PX-UV (2 events and 2102 patient days); 13.84 with standard cleaning/disinfection (4 events and 2852 patient days) | Data extracted are for before–after comparison in intervention units only; adjusted IRRs extracted for NMA; rates for both microorganisms are from Poisson regression model and so not exactly events divided by patient days; two-drug resistant *A. baumannii* refers to resistance to two classes of antimicrobial (carbapenem and quinolone) |
| Murphy 2020[29]USAJanuary 2016 to December 2018 | Interrupted time series | Bone marrow transplant and oncology units in an academic medical centre | UV-C at every terminal discharge or UV-C only at terminal discharge of patients with *C. difficile* infection | Not applicable | *C. difficile* infections per 10,000 patient days, bone marrow transplant unit segmented regression: change in intercept, unquantified decrease, p=0.044; change in slope, unquantified decrease, p=0.417*C. difficile* infections per 10,000 patient days, oncology unit segmented regression: change in intercept, unquantified increase, p=0.283; change in slope, unquantified decrease, p=0.870CLABSIs per 10,000 patient days, bone marrow transplant unit segmented regression: change in intercept, unquantified decrease, p=0.048; change in slope, unquantified decrease, p=0.204CLABSIs per 10,000 patient days, oncology unit segmented regression: change in intercept unquantified decrease, p=0.160; change in slope, unquantified decrease, p=0.150Respiratory viral infections per 10,000 patient days, bone marrow transplant unit segmented regression: change in intercept, unquantified decrease, p=0.805; change in slope, unquantified decrease, p=0.254Respiratory viral infections per 10,000 patient days, oncology unit segmented regression: change in intercept, unquantified decrease, p=0.057; change in slope, unquantified decrease, p=0.574 |  |
| Murrell 2019[30]USAOctober 2015 to October 2017 | Controlled before–after study | Orthopaedic surgery operating theatres in a regional hospital | Visible (indigo and white) light continuous disinfection system | Standard cleaning/disinfection | Surgical site infections per 100 procedures: 0.33 with visible (indigo and white) light (5 events and 1,510 procedures); 1.31 with standard cleaning/disinfection (19 events and 1,450 procedures); adjusted OR 0.22 (95% CI 0.05 to 0.90) | Extracted data are combined before–after comparisons for operating theatres 1 and 2; adjusted OR refers to interaction between after phase of study and combined effect of operating theatres 1 and 2 |
| Napolitano 2015[32]USAOctober 2012 to March 2013 | Uncontrolled before–after study | Patient rooms in acute care units in a community hospital | UV-C | Standard cleaning/disinfection | *A. baumannii* infections per 1,000 patient days: 0.11 with UV-C (2 events and 18,184 patient days); 0.39 with standard cleaning/disinfection (7 events and 17,933 patient days)*C. difficile* infections per 1,000 patient days: 0.66 with UV-C (12 events and 18,184 patient days); 1.23 with standard cleaning/disinfection (22 events and 17,933 patient days)*K. pneumoniae* infections per 1,000 patient days: 0 with UV-C (0 events and 18,184 patient days); 0.44 with standard cleaning/disinfection (8 events and 17,933 patient days)MRSA infections per 1,000 patient days: 0.38 with UV-C (7 events and 18,184 patient days); 0.39 with standard cleaning/disinfection (7 events and 17,933 patient days)VRE infections per 1,000 patient days: 0.88 with UV-C (16 events and 18,184 patient days); 1.00 with standard cleaning/disinfection (18 events and 17,933 patient days) | Article reported all clinical outcomes as infection, although article text states that patients might have had colonization or infection contributing to extended duration of stay – treated as infection here; total infections also reported – not extracted to avoid duplication of data; article did not report whether or not *A. baumannii* was multidrug resistant; incidence rate for *K. pneumoniae* infection with standard cleaning/disinfection should read 0.45 (assuming numbers of events and patients days reported in the article are correct) |
| Passaretti 2013[33]USAJanuary 2007 to June 2009 | Controlled before–after study | ICUs and a high-risk surgical unit in a tertiary referral hospital | HPV | Standard cleaning/disinfection | *C. difficile* infections per 1,000 patient days: 1.0 with HPV (4 events and 4,029 patient days); 2.7 with standard cleaning/disinfection (26 events and 9,676 patient days) MRSA acquisitions per 1,000 patient days: 1.2 with HPV (5 events and 4,010 patient days); 3.7 with standard cleaning/disinfection (14 events and 3,736 patient days) VRE acquisitions per 1,000 patient days: 2.4 with HPV (8 events and 3,267 patient days); 11.6 with standard cleaning/disinfection (53 events and 4,566 patient days) MDR-GNR acquisitions per 1,000 patient days: 1.7 with HPV (7 events and 4,225 patient days); 2.3 with standard cleaning/disinfection (23 events and 9,928 patient days) | All target microorganisms also reported – not extracted to avoid duplication of data; adjusted IRRs extracted for NMA |
| Pegues 2017[34]USAJanuary 2013 to January 2015 | Interrupted time series | Patient rooms in haematology-oncology units in an academic tertiary care hospital | UV-C | Standard cleaning/disinfection | *C. difficile* infections per 10,000 patient days: 22.85 with UV-C (66 events and 28,884 patient days); 30.34 with standard cleaning/disinfection (87 events and 28,672 patient days) | Adjusted IRR extracted for NMA |
| Raggi 2018[35]USAApril 2015 to March 2017 | Uncontrolled before–after study | Patient rooms, operating theatres and emergency rooms in acute care inpatient units in a community hospital  | UV-C | Standard cleaning/disinfection | *A. baumannii* infections per 1,000 patient days: 0.16 with UV-C (10 events and 62,242 patient days); 0.34 with standard cleaning/disinfection (22 events and 64,262 patient days)*K. pneumoniae* infections per 1,000 patient days: 1.22 with UV-C (76 events and 62,242 patient days); 1.16 with standard cleaning/disinfection (73 events and 64,262 patient days)MRSA infections per 1,000 patient days: 0.98 with UV-C (61 events and 62,242 patient days); 1.42 with standard cleaning/disinfection (91 events and 64,262 patient days)*P. aeruginosa* infections per 1,000 patient days: 1.16 with UV-C (70 events and 62,242 patient days); 1.29 with standard cleaning/disinfection (83 events and 64,262 patient days)VRE infections per 1,000 patient days: 0.45 with UV-C (28 events and 62,242 patient days); 0.68 with standard cleaning/disinfection (44 events and 64,262 patient days) | Article abstract reported all microorganisms studied as being multidrug-resistant bacteria; total infections (associated with multidrug-resistant microorganisms) also reported – not extracted to avoid duplication of data;incidence rate for *K. pneumoniae* infection with standard cleaning/disinfection should read 1.14 (assuming numbers of events and patients days reported in the article are correct); incidence rate for *P. aeruginosa* infection with UV-C should read 1.12 (assuming numbers of events and patients days reported in the article are correct) |
| Sampathkumar 2019[37]USAJanuary 2013 to March 2015 | Controlled before–after study | Patient rooms in haematology, bone marrow transplant, medical-surgical and similar units in a tertiary care hospital | PX-UV | Standard cleaning/disinfection | *C. difficile* infections per 10,000 patient days: 11.2 with PX-UV (10 events and 8,958 patient days); 21.3 with standard cleaning/disinfection (59 events and 27,707 patient days)VRE acquisitions per 10,000 patient days: 12.3 with PX-UV (4 events and 4,085 patient days); 25.6 with standard cleaning/disinfection (35 events and 13,686 patient days) | Data extracted are for before–after comparisons in intervention units only; incidence rate for VRE acquisitions with PX-UV should read 0.98 (assuming numbers of events and patients days reported in the article are correct) |
| Schaffzin 2020[38]USAJanuary 2015 to December 2018 | Interrupted time series | Patient rooms in a paediatricquaternary referral hospital | UV-C | Standard cleaning/disinfection | *C. difficile* infections per 1,000 patient days: 0.75 with UV-C (numbers of events and patient days not reported); 0.94 with standard cleaning/disinfection (numbers of events and patient days not reported) | Unlike other interrupted time series studies, no segmented regression analysis was reported; not included in NMA because analysis seems *ad hoc* in terms of when changes to rates were assessed (not driven by fixed date of introduction of UV-C), also hydrogen peroxide wipes introduced gradually during study period; results also reported for all healthcare-associated infections and for multidrug-resistant Gram-negative infections as a percentage of all infections – data not extracted |
| Vianna 2016[39]USAJanuary 2011 to August 2014 | Uncontrolled before–after study | Patient rooms in a community hospital | PX-UV | Standard cleaning/disinfection | *C. difficile* infections per 1,000 patient days: 0.49 (43 events and 87,966 patient days) with PX-UV; 0.83 (82 events and 99,356 patient days) with standard cleaning/disinfectionMRSA infections per 1,000 patient days: 0.41 (36 events and 87,966 patient days) with PX-UV; 0.34 (34 events and 99,356 patient days) with standard cleaning/disinfectionVRE infections per 1,000 patient days: 0.17 (15 events and 87,966 patient days) with PX-UV; 0.34 (34 events and 99,356 patient days) with standard cleaning/disinfection |  |

\* Shaded rows indicate studies reporting both clinical and environmental sampling outcomes (latter not extracted)
AHP aerosolized hydrogen peroxide; ANOVA analysis of variance; CAUTI catheter-associated urinary tract infection; CI confidence interval; CLABSI central line-associated bloodstream infection; ESBL extended-spectrum beta lactamase-producing; ESBL-GNB extended-spectrum beta lactamase-producing Gram-negative bacteria; HPV hydrogen peroxide vapour; ICU intensive care unit; IRR incidence rate ratio; MDR-GNB multidrug-resistant Gram-negative bacteria; MDR-GNR multidrug-resistant Gram-negative rods; MRSA meticillin-resistant *Staphylococcus aureus*; NMA network meta-analysis; OR odds ratio; PX-UV pulsed-xenon ultraviolet; UTI urinary tract infection; UV-C ultraviolet C; VRE vancomycin-resistant *Enterococcus*

## Table F.2: Additional evidence – studies reporting only environmental sampling outcomes

| **Studies involving detection of clinically occurring environmental contamination** | **Studies limited to experimental inoculation of surfaces** |
| --- | --- |
| **Brief citation** | **Full citation** | **Brief citation** | **Full citation** |
| Barbut 2009[40] | Barbut, F., et al., Comparison of the efficacy of a hydrogen peroxide dry-mist disinfection system and sodium hypochlorite solution for eradication of clostridium difficile spores. Infection Control & Hospital Epidemiology, 2009. 30(6): p. 507-514. | Ali 2016[54] | Ali, S., et al., Efficacy of two hydrogen peroxide vapour aerial decontamination systems for enhanced disinfection of meticillin-resistant Staphylococcus aureus, Klebsiella pneumoniae and Clostridium difficile in single isolation rooms. Journal of Hospital Infection, 2016. 93(1): p. 70-77. |
| Blazejewski 2015[41] | Blazejewski, C., et al., Efficiency of hydrogen peroxide in improving disinfection of ICU rooms. Critical care (London, England), 2015. 19: p. 30. | Ali 2017[55] | Ali, S., et al., Comparison of two whole-room ultraviolet irradiation systems for enhanced disinfection of contaminated hospital patient rooms. Journal of Hospital Infection, 2017. 97(2): p. 180-184. |
| French 2004[42] | French, G.L., et al., Tackling contamination of the hospital environment by methicillin-resistant Staphylococcus aureus (MRSA): A comparison between conventional terminal cleaning and hydrogen peroxide vapour decontamination. Journal of Hospital Infection, 2004. 57(1): p. 31-37. | Doan 2012[56] | Doan, L., et al., Clinical and cost effectiveness of eight disinfection methods for terminal disinfection of hospital isolation rooms contaminated with Clostridium difficile 027. Journal of Hospital Infection, 2012. 82(2): p. 114-121. |
| Ghantoji 2015[43] | Ghantoji, S.S., et al., Non-inferiority of pulsed xenon UV light versus bleach for reducing environmental Clostridium difficile contamination on high-touch surfaces in Clostridium difficile infection isolation rooms. Journal of Medical Microbiology, 2015. 64(2): p. 191-194. | Havill 2012[57] | Havill, N.L., B.A. Moore, and J.M. Boyce, Comparison of the microbiological efficacy of hydrogen peroxide vapor and ultraviolet light processes for room decontamination. Infection Control & Hospital Epidemiology, 2012. 33(5): p. 507-512. |
| Jinadatha 2014[44] (pilot study linked to Zeber 2018)[52] | Jinadatha, C., et al., Evaluation of a pulsed-xenon ultraviolet room disinfection device for impact on contamination levels of methicillin-resistant Staphylococcus aureus. BMC Infectious Diseases, 2014. 14(1): p. 187. | Jelden 2017[58] | Jelden, K.C., et al., Ultraviolet (UV)-reflective paint with ultraviolet germicidal irradiation (UVGI) improves decontamination of nosocomial bacteria on hospital room surfaces. Journal of Occupational and Environmental Hygiene, 2017. 14(6): p. 456-460. |
| Lerner 2020[45] | Lerner, A.O., et al., Environmental contamination by carbapenem-resistant Acinetobacter baumannii: The effects of room type and cleaning methods. Infection Control & Hospital Epidemiology, 2020. 41(2): p. 166-171. | Rutala 2013a[59] | Rutala, W.A., et al., Rapid hospital room decontamination using ultraviolet (UV) light with a nanostructured UV-reflective wall coating. Infection Control & Hospital Epidemiology, 2013. 34(5 SPL): p. 527-529. |
| Maclean 2010[46] | Maclean, M., et al., Environmental decontamination of a hospital isolation room using high-intensity narrow-spectrum light. Journal of Hospital Infection, 2010. 76(3): p. 247-251. | Rutala 2014[60] | Rutala, W.A., et al., Room decontamination using an ultraviolet-C device with short ultraviolet exposure time. Infection Control & Hospital Epidemiology, 2014. 35(8): p. 1070-1072. |
| Mosci 2017[47] | Mosci, D., et al., Automatic environmental disinfection with hydrogen peroxide and silver ions versus manual environmental disinfection with sodium hypochlorite: a multicentre randomized before-and-after trial. Journal of Hospital Infection, 2017. 97(2): p. 175-179. |  |
| Sitzlar 2013[48] | Sitzlar, B., et al., An environmental disinfection odyssey: Evaluation of sequential interventions to improve disinfection of Clostridium difficile isolation rooms. Infection Control & Hospital Epidemiology, 2013. 34(5 SPL): p. 459-465. |  |
| Warren 2020[49] | Warren, B.G., et al., Measuring the impact of continuous disinfection strategies on environmental burden in outpatient settings: A prospective randomized controlled trial. Open Forum Infectious Diseases, 2020. 7(10). ofaa431. |  |
| Wong 2016[50] | Wong, T., et al., Postdischarge decontamination of MRSA, VRE, and Clostridium difficile isolation rooms using 2 commercially available automated ultraviolet-C-emitting devices. American Journal of Infection Control, 2016. 44(4): p. 416-420. |  |
| Yui 2017[51] | Yui, S., et al., Identification of Clostridium difficile Reservoirs in the Patient Environment and Efficacy of Aerial Hydrogen Peroxide Decontamination. Infection Control & Hospital Epidemiology, 2017. 38(12): p. 1487-1492. |  |
| Zeber 2018[52] (linked to pilot study of Jinadatha 2014)[44] | Zeber, J.E., et al., Effect of pulsed xenon ultraviolet room disinfection devices on microbial counts for methicillin-resistant Staphylococcus aureus and aerobic bacterial colonies. American Journal of Infection Control, 2018. 46(6): p. 668-673. |  |
| Zeber 2019[53] | Zeber, J.E., et al., Use of ultraviolet irradiation in addition to commonly used hospital disinfectants or cleaners further reduces the bioburden on high-touch surfaces. Open Forum Infectious Diseases, 2019. 6(12). ofz529. |  |

# Appendix G – Methodological quality of studies reporting clinical outcomes

## Table G.1: Controlled trials\*

| **Citation** | **Appropriate and clear question** | **Random assignment** | **Adequate concealment** | **Subject and investigators blinded** | **Groups similar at start** | **Groups differ only in treatment** | **Standard, valid and reliable outcome measurement** | **Dropout percentage** | **Intention to treat analysis** | **Results comparable across sites** | **Overall rating** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Anderson 2017[8] | Yes | Yes | No | No | Yes | Yes | Yes | 41% | Yes | Can’t say | Acceptable |
| Boyce 2017[12] | Yes | Yes | No | No | Can’t say | Yes | Yes | Can’t say | Can’t say | Can’t say | Acceptable |

\* Scottish Intercollegiate Guidelines Network (SIGN) methodology checklists 2 (randomized controlled trials) and 3 (cohort studies), <https://www.sign.ac.uk/what-we-do/methodology/checklists/>

## Table G.2: Controlled before–after studies\*

| **Citation** | **Random sequence generation** | **Allocation concealment** | **Baseline outcome measurements similar** | **Baseline characteristics similar** | **Incomplete outcome data** | **Knowledge of allocation prevented** | **Protection against contamination** | **Selective outcome reporting** | **Other risks of bias** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Kitagawa 2021[20] | High risk | High risk | Unclear risk | High risk | Unclear risk | Unclear risk | Unclear risk | Low risk | Low risk |
| Morikane 2020[28] | High risk | High risk | Unclear risk | High risk | Unclear risk | Unclear risk | Unclear risk | Low risk | Low risk |
| Murrell 2019[30] | High risk | High risk | Unclear risk | High risk | Unclear risk | Unclear risk | Unclear risk | Low risk | Low risk |
| Passaretti 2013[33] | High risk | High risk | Unclear risk | Low risk | Unclear risk | Unclear risk | Unclear risk | Unclear risk | Low risk |
| Sampathkumar 2019[37] | High risk | High risk | Unclear risk | Unclear risk | Unclear risk | Unclear risk | Unclear risk | Unclear risk | High risk |

\* Cochrane Effective Practice and Organisation of Care (EPOC) resources for review authors, Risk of bias, Suggested risk of bias criteria for EPOC reviews (controlled before–after studies and interrupted time series), <https://epoc.cochrane.org/resources/epoc-resources-review-authors>

## Table G.3: Interrupted time series\*

| **Citation** | **Intervention independent of other changes** | **Shape of intervention effect pre-specified** | **Intervention unlikely to affect data collection** | **Knowledge of allocation prevented** | **Incomplete outcome data** | **Selective outcome reporting** | **Other risks of bias** |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Brite 2018[13] | Low risk | Low risk | Unclear risk | Unclear risk | Unclear risk | Low risk | Low risk |
| Doll 2020[15] | Low risk | Low risk | Unclear risk | Unclear risk | Unclear risk | Low risk | Low risk |
| McCord 2016[24] | Low risk | Low risk | Unclear risk | Unclear risk | Unclear risk | Low risk | Low risk |
| Mitchell 2014[27] | Low risk | Low risk | Unclear risk | Unclear risk | Unclear risk | Low risk | Low risk |
| Murphy 2020[29] | Low risk | Low risk | Unclear risk | Unclear risk | Unclear risk | Low risk | Low risk |
| Pegues 2017[34] | Unclear risk | Low risk | Unclear risk | Unclear risk | Unclear risk | Low risk | Low risk |
| Schaffzin 2020[38] | Low risk | Low risk | Unclear risk | Unclear risk | Unclear risk | Low risk | Unclear risk |

\* Cochrane Effective Practice and Organisation of Care (EPOC) resources for review authors, Risk of bias, Suggested risk of bias criteria for EPOC reviews (controlled before–after studies and interrupted time series), <https://epoc.cochrane.org/resources/epoc-resources-review-authors>

## Table G.4: Quasi-experimental (uncontrolled before–after) studies\*

| **Citation** | **Cause and effect order clear** | **Participants included in comparisons similar** | **Participants included in comparisons receiving similar treatment/care** | **Control group** | **Multiple outcome measurements both before and after** | **Follow up complete/explained** | **Outcome measurement consistent** | **Outcome measurement reliable** | **Statistical analysis appropriate** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Attia 2020[10] | Yes | Yes | Yes | No | Yes | Unclear | Yes | Yes | Yes |
| Boyce 2008[11] | Yes | Yes | Yes | No | Yes | Unclear | Yes | Yes | Yes |
| Catalanotti 2016[14] | Yes | Yes | Yes | No | Yes | Unclear | Yes | Yes | Yes |
| Green 2017[16] | Yes | Yes | Yes | No | No | Unclear | Yes | Yes | Yes |
| Haas 2014[17] | Yes | Yes | Unclear | No | Yes | Unclear | Yes | Yes | Yes |
| Hardy 2007[18] | Yes | Yes | Yes | No | Yes | Unclear | Yes | Yes | Yes |
| Horn 2015[19] | Yes | Yes | Yes | No | No | Unclear | Unclear | Unclear | Yes |
| Kovach 2017[21] | Yes | Yes | Yes | No | No | Unclear | Yes | Yes | Yes |
| Levin 2013[22] | Yes | Yes | Unclear | No | No | Unclear | Yes | Yes | Yes |
| Manian 2013[23] | Yes | Yes | Yes | No | No | Unclear | Yes | Yes | Yes |
| McMullen 2020[25] | Yes | Yes | Yes | No | No | Unclear | Yes | Yes | Yes |
| Miller 2015[26] | Yes | Yes | Yes | No | Yes | Unclear | Yes | Yes | Yes |
| Napolitano 2015[32] | Yes | Yes | Yes | No | No | Unclear | Yes | Unclear | Yes |
| Raggi 2018[35] | Yes | Yes | Yes | No | Yes | Unclear | Yes | Yes | Yes |
| Vianna 2016[39] | Yes | Unclear | Yes | No | No | Unclear | Unclear | Unclear | Yes |

\* Joanna Briggs Institute (JBI) critical appraisal tools, Checklist for Quasi-Experimental Studies, <https://jbi.global/critical-appraisal-tools>

# Appendix H – Network meta-analysis for the clinical outcomes of infection or acquisition

## Data inputs

The input data for the NMAs comprised the log-IRRs for each intervention-comparator pair and their associated SEs (with the most conservative approach to manual cleaning/disinfection in the relevant study being defined as the reference treatment). NMA was attempted for clinical outcomes with at least three log-IRRs to use as data inputs. Automated decontamination systems based on ultraviolet C (UV-C), pulsed-xenon ultraviolet (PX-UV), hydrogen peroxide vapour (HPV; 30–35% hydrogen peroxide) and aerosolized hydrogen peroxide (AHP; 5–6% hydrogen peroxide) were treated as separate interventions (rather than, for example, grouping together all interventions based on ultraviolet light, or all interventions based on no-touch hydrogen peroxide systems, which would have assumed that such systems have equal effectiveness). The data inputs for NMAs based on *Acinetobacter* spp., *Clostridioides difficile*, meticillin-resistant *Staphylococcus aureus* (MRSA) and vancomycin-resistant *Enterococcus* (VRE) are presented in Tables H.1 to H.4, respectively.

## Table H.1: Network meta-analysis data inputs for *Acinetobacter* spp.

| **Citation** | **Risk of** | **Intervention** | **Reference treatment** | **log-IRR** | **SE of log-IRR** | **Reviewer comments** |
| --- | --- | --- | --- | --- | --- | --- |
| Anderson 2017[8] | Acquisition | UV-Ca | Manual cleaning/disinfectionb | -0.4473 | 2.0000 | Adjustment for zero events with UV-C and manual cleaning/disinfection |
| Anderson 2017[8] | Acquisition | UV-Cc | Manual cleaning/disinfectionb | -0.2434 | 2.0000 | Adjustment for zero events with UV-C and manual cleaning/disinfection |
| Anderson 2017[8] | Acquisition | Manual cleaning/disinfectiond | Manual cleaning/disinfectionb | 1.5635 | 1.6330 | Adjustment for zero events with standard manual cleaning/disinfection |
| Morikane 2020[28] | Infection | PX-UV | Manual cleaning/disinfection | -0.9943 | 0.5669 | Back calculation of SE from 95% CI for adjusted IRR |
| Napolitano 2015[32] | Infection | UV-C | Manual cleaning/disinfection | -1.2667 | 0.8018 |  |
| Raggi 2018[35] | Infection | UV-C | Manual cleaning/disinfection | -0.7565 | 0.3814 |  |

CI confidence interval; IRR incidence rate ratio; PX-UV pulsed-xenon ultraviolet; SE standard error; UV-C ultraviolet C
a After bleach disinfection
b Standard cleaning/disinfection
c After standard cleaning/disinfection
d Bleach disinfection

## Table H.2: Network meta-analysis data inputs for *Clostridioides difficile*

| **Citation** | **Risk of** | **Intervention** | **Reference treatment** | **log-IRR** | **SE of log-IRR** | **Reviewer comments** |
| --- | --- | --- | --- | --- | --- | --- |
| Anderson 2017[8] | Infection | UV-Ca | Manual cleaning/disinfectionb | 0.0000 | 0.2862 | Back calculation of SE from 95% CI for adjusted IRR |
| Attia 2020[10] | Infection | PX-UV | Manual cleaning/disinfection | 0.0252 | 0.1934 | Back calculation of events from reported incidence rates and numbers of patient days |
| Boyce 2008[11] | Infection | HPV | Manual cleaning/disinfection | -0.7644 | 0.3848 | Back calculation of SE from p=0.047 |
| Brite 2018[13] | Infection | PX-UV | Manual cleaning/disinfection | -0.2363 | 0.6134 | Back calculation of SE from p=0.70 |
| Green 2017[16] | Infection | PX-UV | Manual cleaning/disinfection | -0.9890 | 1.4907 | Adjustment for zero events with PX-UV |
| Haas 2014[17] | Infection | PX-UV | Manual cleaning/disinfection | -0.1951 | 0.0834 | Back calculation of patient days from events and incidence rates |
| Horn 2015[19] | Infection | HPV | Manual cleaning/disinfection | -0.4274 | 0.1432 | Back calculation of patient days from events and incidence rates |
| Levin 2013[22] | Infection | PX-UV | Manual cleaning/disinfection | -0.7539 | 0.3114 |  |
| Manian 2013[23] | Infection | HPV | Manual cleaning/disinfection | -0.4605 | 0.1108 |  |
| McCord 2016[24] | Infection | HPV | Manual cleaning/disinfection | -0.9163 | 0.1096 | Back calculation of patient days from events and incidence rates |
| McMullen 2020[25] | Infection | PX-UV | Manual cleaning/disinfection | -0.0684 | 0.1095 | Hospital A |
| McMullen 2020[25] | Infection | UV-C | Manual cleaning/disinfection | 0.2932 | 0.2412 | Hospital B |
| McMullen 2020[25] | Infection | PX-UV | Manual cleaning/disinfection | 0.2018 | 0.1642 | Hospital C |
| Miller 2015[26] | Infection | PX-UV | Manual cleaning/disinfection | -0.8438 | 0.2982 | Back calculation of patient days from events and incidence rates |
| Napolitano 2015[32] | Infection | UV-C | Manual cleaning/disinfection | -0.6200 | 0.3589 |  |
| Passaretti 2013[33] | Infection | HPV | Manual cleaning/disinfection | -0.7133 | 0.5658 | Back calculation of SE from 95% CI for adjusted IRR |
| Pegues 2017[34] | Infection | UV-C | Manual cleaning/disinfection | -0.7133 | 0.3279 | Back calculation of SE from 95% CI for adjusted IRR |
| Sampathkumar 2019[37] | Infection | PX-UV | Manual cleaning/disinfection | -0.6458 | 0.3420 |  |
| Vianna 2016[39] | Infection | PX-UV | Manual cleaning/disinfection | -0.5238 | 0.1883 |  |
| Boyce 2017[12] | Infection | Manual cleaning/disinfectionc | Manual cleaning/disinfectiond | -0.6257 | 0.5000 | Included in NMA only to strengthen estimation of between-study SD |

CI confidence interval; HPV hydrogen peroxide vapour; IRR incidence rate ratio; NMA network meta-analysis; PX-UV pulsed-xenon ultraviolet; SD standard deviation; SE standard error; UV-C ultraviolet C
a After bleach disinfection
b Bleach disinfection
c Improved hydrogen peroxide cleaning/disinfection
d Standard cleaning/disinfection

## Table H.3: Network meta-analysis data inputs for methicillin-resistant *Staphylococcus aureus*

| **Citation** | **Risk of** | **Intervention** | **Reference treatment** | **log-IRR** | **SE of log-IRR** | **Reviewer comments** |
| --- | --- | --- | --- | --- | --- | --- |
| Anderson 2017[8] | Acquisition | UV-Ca | Manual cleaning/disinfectionb | -0.0305 | 0.1141 | Back calculation of SE from 95% CI for adjusted IRR |
| Anderson 2017[8] | Acquisition | UV-Cc | Manual cleaning/disinfectionb | -0.2485 | 0.1514 | Back calculation of SE from 95% CI for adjusted IRR |
| Anderson 2017[8] | Acquisition | Manual cleaning/disinfectiond | Manual cleaning/disinfectionb | 0.0000 | 0.0993 | Back calculation of SE from 95% CI for adjusted IRR |
| Green 2017[16] | Acquisition | PX-UV | Manual cleaning/disinfection | 0.2274 | 0.6770 |  |
| Haas 2014[17] | Acquisition | PX-UV | Manual cleaning/disinfection | -0.3102 | 0.1144 | Back calculation of patient days from events and incidence rates |
| Horn 2015[19] | Acquisition | HPV | Manual cleaning/disinfection | -0.5705 | 0.4174 | Back calculation of patient days from events and incidence rates |
| Kitagawa 2021[20] | Acquisition | PX-UV | Manual cleaning/disinfection | -0.5870 | 0.2993 | Back calculation of SE from 95% CI for adjusted IRR |
| Mitchell 2014[27] | Acquisition | AHP | Manual cleaning/disinfection | -0.3747 | 0.6771 | Back calculation of SE from p=0.58 |
| Morikane 2020[28] | Infection | PX-UV | Manual cleaning/disinfection | -0.3425 | 0.1108 | Back calculation of SE from 95% CI for adjusted IRR |
| Napolitano 2015[32] | Infection | UV-C | Manual cleaning/disinfection | -0.0139 | 0.5345 |  |
| Passaretti 2013[33] | Acquisition | HPV | Manual cleaning/disinfection | -0.6349 | 0.6160 | Back calculation of SE from 95% CI for adjusted IRR |
| Raggi 2018[35] | Infection | UV-C | Manual cleaning/disinfection | -0.3680 | 0.1655 |  |
| Vianna 2016[39] | Infection | PX-UV | Manual cleaning/disinfection | 0.1789 | 0.2391 |  |
| Boyce 2017[12] | Acquisition | Manual cleaning/disinfectione | Manual cleaning/disinfectionb | -0.3538 | 0.2808 | Included in NMA only to strengthen estimation of between-study SD |

AHP aerosolized hydrogen peroxide; CI confidence interval; HPV hydrogen peroxide vapour; IRR incidence rate ratio; NMA network meta-analysis; PX-UV pulsed-xenon ultraviolet; SD standard deviation; SE standard error; UV-C ultraviolet C
a After bleach disinfection
b Standard cleaning/disinfection
c After standard cleaning/disinfection
d Bleach disinfection
e Improved hydrogen peroxide cleaning/disinfection

## Table H.4: Network meta-analysis data inputs for vancomycin-resistant *Enterococcus*

| **Citation** | **Risk of** | **Intervention** | **Reference treatment** | **log-IRR** | **SE of log-IRR** | **Reviewer comments** |
| --- | --- | --- | --- | --- | --- | --- |
| Anderson 2017[8] | Acquisition | UV-Ca | Manual cleaning/disinfectionb | -1.0217 | 0.3465 | Back calculation of SE from 95% CI for adjusted IRR |
| Anderson 2017[8] | Acquisition | UV-Cc | Manual cleaning/disinfectionb | -0.8916 | 0.5509 | Back calculation of SE from 95% CI for adjusted IRR |
| Anderson 2017[8] | Acquisition | Manual cleaning/disinfectiond | Manual cleaning/disinfectionb | -0.8440 | 0.4237 | Back calculation of SE from 95% CI for adjusted IRR |
| Brite 2018[13] | Infection | PX-UV | Manual cleaning/disinfection | 0.1907 | 0.3636 | Back calculation of SE from p=0.60 |
| Haas 2014 [17] | Acquisition | PX-UV | Manual cleaning/disinfection | -0.2094 | 0.0784 | Back calculation of patient days from events and incidence rates |
| Horn 2015[19] | Acquisition | HPV | Manual cleaning/disinfection | -3.0445 | 1.0488 | Back calculation of patient days from events and incidence rates |
| Napolitano 2015[32] | Infection | UV-C | Manual cleaning/disinfection | -0.1317 | 0.3436 |  |
| Passaretti 2013[33] | Acquisition | HPV | Manual cleaning/disinfection | -1.3863 | 0.4571 | Back calculation of SE from 95% CI for adjusted IRR |
| Raggi 2018[35] | Infection | UV-C | Manual cleaning/disinfection | -0.4200 | 0.2417 |  |
| Sampathkumar 2019[37] | Acquisition | PX-UV | Manual cleaning/disinfection | -0.9600 | 0.5278 |  |
| Vianna 2016[39] | Infection | PX-UV | Manual cleaning/disinfection | -0.6966 | 0.3100 |  |
| Boyce 2017[12] | Acquisition | Manual cleaning/disinfectione | Manual cleaning/disinfectionb | -0.1858 | 0.1735 | Included in NMA only to strengthen estimation of between-study SD |

CI confidence interval; HPV hydrogen peroxide vapour; IRR incidence rate ratio; NMA network meta-analysis; PX-UV pulsed-xenon ultraviolet; SD standard deviation; SE standard error; UV-C ultraviolet C
a After bleach disinfection
b Standard cleaning/disinfection
c After standard cleaning/disinfection
d Bleach disinfection
e Improved hydrogen peroxide cleaning/disinfection

The decision set for each NMA comprised any automated room decontamination system that had been compared with manual cleaning/disinfection or another automated system. However, the comparator set (which determined the full breadth of studies or treatment arms included in each NMA) included studies identified through the systematic literature searches that compared different approaches to manual cleaning/disinfection. The inclusion of additional studies or treatment arms comparing manual approaches to cleaning/disinfection ensured that the widest possible interpretation of manual cleaning/disinfection was considered in the analysis. This served to strengthen the estimation of between-study standard deviations (SDs) in random effects NMAs (see below) and aided interpretation of NMA results in terms of realistic choices between automated and manual approaches to cleaning/disinfection. The NMA data inputs for *C. difficile*, MRSA and VRE included a multi-arm study,[8] in which manual cleaning/disinfection was performed using either standard cleaning/disinfection or bleach disinfection, with both arms being included in the NMAs. Another study,[12] which compared two approaches to manual cleaning/disinfection was included in the NMAs to strengthen the between-study SD estimate.

## Network diagrams

The R package *network*[103, 104] was used to create the network diagrams presented in Figure H.1. The size of each node in the figure is proportional to the number of patient days recorded for that node relative to the total number of patient days recorded for *C. difficile*. The thickness of the connecting lines is proportional to the number of study arms reporting that treatment comparison.

The geometry of each network was explored, for example, in terms of potential biases feeding into the determination of GRADE quality ratings.

## Model fitting

Log-transformed IRRs can be assumed to follow a normal distribution and so the NMAs were fitted using a model with a normal likelihood in which the data were differences between treatments in different study arms (log-IRRs are equivalent to differences between log-transformed incidence rates for different study arms) and an identity link function. Model fitting was performed using WinBUGS code adapted from Dias (2011).[6] The code incorporated adjustments for correlation in multi-arm studies; correlation arises because studies involving three or more treatment arms contribute multiple log-IRRs to an NMA in which each log-IRR is calculated using the same data for the reference treatment.

As part of the model-fitting process, IRRs for all pairwise treatment contrasts supported by the network were calculated (since these are easier to interpret than log-IRRs). Model results were obtained from posterior distributions in the form of medians and 95% credible intervals (CrIs; analogous to 95% CIs used in frequentist approaches to statistical inference). Treatment rankings were also calculated for each iteration involved in model fitting, and these were summarised using surface under cumulative ranking (SUCRA) scores. SUCRA scores were expressed as percentages such that a treatment uniformly ranked most (least) effective over all iterations would have a score of 100% (0%).

NMA relies on assumptions of transitivity (meaning that, for example, patients in different settings could equally well have experienced the same interventions in terms of automated decontamination, rather than the interventions being setting-specific) and consistency (meaning that treatment effects estimated via direct and indirect evidence are equivalent). As part of each NMA, the validity of these assumptions was assessed as far as practicable in line with best practice.[5, 7]

## Figure H.1: Network diagrams for the clinical outcomes of infection or acquisition\*



\* Total numbers of patient days (approximated because of incomplete reporting): *Acinetobacter* spp. 168,584; *C. difficile* 3,586,898; MRSA 1,557,848; VRE 1,429,978
AHP aerosolized hydrogen peroxide; HPV hydrogen peroxide vapour; MRSA meticillin-resistant *Staphylococcus aureus*; PX-UV pulsed-xenon ultraviolet; UV-C ultraviolet C; VRE vancomycin-resistant *Enterococcus*

## Results

## Table H.5: Network meta-analysis results for clinical outcomes of infection or acquisition – *Acinetobacter* spp. incidence rate ratios (95% credible intervals)\*

|  |  |  |
| --- | --- | --- |
| **Manual cleaning/disinfection** |  |  |
| 0.376(0.068 to 1.638) | **UV-C** |  |
| 0.370(0.023 to 5.755) | 0.987(0.046 to 26.310) | **PX-UV** |

\* IRRs lower (greater) than 1 favour the row (column) defining treatment; 95% CrIs that exclude one shown in **bold**; posterior median of log-IRR between-study SD, 0.638 (95% CrI 0.027 to 3.261)
CrI credible interval; IRR incidence rate ratio; PX-UV pulsed-xenon ultraviolet; SD standard deviation; UV-C ultraviolet C

## Table H.6: Network meta-analysis results for clinical outcomes of infection or acquisition – *Clostridioides difficile* incidence rate ratios (95% credible intervals)\*

|  |  |  |  |
| --- | --- | --- | --- |
| **Manual cleaning/disinfection** |  |  |  |
| 0.822(0.525 to 1.258) | **UV-C** |  |  |
| **0.761(0.571 to 0.972)** | 0.925(0.553 to 1.531) | **PX-UV** |  |
| **0.532(0.372 to 0.755)** | 0.646(0.373 to 1.145) | 0.699(0.458 to 1.108) | **HPV** |

\* IRRs lower (greater) than 1 favour the row (column) defining treatment; 95% CrIs that exclude one shown in **bold**; posterior median of log-IRR between-study SD, 0.295 (95% CrI 0.140 to 0.538)
CrI credible interval; HPV hydrogen peroxide vapour; IRR incidence rate ratio; PX-UV pulsed-xenon ultraviolet; SD standard deviation; UV-C ultraviolet C

## Table H.7: Network meta-analysis results for clinical outcomes of infection or acquisition – meticillin-resistant *Staphylococcus aureus* incidence rate ratios (95% credible intervals)\*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Manual cleaning/disinfection** |  |  |  |  |
| 0.838(0.656 to 1.052) | **UV-C** |  |  |  |
| **0.760(0.621 to 0.966)** | 0.907(0.674 to 1.288) | **PX-UV** |  |  |
| 0.554(0.272 to 1.150) | 0.663(0.314 to 1.430) | 0.727(0.343 to 1.543) | **HPV** |  |
| 0.701(0.170 to 2.677) | 0.838(0.200 to 3.248) | 0.919(0.220 to 3.545) | 1.261(0.263 to 5.709) | **AHP** |

\* IRRs lower (greater) than 1 favour the row (column) defining treatment; 95% CrIs that exclude one shown in **bold**; posterior median of log-IRR between-study SD, 0.096 (95% CrI 0.004 to 0.361)
AHP aerosolized hydrogen peroxide; CrI credible interval; HPV hydrogen peroxide vapour; IRR incidence rate ratio; PX-UV pulsed-xenon ultraviolet; SD standard deviation; UV-C ultraviolet C

## Table H.8: Network meta-analysis results for clinical outcomes of infection or acquisition – vancomycin-resistant *Enterococcus* incidence rate ratios (95% credible intervals)\*

|  |  |  |  |
| --- | --- | --- | --- |
| **Manual cleaning/disinfection** |  |  |  |
| 0.626(0.376 to 1.075) | **UV-C** |  |  |
| 0.740(0.427 to 1.139) | 1.177(0.534 to 2.254) | **PX-UV** |  |
| **0.180(0.060 to 0.482)** | **0.287(0.084 to 0.860)** | **0.247(0.077 to 0.742)** | **HPV** |

\* IRRs lower (greater) than 1 favour the row (column) defining treatment; 95% CrIs that exclude one shown in **bold**; posterior median of log-IRR between-study SD, 0.284 (95% CrI 0.017 to 0.830)
CrI credible interval; HPV hydrogen peroxide vapour; IRR incidence rate ratio; PX-UV pulsed-xenon ultraviolet; SD standard deviation; UV-C ultraviolet C

## Table H.9: Network meta-analysis results for clinical outcomes of infection or acquisition – treatment rankings based on surface under cumulative ranking scores\*

|  |  |
| --- | --- |
| **Microorganism** | **← Less effective** **More effective →** |
| *Acinetobacter* spp.a,b | Manual cleaning/disinfection (SUCRA=11%) | PX-UV(SUCRA=34%) | UV-C(SUCRA=36%) |  |  |
| *C. difficile*a | Manual cleaning/disinfection (SUCRA=6%) | UV-C(SUCRA=32%) | **PX-UV(SUCRA=42%)** | **HPV(SUCRA=72%)** |  |
| MRSA | Manual cleaning/disinfection (SUCRA=11%) | UV-C(SUCRA=44%) | AHP(SUCRA=56%) | **PX-UV(SUCRA=60%)** | HPV(SUCRA=81%) |
| VREb | Manual cleaning/disinfection (SUCRA=3%) | PX-UV(SUCRA=31%) | UV-C(SUCRA=42%) | **HPV(SUCRA=74%)** |  |

\* **Bold** in columns two to six signifies statistically significantly more effective than manual cleaning/disinfection
AHP aerosolized hydrogen peroxide; HPV hydrogen peroxide vapour; MRSA meticillin-resistant *Staphylococcus aureus*; PX-UV pulsed-xenon ultraviolet; SUCRA surface under cumulative ranking; UV-C ultraviolet C; VRE vancomycin-resistant *Enterococcus*
a No data for HPV
b No data for AHP

## Model checking and interpretation

Visual examination of deviance residuals for the log-IRRs included in each NMA revealed no systematic patterns or outliers. The median of the posterior distribution for the between-study SD was 0.096 for MRSA, 0.284 for VRE and 0.295 for *C. difficile*, all of which suggest low heterogeneity, while the posterior median for *Acinetobacter* spp. was 0.638, indicating moderate heterogeneity. The degree of heterogeneity in the data for *Acinetobacter* spp. was perhaps not surprising given that the outcomes were defined somewhat differently in the studies (multidrug-resistant *Acinetobacter* acquisitions,[8] two-drug resistant *A. baumannii* infections,[28] and *A. baumannii* infections)[32, 35] whereas the definitions of *C. difficile*, MRSA and VRE infections or acquisitions were more consistent across studies.

Some of the studies included in the NMAs focused on settings occupied by immunocompromised patients (such as patient rooms in the bone marrow transplant unit of a tertiary-care cancer).[13 ] However, there was nothing to suggest that particular systems for automated room decontamination could not have been implemented in these settings, and so the assumption of transitivity was expected to hold.

The validity of the assumption of consistency could not be investigated because each NMA was based on a star network in which direct evidence was available only for comparisons between automated room decontamination systems and manual cleaning/disinfection. Treatment comparisons involving any two automated decontamination systems were wholly reliant on indirect evidence. The 95% CrIs for these effect estimates tended to be very wide, indicating a large amount of uncertainty in the estimates. This was recognized when determining GRADE quality ratings for the domain of imprecision (see Appendix I).

# Appendix I – GRADE tables

## Table I.1: *Acinetobacter* spp. infection or acquisition

|  |  |  |  |
| --- | --- | --- | --- |
| **Quality assessment** | **Number of events (rate)** | **Effect** | **Quality** |
| **Number of studies** | **Design** | **Risk of bias** | **Inconsistency** | **Indirectness** | **Imprecision** | **Other considerations** | **Intervention** | **Comparator** | **Relative** | **Absolute** |
| ***Acinetobacter* spp. infections or acquisitions per 1,000 patient days, UV-C versus PX-UV versus standard cleaning/disinfection** |
| 4 (Anderson 2017;[8] Morikane 2020;[28] Napolitano 2015;[32] Raggi 2018)[35] | Multicentre cluster randomized controlled crossover trial (1), controlled before–after study (1), uncontrolled before–after study (2) | Seriousa | Seriousb | No serious indirectness | Very seriousc | None | See NMA data inputs in Table H.1 | See NMA data inputs in Table H.1 | See NMA results for all pairwise comparisons (direct and indirect) in Table H.5 | Not calculable | Very low |

CrI credible interval; NMA network meta-analysis; PX-UV pulsed-xenon ultraviolet; UV-C ultraviolet C
a NMA in which at least 50% of included studies have a limitation related to design, analysis or reporting that is not covered by the other quality domains
b NMA based on a star network for which inconsistency cannot be assessed
c NMA in which at least 50% of 95% CrIs for relative effects cross both the lower (0.8) and upper (1.25) default thresholds for imprecision

## Table I.2: *Clostridioides difficile* infection or acquisition

|  |  |  |  |
| --- | --- | --- | --- |
| **Quality assessment** | **Number of events (rate)** | **Effect** | **Quality** |
| **Number of studies** | **Design** | **Risk of bias** | **Inconsistency** | **Indirectness** | **Imprecision** | **Other considerations** | **Intervention** | **Comparator** | **Relative** | **Absolute** |
| ***C. difficile* infections per 1,000 patient days, UV-C versus PX-UV versus HPV versus standard cleaning/disinfection** |
| 18 (Anderson 2017;[8] Attia 2020;[10] Boyce 2008;[11] Boyce 2017;[12] Brite 2018;[13] Green 2017;[16] Haas 2014;[17] Horn 2015;[19] Levin 2013[22] Manian 2013;[23] McCord 2016;[24] McMullen 2020;[25] Miller 2015;[26] Napolitano 2015;[32] Passaretti 2013;[33] Pegues 2017;[34] Sampathkumar 2019;[37] Vianna 2016)[39] | Multicentre cluster randomized controlled crossover trial (2), controlled before–after study (2), interrupted time series (3), uncontrolled before–after study (11) | Seriousa | Seriousb | No serious indirectness | Seriousc | None | See NMA data inputs in Table H.2 | See NMA data inputs in Table H.2 | See NMA results for all pairwise comparisons (direct and indirect) in Table H.6 | Not calculable | Low |
| ***C. difficile* infections per 10,000 patient days, UV-C versus standard cleaning/disinfection** |
| 1 (Doll 2020)[15] | Interrupted time series | Seriousd | No serious inconsistency | No serious indirectness | Very seriouse | None | Not calculable | Not calculable | Segmented regression: change in intercept, 0.095 (95% CI -4.294 to 4.483); change in slope, -0.149 (95% CI -0.787 to 0.489) | Not calculable | Very low |
| ***C. difficile* infections per 10,000 patient days in bone marrow transplant unit, UV-C at every terminal discharge versus UV-C only at terminal discharge of patients with *C. difficile* infection** |
| 1 (Murphy 2020)[29] | Interrupted time series | Seriousd | No serious inconsistency | No serious indirectness | Very seriouse | None | Not calculable | Not calculable | Segmented regression: change in intercept, unquantified decrease, p=0.044; change in slope, unquantified decrease, p=0.417 | Not calculable | Very low |
| ***C. difficile* infections per 10,000 patient days in oncology unit, UV-C at every terminal discharge versus UV-C only at terminal discharge of patients with *C. difficile* infection** |
| 1 (Murphy 2020)[29] | Interrupted time series | Seriousd | No serious inconsistency | No serious indirectness | Very seriouse | None | Not calculable | Not calculable | Segmented regression: change in intercept, unquantified increase, p=0.283; change in slope, unquantified decrease, p=0.870 | Not calculable | Very low |

CI confidence interval; CrI credible interval; HPV hydrogen peroxide vapour; IRR incidence rate ratio; NMA network meta-analysis; PX-UV pulsed-xenon ultraviolet; UV-C ultraviolet C
a NMA in which at least 50% of included studies have a limitation related to design, analysis or reporting that is not covered by the other quality domains
b NMA based on a star network for which inconsistency cannot be assessed
c NMA in which at least 50% of 95% CrIs for relative effects cross either the lower (0.8) or upper (1.25) default thresholds for imprecision
d Single study with at least one limitation related to design, analysis or reporting that is not covered by the other quality domains
e IRR and associated CI not calculable

## Table I.3: *Klebsiella pneumoniae* infection or acquisition

|  |  |  |  |
| --- | --- | --- | --- |
| **Quality assessment** | **Number of events (rate)** | **Effect** | **Quality** |
| **Number of studies** | **Design** | **Risk of bias** | **Inconsistency** | **Indirectness** | **Imprecision** | **Other considerations** | **Intervention** | **Comparator** | **Relative** | **Absolute** |
| ***K. pneumoniae* infections per 1,000 patient days, UV-C versus standard cleaning/disinfection** |
| 1 (Napolitano 2015)[32] | Uncontrolled before–after study | Seriousa | No serious inconsistency | No serious indirectness | Seriousb | See footnotec | 0/18,184 (0 per 1,000 patient days) | 8/17,933 (0.44c per 1,000 patient days) | IRR=0.058 (95% CI 0.003 to 1.005) | Not calculable | Low |
| ***K. pneumoniae* infections per 1,000 patient days, UV-C versus standard cleaning/disinfection** |
| 1 (Raggi 2018)[35] | Uncontrolled before–after study | Seriousa | No serious inconsistency | No serious indirectness | Very seriousd | See footnotee | 76/62,242 (1.22 per 1,000 patient days) | 73/64,262 (1.16e per 1,000 patient days) | IRR=1.075 (95% CI 0.780 to 1.482) | Not calculable | Very low |

CI confidence interval; IRR incidence rate ratio; UV-C ultraviolet C
a Single study with at least one limitation related to design, analysis or reporting that is not covered by the other quality domains
b Single study with a 95% CI for the relative effect that crosses either the lower (0.8) or upper (1.25) default thresholds for imprecision
c Intervention rate reported as 0.44 in the article, but 8/17,933=0.45
d Single study with a 95% CI for the relative effect that crosses both the lower (0.8) and upper (1.25) default thresholds for imprecision
e Comparator rate reported as 1.16 in the article, but 73/64,262=1.14

## Table I.4: Meticillin-resistant *Staphylococcus aureus* infection or acquisition

|  |  |  |  |
| --- | --- | --- | --- |
| **Quality assessment** | **Number of events (rate)** | **Effect** | **Quality** |
| **Number of studies** | **Design** | **Risk of bias** | **Inconsistency** | **Indirectness** | **Imprecision** | **Other considerations** | **Intervention** | **Comparator** | **Relative** | **Absolute** |
| **MRSA infections or acquisitions per 1,000 patient days, UV-C versus PX-UV versus HPV versus AHP versus standard cleaning/disinfection** |
| 12 (Anderson 2017;[8] Boyce 2017;[12] Green 2017;[16] Haas 2014;[17] Horn 2015;[19] Kitagawa 2021;[20] Mitchell 2014;[27] Morikane 2020;[28] Napolitano 2015;[32] Passaretti 2013;[33] Raggi 2018;[35] Vianna 2016)[39] | Multicentre cluster randomized controlled crossover trial (2), controlled before–after study (3), interrupted time series (1), uncontrolled before–after study (6) | Seriousa | Seriousb | Seriousc | Very seriousd | None | See NMA data inputs in Table H.3 | See NMA data inputs in Table H.3 | See NMA results for all pairwise comparisons (direct and indirect) in Table H.7 | Not calculable | Very low |
| **MRSA colonizations, HPV versus standard cleaning/disinfection** |
| 1 (Hardy 2007)[18] | Uncontrolled before–after study | Seriouse | No serious inconsistency | No serious indirectness | Very seriousf | See footnoteg | 7g | 3g | Not calculable | Not calculable | Very low |

AHP aerosolized hydrogen peroxide; CI confidence interval; CrI credible interval; HPV hydrogen peroxide vapour; IRR incidence rate ratio; MRSA meticillin-resistant *Staphylococcus aureus*; NMA network meta-analysis; PX-UV pulsed-xenon ultraviolet; UV-C ultraviolet C
a NMA in which at least 50% of included studies have a limitation related to design, analysis or reporting that is not covered by the other quality domains
b NMA based on a star network for which inconsistency cannot be assessed
c AHP in single-occupancy rooms only (manually applied hydrogen peroxide in shared rooms)
d NMA in which at least 50% of 95% CrIs for relative effects cross both the lower (0.8) and upper (1.25) default thresholds for imprecision
e Single study with at least one limitation related to design, analysis or reporting that is not covered by the other quality domains
f IRR and associated CI not calculable
g One-off application of HPV; article reported only the number of patients who become colonized with MRSA during the study period

## Table I.5: *Pseudomonas aeruginosa* infection or acquisition

|  |  |  |  |
| --- | --- | --- | --- |
| **Quality assessment** | **Number of events (rate)** | **Effect** | **Quality** |
| **Number of studies** | **Design** | **Risk of bias** | **Inconsistency** | **Indirectness** | **Imprecision** | **Other considerations** | **Intervention** | **Comparator** | **Relative** | **Absolute** |
| ***P. aeruginosa* infections per 1,000 patient days, UV-C versus standard cleaning/disinfection** |
| 1 (Raggi 2018)[35] | Uncontrolled before–after study | Seriousa | No serious inconsistency | No serious indirectness | Seriousb | See footnotec | 70/62,242 (1.16c per 1,000 patient days) | 83/64,262 (1.29 per 1,000 patient days) | IRR=0.871 (95% CI 0.634 to 1.197) | Not calculable | Low |
| **Multidrug resistant *P. aeruginosa* acquisitions per 1,000 patient days, PX-UV versus standard cleaning/disinfection** |
| 1 (Green 2017)[16] | Uncontrolled before–after study | Seriousa | No serious inconsistency | No serious indirectness | Very seriousd | None | 0/653 (0.0 per 1,000 patient days) | 2/2,186 (0.91 per 1,000 patient days) | IRR=0.670 (95% CI 0.032 to 13.947) | Not calculable | Very low |

CI confidence interval; IRR incidence rate ratio; PX-UV pulsed-xenon ultraviolet; UV-C ultraviolet C
a Single study with at least one limitation related to design, analysis or reporting that is not covered by the other quality domains
b Single study with a 95% CI for the relative effect that crosses either the lower (0.8) or upper (1.25) default thresholds for imprecision
c Intervention rate reported as 1.16 in the article, but 70/62,242=1.12
d Single study with a 95% CI for the relative effect that crosses both the lower (0.8) and upper (1.25) default thresholds for imprecision

## Table I.6: *Stenotrophomonas maltophilia* infection or acquisition

|  |  |  |  |
| --- | --- | --- | --- |
| **Quality assessment** | **Number of events (rate)** | **Effect** | **Quality** |
| **Number of studies** | **Design** | **Risk of bias** | **Inconsistency** | **Indirectness** | **Imprecision** | **Other considerations** | **Intervention** | **Comparator** | **Relative** | **Absolute** |
| ***S. maltophilia* acquisitions per 1,000 patient days, PX-UV versus standard cleaning/disinfection** |
| 1 (Green 2017)[16] | Uncontrolled before–after study | Seriousa | No serious inconsistency | No serious indirectness | Very seriousb | None | 3/653 (4.6 per 1,000 patient days) | 4/2,186 (1.83 per 1,000 patient days) | IRR=2.511 (95% CI 0.562 to 11.218) | Not calculable | Very low |

CI confidence interval; IRR incidence rate ratio; PX-UV pulsed-xenon ultraviolet
a Single study with at least one limitation related to design, analysis or reporting that is not covered by the other quality domains
b Single study with a 95% CI for the relative effect that crosses both the lower (0.8) and upper (1.25) default thresholds for imprecision

## Table I.7: Vancomycin-resistant *Enterococcus* infection or acquisition

|  |  |  |  |
| --- | --- | --- | --- |
| **Quality assessment** | **Number of events (rate)** | **Effect** | **Quality** |
| **Number of studies** | **Design** | **Risk of bias** | **Inconsistency** | **Indirectness** | **Imprecision** | **Other considerations** | **Intervention** | **Comparator** | **Relative** | **Absolute** |
| **VRE infections or acquisitions per 1,000 patient days, UV-C versus PX-UV versus HPV versus standard cleaning/disinfection** |
| 10 (Anderson 2017;[8] Boyce 2017;[12] Brite 2018;[13] Haas 2014;[17] Horn 2015;[19] Napolitano 2015;[32] Passaretti 2013;[33] Raggi 2018;[35] Sampathkumar 2019;[37] Vianna 2016)[39] | Multicentre cluster randomized controlled crossover trial (2), controlled before–after study (2), interrupted time series (1), uncontrolled before–after study (5) | Seriousa | Seriousb | No serious indirectness | Seriousc | None | See NMA data inputs in Table H.4 | See NMA data inputs in Table H.4 | See NMA results for all pairwise comparisons (direct and indirect) in Table H.8 | Not calculable | Low |

CrI credible interval; HPV hydrogen peroxide vapour; NMA network meta-analysis; PX-UV pulsed-xenon ultraviolet; UV-C ultraviolet C; VRE vancomycin-resistant *Enterococcus*
a NMA in which at least 50% of included studies have a limitation related to design, analysis or reporting that is not covered by the other quality domains
b NMA based on a star network for which inconsistency cannot be assessed
c NMA in which at least 50% of 95% CrIs for relative effects cross either the lower (0.8) or upper (1.25) default thresholds for imprecision

## Table I.8: Enterobacteriaceae infection or acquisition

|  |  |  |  |
| --- | --- | --- | --- |
| **Quality assessment** | **Number of events (rate)** | **Effect** | **Quality** |
| **Number of studies** | **Design** | **Risk of bias** | **Inconsistency** | **Indirectness** | **Imprecision** | **Other considerations** | **Intervention** | **Comparator** | **Relative** | **Absolute** |
| **ESBL Enterobacteriaceae acquisitions per 1,000 patient days, PX-UV versus standard cleaning/disinfection** |
| 1 (Green 2017)[16] | Uncontrolled before–after study | Seriousa | No serious inconsistency | No serious indirectness | Very seriousb | None | 1/653 (1.5 per 1,000 patient days) | 2/2,186 (0.91 per 1,000 patient days) | IRR=1.674 (95% CI 0.152 to 18.460) | Not calculable | Very low |

CI confidence interval; ESBL extended-spectrum beta lactamase-producing; IRR incidence rate ratio; PX-UV pulsed-xenon ultraviolet
a Single study with at least one limitation related to design, analysis or reporting that is not covered by the other quality domains
b Single study with a 95% CI for the relative effect that crosses both the lower (0.8) and upper (1.25) default thresholds for imprecision

## Table I.9: Multidrug-resistant Gram-negative rod infection or acquisition

|  |  |  |  |
| --- | --- | --- | --- |
| **Quality assessment** | **Number of events (rate)** | **Effect** | **Quality** |
| **Number of studies** | **Design** | **Risk of bias** | **Inconsistency** | **Indirectness** | **Imprecision** | **Other considerations** | **Intervention** | **Comparator** | **Relative** | **Absolute** |
| **MDR-GNR acquisitions per 1,000 patient days, PX-UV versus standard cleaning/disinfection** |
| 1 (Green 2017)[16] | Uncontrolled before–after study | Seriousa | No serious inconsistency | No serious indirectness | Very seriousb | None | 4/653 (6.1 per 1,000 patient days) | 8/2,186 (3.66 per 1,000 patient days) | IRR=1.674 (95% CI 0.504 to 5.559) | Not calculable | Very low |
| **MDR-GNR acquisitions per 1,000 patient days, HPV versus standard cleaning/disinfection** |
| 1 (Passaretti 2013)[33] | Controlled before–after study | Seriousa | No serious inconsistency | No serious indirectness | Very seriousb | None | 7/4,225 (1.7 per 1,000 patient days) | 23/9,928 (2.3 per 1,000 patient days) | IRR=0.715 (95% CI 0.307 to 1.667) | Not calculable | Very low |

CI confidence interval; HPV hydrogen peroxide vapour; IRR incidence rate ratio; MDR-GNR multidrug-resistant Gram-negative rods; PX-UV pulsed-xenon ultraviolet
a Single study with at least one limitation related to design, analysis or reporting that is not covered by the other quality domains
b Single study with a 95% CI for the relative effect that crosses both the lower (0.8) and upper (1.25) default thresholds for imprecision

## Table I.10: Extended-spectrum beta lactamase-producing Gram-negative bacterial infection or acquisition

|  |  |  |  |
| --- | --- | --- | --- |
| **Quality assessment** | **Number of events (rate)** | **Effect** | **Quality** |
| **Number of studies** | **Design** | **Risk of bias** | **Inconsistency** | **Indirectness** | **Imprecision** | **Other considerations** | **Intervention** | **Comparator** | **Relative** | **Absolute** |
| **ESBL-GNB acquisitions per 1,000 patient days, HPV versus standard cleaning/disinfection** |
| 1 (Horn 2015)[19] | Uncontrolled before–after study | Seriousa | No serious inconsistency | No serious indirectness | No serious imprecision | None | 1/NR (0.01 per 1,000 patient days) | 8/NR (0.16 per 1,000 patient days) | IRR=0.063 (95% CI 0.008 to 0.500) | Not calculable | Low |

CI confidence interval; ESBL-GNB extended-spectrum beta lactamase-producing Gram-negative bacteria; HPV hydrogen peroxide vapour; IRR incidence rate ratio; NR not reported
a Single study with at least one limitation related to design, analysis or reporting that is not covered by the other quality domains

## Table I.11: Multidrug-resistant Gram-negative bacterial infection or acquisition

|  |  |  |  |
| --- | --- | --- | --- |
| **Quality assessment** | **Number of events (rate)** | **Effect** | **Quality** |
| **Number of studies** | **Design** | **Risk of bias** | **Inconsistency** | **Indirectness** | **Imprecision** | **Other considerations** | **Intervention** | **Comparator** | **Relative** | **Absolute** |
| **MDR-GNB acquisitions per 1,000 patient days, PX-UV versus standard cleaning/disinfection** |
| 1 (Haas 2014)[17] | Uncontrolled before–after study | Seriousa | No serious inconsistency | No serious indirectness | Seriousb | None | 148/NR (0.42 per 1,000 patient days) | 260/NR (0.52 per 1,000 patient days) | IRR=0.81 (95% CI 0.66 to 0.98) | Not calculable | Low |

CI confidence interval; MDR-GNB multidrug-resistant Gram-negative bacteria; IRR incidence rate ratio; NR not reported; PX-UV pulsed-xenon ultraviolet
a Single study with at least one limitation related to design, analysis or reporting that is not covered by the other quality domains
b Single study with a 95% CI for the relative effect that crosses either the lower (0.8) or upper (1.25) default thresholds for imprecision

## Table I.12: Surgical site infection

|  |  |  |  |
| --- | --- | --- | --- |
| **Quality assessment** | **Number of events (rate)** | **Effect** | **Quality** |
| **Number of studies** | **Design** | **Risk of bias** | **Inconsistency** | **Indirectness** | **Imprecision** | **Other considerations** | **Intervention** | **Comparator** | **Relative** | **Absolute** |
| **Surgical site infections per 100 class 1 (clean wound) procedures, PX-UV versus standard cleaning/disinfection** |
| 1 (Catalanotti 2016)[14] | Uncontrolled before–after study | Seriousa | No serious inconsistency | No serious indirectness | Seriousb | None | 29/10,883 (0.26 per 100 procedures) | 31/6,439 (0.48 per 100 procedures) | IRR=0.553 (95% CI 0.334 to 0.918) | Not calculable | Low |
| **Surgical site infections per 100 class 2 (clean contaminated wound) procedures, PX-UV versus standard cleaning/disinfection** |
| 1 (Catalanotti 2016)[14] | Uncontrolled before–after study | Seriousa | No serious inconsistency | No serious indirectness | Very seriousc | None | 26/7,825 (0.33 per 100 procedures) | 13/4,811 (0.27 per 100 procedures) | IRR=1.230 (95% CI 0.632 to 2.393) | Not calculable | Very low |
| **Surgical site infections per 100 orthopaedic procedures, visible (indigo and white) light versus standard cleaning/disinfection** |
| 1 (Murrell 2019)[30] | Controlled before–after study | Seriousa | No serious inconsistency | No serious indirectness | Seriousb | None | 5/1,510 (0.33 per 100 procedures) | 19/1,450 (1.31 per 100 procedures) | Adjusted OR=0.22 (95% CI 0.05 to 0.90) | Not calculable | Low |

CI confidence interval; IRR incidence rate ratio; OR odds ratio; PX-UV pulsed-xenon ultraviolet
a Single study with at least one limitation related to design, analysis or reporting that is not covered by the other quality domains
b Single study with a 95% CI for the relative effect that crosses either the lower (0.8) or upper (1.25) default thresholds for imprecision c Single study with a 95% CI for the relative effect that crosses both the lower (0.8) and upper (1.25) default thresholds for imprecision

## Table I.13: Device-associated infection

|  |  |  |  |
| --- | --- | --- | --- |
| **Quality assessment** | **Number of events (rate)** | **Effect** | **Quality** |
| **Number of studies** | **Design** | **Risk of bias** | **Inconsistency** | **Indirectness** | **Imprecision** | **Other considerations** | **Intervention** | **Comparator** | **Relative** | **Absolute** |
| **CAUTIs per 1,000 device-utilization days, PX-UV versus standard cleaning/disinfection** |
| 1 (Green 2017)[16] | Uncontrolled before–after study | Seriousa | No serious inconsistency | No serious indirectness | Very seriousb | None | NR/558 (1.79 per 1,000 device-utilization days) | NR/1,956 (rate per 1,000 device-utilization days NR) | p=0.23 | Not calculable | Very low |
| **CLABSIs per 1,000 device-utilization days, PX-UV versus standard cleaning/disinfection** |
| 1 (Green 2017)[16] | Uncontrolled before–after study | Seriousa | No serious inconsistency | No serious indirectness | Very seriousb | None | NR/542 (1.85 per 1,000 device-utilization days) | NR/1,899 (rate per 1,000 device-utilization days NR) | p=0.20 | Not calculable | Very low |
| **CLABSIs per 10,000 patient days in bone marrow transplant unit, UV-C at every terminal discharge versus UV-C only at terminal discharge of patients with *C. difficile* infection** |
| 1 (Murphy 2020)[29] | Interrupted time series | Seriousa | No serious inconsistency | No serious indirectness | Very seriousb | None | Not calculable | Not calculable | Segmented regression: change in intercept, unquantified decrease, p=0.048; change in slope, unquantified decrease, p=0.204 | Not calculable | Very low |
| **CLABSIs per 10,000 patient days in oncology unit, UV-C at every terminal discharge versus UV-C only at terminal discharge of patients with *C. difficile* infection** |
| 1 (Murphy 2020)[29] | Interrupted time series | Seriousa | No serious inconsistency | No serious indirectness | Very seriousb | None | Not calculable | Not calculable | Segmented regression: change in intercept unquantified decrease, p=0.160; change in slope, unquantified decrease, p=0.150 | Not calculable | Very low |
| **Ventilator-associated pneumonias per 1,000 device-utilization days, PX-UV versus standard cleaning/disinfection** |
| 1 (Green 2017)[16] | Uncontrolled before–after study | Seriousa | No serious inconsistency | No serious indirectness | Very seriousb | None | NR/381 (7.87 per 1,000 device-utilization days) | NR/1,466 (rate per 1,000 device-utilization days NR) | p=0.12 | Not calculable | Very low |

CAUTI catheter-associated urinary tract infection; CLABSI central line-associated bloodstream infection; CI confidence interval; IRR incidence rate ratio; NR not reported; PX-UV pulsed-xenon ultraviolet; UV-C ultraviolet C
a Single study with at least one limitation related to design, analysis or reporting that is not covered by the other quality domains
b IRR and associated CI not calculable

## Table I.14: Infection of specific body organs or systems

|  |  |  |  |
| --- | --- | --- | --- |
| **Quality assessment** | **Number of events (rate)** | **Effect** | **Quality** |
| **Number of studies** | **Design** | **Risk of bias** | **Inconsistency** | **Indirectness** | **Imprecision** | **Other considerations** | **Intervention** | **Comparator** | **Relative** | **Absolute** |
| **Enteric infections per 1,000 patient days, PX-UV versus standard cleaning/disinfection** |
| 1 (Kovach 2017)[21] | Uncontrolled before–after study | Seriousa | No serious inconsistency | No serious indirectness | Very seriousb | None | NR/NR (0.00 per 1,000 patient days) | NR/NR (rate per 1,000 patient days NR) | No inferential analyses reported | Not calculable | Very low |
| **Respiratory system infections per 1,000 patient days, PX-UV versus standard cleaning/disinfection** |
| 1 (Kovach 2017)[21] | Uncontrolled before–after study | Seriousa | No serious inconsistency | No serious indirectness | Very seriousb | None | NR/NR (0.04 per 1,000 patient days) | NR/NR (rate per 1,000 patient days NR) | p=0.017 | Not calculable | Very low |
| **Respiratory viral infections per 10,000 patient days in bone marrow transplant unit, UV-C at every terminal discharge versus UV-C only at terminal discharge of patients with *C. difficile* infection** |
| 1 (Murphy 2020)[29] | Interrupted time series | Seriousa | No serious inconsistency | No serious indirectness | Very seriousb | None | Not calculable | Not calculable | Segmented regression: change in intercept, unquantified decrease, p=0.805; change in slope, unquantified decrease, p=0.254 | Not calculable | Very low |
| **Respiratory viral infections per 10,000 patient days in oncology unit, UV-C at every terminal discharge versus UV-C only at terminal discharge of patients with *C. difficile* infection** |
| 1 (Murphy 2020)[29] | Interrupted time series | Seriousa | No serious inconsistency | No serious indirectness | Very seriousb | None | Not calculable | Not calculable | Segmented regression: change in intercept, unquantified decrease, p=0.057; change in slope, unquantified decrease, p=0.574 | Not calculable | Very low |
| **Skin and soft tissue infections per 1,000 patient days, PX-UV versus standard cleaning/disinfection** |
| 1 (Kovach 2017)[21] | Uncontrolled before–after study | Seriousa | No serious inconsistency | No serious indirectness | Very seriousb | None | NR/NR (0.03 per 1,000 patient days) | NR/NR (rate per 1,000 patient days NR) | p=0.014 | Not calculable | Very low |
| **UTIs per 1,000 patient days, PX-UV versus standard cleaning/disinfection** |
| 1 (Kovach 2017)[21] | Uncontrolled before–after study | Seriousa | No serious inconsistency | No serious indirectness | Very seriousb | None | NR/NR (0.05 per 1,000 patient days) | NR/NR (rate per 1,000 patient days NR) | p=0.014 | Not calculable | Very low |

CI confidence interval; IRR incidence rate ratio; NR not reported; PX-UV pulsed-xenon ultraviolet; UTI urinary tract infection; UV-C ultraviolet C
a Single study with at least one limitation related to design, analysis or reporting that is not covered by the other quality domains
b IRR and associated CI not calculable

# Appendix J – Consultation

This part of the report will be completed after the stakeholder consultation to reflect comments received and actions taken in response