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CADTH RAPID RESPONSE REPORT:
SUMMARY WITH CRITICAL APPRAISAL

Non-Manual Ultraviolet Light Disinfection for Hospital Acquired Infections: A Review of Clinical Effectiveness and Guidelines

Service Line:	Rapid Response Service
Version:	1.0
Publication Date:	April 5, 2019
Report Length:	30 Pages

CADTH

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Cite As: Non-Manual Ultraviolet Light Disinfection for Hospital Acquired Infections: A Review of Clinical Effectiveness and Guidelines. Ottawa: CADTH; 2019 Apr. (CADTH rapid response report: summary with critical appraisal).

ISSN: 1922-8147 (online)

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Funding: CADTH receives funding from Canada's federal, provincial, and territorial governments, with the exception of Quebec.

Abbreviations

AGREE	Appraisal of Guidelines for Research & Evaluation
AMSTAR	Assessing the Methodological Quality of Systematic Reviews
CAUTI	Catheter-associated urinary tract infection
CI	Confidence interval
CLABSI	Central line-associated bloodstream infection
C. difficile	*Clostridium difficile*
CPA	Carbapenemase-producing *Acinobacter*
CPE	Carbapenemase-producing *Enterobacteriaceae*
CT	Clinical trial
HAI	Healthcare-acquired infection
HTA	Health technology assessment
ICU	Intensive care unit
IRR	Incidence rate ratio
JBI	Joanna Briggs Institute
MA	Meta-analysis
MDRO	Multidrug-resistant organisms
MRSA	Methicillin-resistant *Staphylococcus aureus*
NA	Not applicable
NR	Not reported
OR	Odds Ratio
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PX	Pulsed xenon
RCT	Randomized controlled trial
RR	Relative risk
SD	Standard deviation
SR	Systematic reviews
UV	Ultraviolet
VAP	Ventilator-associated pneumonia
VRE	Vancomycin-resistant enterococci

Context and Policy Issues

Healthcare-acquired infections (HAIs), also known as nosocomial infections, are infections that patients acquire during their presence in a healthcare setting such as hospitals, long-term care facilities, clinics or home care services.[1] At any given time in Canada, about 10% of adults and 8% of children have nosocomial infections.[2] According to a 2013 Public Health Agency of Canada report, over 200,000 Canadians acquire HAIs each year, and about 8,000 of these patients die as a result of infection.[3] HAIs can be caused by all types of microorganisms, including bacteria, viruses, or fungi that are present in the environment of hospitals and healthcare facilities. Common nosocomial infection microorganisms that are currently monitored by the Canadian Nosocomial Infection Surveillance Program include *Clostridium difficile* (*C. difficile*), vancomycin-resistant enterococci (VRE), methicillin-resistant *Staphylococcus aureus* (MRSA), carbapenemase-producing *Enterobacteriaceae* (CPE) and carbapenemase-producing *Acinetobacter* (CPA).[4] These microorganisms can survive for weeks on environmental surfaces or become airborne

which serve as sources of transmission.[5] Transmission of HAIs commonly occurs by direct contact with the contaminated environmental surfaces or through hospital staff or visitors who act as carriers.[6] Thus, hand hygiene, proper cleaning of equipment and environments in the healthcare facilities, and monitoring infection are necessary to reduce HAIs, and to prevent the spread of pathogenic organisms.[4]

There are policies and best practice recommendations that describe the types of disinfectants and detailed protocols and procedures for routine and terminal cleaning and disinfection of the environments in healthcare settings.[2] Given the increased awareness of the heterogeneity of the standard environmental cleaning and disinfection practices, whose outcomes are often suboptimal, several automated (non-manual) technologies including hydrogen peroxide (e.g., vapors or dry aerosols), and ultraviolet (UV) irradiation devices (e.g., continuous UV-C light, pulsed xenon UV light) have been developed for use in conjunction with the standard manual cleaning and disinfection.[7] Two types of non-manual UV devices or units have been used for disinfection of air and surfaces in healthcare facilities.[8,9] For air disinfection, the units can be either portable or housed atop a standard light fixture, and contain a fully shielded chamber with UV-C light bulb to prevent UV leakage, and fans, which draw air into the UV chamber through a filter and push air out into the occupied rooms.[8] For surface disinfection, the devices are usually portable with UV-C light or pulsed xenon UV light, and can be placed in patient rooms after patient discharge and standard manual cleaning and disinfection.[9] These new technologies have been demonstrated to be effective against pathogens (e.g., *C. difficile*, VRE, MRSA, and CPE) in healthcare facility environments.[7,10,11] However, their clinical effectiveness in improving patient outcomes (e.g., reducing the rates of colonization and HAI) is less understood.

The aim of this report is to review the clinical effectiveness and evidence-based guidelines on the use of non-manual ultraviolet light disinfection for reducing rates of infection and colonization in healthcare facilities.

Research Questions

1. What is the clinical effectiveness of non-manual ultraviolet light disinfection for reducing rates of infection and colonisation in healthcare facilities?
2. What is the comparative clinical effectiveness of non-manual ultraviolet light disinfection methods versus accelerated hydrogen peroxide for reducing rates of infection and colonisation in healthcare facilities?
3. What are the evidence-based guidelines regarding ultraviolet light disinfection methods for reducing rates of infection and colonisation in healthcare facilities?

Key Findings

Low to very low quality evidence from inconsistent and mixed findings precludes a definitive conclusion regarding the clinical effectiveness of non-manual ultraviolet light disinfection in both air and surface for reducing rates of infection and colonization in healthcare facilities. Evidence regarding the comparative clinical effectiveness between non-manual ultraviolet light disinfection methods and accelerated hydrogen peroxide for reducing healthcare-acquired infections was not identified. The Health Quality Ontario guideline recommends against public funding of portable ultraviolet light surface-disinfecting devices for prevention of healthcare-acquired infections.

Methods

Literature Search Methods

A limited literature search was conducted on key resources including Medline, CINAHL, the Cochrane Library, University of York Centre for Reviews and Dissemination (CRD) databases, Canadian and major international health technology agencies, as well as a focused Internet search. No filters were applied to limit the retrieval by study type. Where possible, retrieval was limited to the human population. The search was also limited to English language documents published between January 1, 2009 and March 8, 2019. Internet links were provided, where available.

Selection Criteria and Methods

One reviewer screened citations and selected studies. In the first level of screening, titles and abstracts were reviewed and potentially relevant articles were retrieved and assessed for inclusion. The final selection of full-text articles was based on the inclusion criteria presented in Table 1.

Table 1: Selection Criteria

Population	Any patients or healthcare workers in any healthcare facilities (such as: acute care, rehabilitation, long-term care, etc.)
Intervention	Non-manual modalities of ultraviolet light disinfection (such as: Vidashield, etc.)
Comparator	Q1: Other non-manual disinfection techniques; no treatment; Q2: Accelerated hydrogen peroxide Q3: No comparator (guidelines)
Outcomes	Q1, 2: Clinical effectiveness (such as: rates of hospital acquired infection, infection control outcomes, infection prevention outcomes, patient colonization rates, safety, etc.) Q3: Appropriate use guidelines
Study Designs	Health technology assessments (HTAs), systematic reviews (SRs), meta-analyses (MAs), randomized controlled trials (RCTs), non-randomized studies, and evidence-based guidelines

Exclusion Criteria

Studies were excluded if they did not meet the selection criteria in Table 1 and if they were published prior to 2009. Primary studies were excluded if they had been included in the identified SRs. Studies that did not report patient outcomes (e.g. HAIs) were excluded. Guidelines with unclear methodology or that were not clearly evidence-based were also excluded.

Critical Appraisal of Individual Studies

The AMSTAR-2 checklist was used to assess the quality of SRs.[12] The critical appraisal checklists of Joanna Briggs Institute were used to assess the quality of the included RCTs and non-randomized studies.[13] The quality of the evidence-based guidelines was assessed using AGREE II instrument.[14] Summary scores were not calculated for the included studies; rather, a review of the strengths and limitations were described narratively.

Summary of Evidence

Quantity of Research Available

A total of 392 citations were identified in the literature search. Following screening of titles and abstracts, 356 citations were excluded and 36 potentially relevant reports from the electronic search were retrieved for full-text review. One potentially relevant publication was retrieved from the grey literature search. Of the 37 potentially relevant articles, 26 publications were excluded for various reasons, while 11 publications including one HTA, one SR, eight primary studies, and one guideline met the inclusion criteria and were included in this report. Appendix 1 presents the PRISMA flowchart of the study selection.

Summary of Study Characteristics

Systematic reviews and primary studies

The characteristics of the identified HTA[15] and SR[16] (Table 2), and primary studies[17-24] (Table 3) are presented in Appendix 2.

Study Design

The identified HTA[15] and SR[16] included RCTs and non-randomized studies. The literature search of major databases was from inception to January 23, 2017,[15] or from inception to April 30, 2017.[16]

Eight additional primary studies were identified including one single-blinded, parallel RCT,[22] two non-randomized studies with control,[20,23] and five non-randomized studies of pre-post design.[17-19,21,24]

Country of Origin and Publication Year

The HTA[15] was conducted by authors from Ontario, Canada. The SR[16] was conducted by authors from USA. Both were published in 2018.

Seven identified primary studies[17-21,23,24] were conducted by authors from USA, and one study[22] was from Spain. Seven studies[17-23] were published in 2018, and one[24] in 2011.

Study Setting, Target Rooms and Timing after Disinfection

The HTA[15] and SR[16] included studies assessing the intervention in the hospital setting. Various types of hospital were studied including community, academic, military, acute care and long-term care. The intervention sites were patient rooms, including bathrooms, and rooms in the intensive care units (ICUs) and non-ICUs. The year of intervention ranged from 2011 to 2014. The intervention was conducted after patients were discharged or transferred to other units.

The additional primary studies also assessed the intervention in various types of hospital setting, including tertiary-care, the Women and Children hospital, community, academic, and long-term acute care settings. The intervention sites were patient rooms, including bathrooms and common areas, in ICUs and non-ICUs. For surface disinfection,[17-20] intervention was conducted after patients were discharged or transferred to other units. For air disinfection or purification,[21-24] the intervention was applied while patients and staff were present.

Interventions and Comparators

Both the HTA[15] and SR[16] assessed the effectiveness of non-manual UV light surface-disinfecting devices for reducing HAIs. The UV devices were used in conjunction with standard hospital room cleaning and disinfection (i.e., manual cleaning), and were compared with manual cleaning done in the control groups or in the period before the intervention. Pulsed xenon UV devices and mercury bulb UV-C devices were included.

In the additional primary studies, four studies[17-20] assessed non-manual UV devices (pulsed xenon or UV-C) for surface disinfection, and four studies[21-24] assessed non-manual UV devices (UV-C) for air disinfection, in which the devices have a fully shielded UV-C bulb and fans that draw air in and out the irradiation chamber. All UV devices were used in conjunction with housekeeping protocols and standard manual cleaning established in the hospitals. Comparators were manual cleaning done in the control groups or in the period before the intervention. None of the studies reported detailed procedures of manual cleaning.

Outcomes

Both the HTA[15] and SR[16] evaluated HAIs as the outcome. Multidrug-resistant organisms included *C. difficile*, VRE, MRSA, and others.

The outcomes investigated in the additional primary studies included HAI or colonization, ventilator-associated pneumonia (VAP), catheter-associated urinary tract infection (CAUTI), central line-associated bloodstream infection (CLABSI), viral infection, length of hospital stay, and 30-day mortality. Common multidrug-resistant organisms investigated were *C. difficile* and VRE.

Treatment Duration

In the HTA,[15] the length of application of the intervention was 7 months in the RCT, or ranged from 3 months to 27 months in the non-randomized studies. The periods before intervention in the non-randomized studies ranged from 3 months to 3 years. Length of application was not reported in the SR.[16] For surface disinfection, the duration of UV treatment varied and was reported in two studies,[17,18] but not in the others.[19,20] For air disinfection, the UV unit was left running continuously in the occupied rooms.[21-24]

In the additional primary studies, the study periods in the controlled studies were 6 months[20,23] and 5 years.[22] For the non-randomized studies of pre-post design, the periods before intervention ranged from 6 months to 19 months, and the periods of intervention ranged from 6 months to 18 months.

Quality Appraisal Tools

The authors of the HTA[15] assessed the quality of the included studies using the Cochrane Risk of Bias tool for RCTs, Effective Practice and Organization of Care (EPOC) tool for non-RCTs and for interrupted time-series studies, and The National Heart, Lung and Blood Institute quality assessment tool for before-after studies with no control groups. In the HTA, the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) framework was used to evaluate the quality of the body of evidence for each outcome on the basis of the following considerations: risk of bias, inconsistency, indirectness, imprecision, publication bias, magnitude of effect, and dose-response gradient. The authors of the SR[16] assessed the quality of the included studies using a published tool[25,26] having items regarding sample representatives, bias and confounding, description of the

intervention, outcomes and follow-up, and statistical analysis. Each item was scored 1 to 4, with 4 being highest quality.

Data Analysis and Synthesis

Giving the substantially clinical heterogeneity in study design and setting, interventions, comparators, and outcome measures, the authors of the HTA[15] decided not to pool the data, but performed a qualitative synthesis of the included studies. The results were summarized and tabulated separately regarding the type of UV devices (i.e., pulsed xenon UV disinfecting devices and UV-C disinfecting devices) and outcome measures. The authors of the SR[16] quantitatively synthesized data from included studies using meta-analysis approach, despite clinical heterogeneity. In the SR, subgroup analyses were performed based on baseline *C. difficile* infection rates, types of hospital, and studies reporting compliance monitoring process.

In the additional primary studies, appropriate statistical methods were used for comparisons of observations between intervention and comparator, or between pre- and post-intervention. The incidence of rate was calculated as number of new infections over the total number of patient days, usually expressed as number of cases per 1,000 patient days. Power analysis was not performed in all studies, except one.[17]

Funding

Both the HTA[15] and SR[16] received public funding for their work. Two identified primary studies[17,22] were supported by public funding, while the rest of the studies[18-21,23,24] did not report the source of funding or received the UV devices from the manufacturers.

Guidelines

The characteristics of the guideline[27] are presented in Table 4 in Appendix 2

Country of Origin

One evidence-based guideline from Health Quality Ontario, Canada[27] was identified.

Objectives

The overall objective of the guideline[27] was to provide recommendations related to the implementation of portable non-manual UV light surface-disinfecting devices for prevention of HAIs.

Target Users of the Guidelines

The guideline[27] was targeted to healthcare professionals and funders, by providing objective advice for improving healthcare of Ontarians.

Methods Used to Formulate Recommendations

The Ontario Health Technology Advisory Committee reviewed the HTA[15] conducted by Health Quality Ontario and made recommendations to the Minister of Health and Long-Term Care. The committee consisted of volunteer members across the province, including healthcare experts and patient perspective representatives.

Summary of Critical Appraisal

The quality assessment of the HTA[15] and SR[16] (Table 5), RCT[22] (Table 6), non-randomized studies[17-21,23,24] (Table 7), and guideline[27] (Table 8) are presented in Appendix 3.

Both the HTA[15] and SR[16] provided appropriate research questions, explanations for selection of the study designs for the inclusion, used comprehensive literature search strategies, described the included studies in adequate detail, and used satisfactory techniques for assessing the risk of bias in individual studies included in the review. It was unclear if the review authors of the HTA and SR performed study selection and data extraction in duplicate. Neither reported if the review methods had been established in a protocol prior to the conduct of the review, they did not provided a list of excluded studies, and did not report the source of funding for the included studies. While meta-analysis was performed in the SR,[16] the authors of the HTA[15] did not perform meta-analysis of the included studies, owing to substantial heterogeneity in study design and setting, interventions, comparators, and outcome measures. The authors of the HTA[15] incorporated risk of bias and clinical heterogeneity in individual studies in the discussion and interpretation of the results, while the authors of the SR[16] did not. The authors of the SR[16] carried out an adequate investigation of publication bias. The HTA[15] did not report potential sources of conflict of interest. Overall, the research methodology of the included HTA was more comprehensive and thorough than that of the SR, as it rated the evidence of each outcome using GRADE, and chose not to pool data from included studies due to clinical and methodological heterogeneity across studies.

The RCT[22] was explicit in 11 of 13 items of the critical appraisal checklist covering adequate randomization, allocation concealment, similarity in baseline characteristics between groups, participant blinding, identical in treatment between groups other than the intervention of interest, no losses to follow-up, similar outcome measurement for treatment groups using reliable method and appropriate statistical analysis. It was unclear if blinding was applied to those delivering treatment and outcome assessors. The RCT had some risk in performance bias as because only patients were blinded.

All of the additional non-randomized studies with[20,23] or without[17-19,21,24] a control group provided appropriate research questions and objectives, measured the outcomes of participants in the same and reliable way, using appropriate statistical analysis. In all studies, it was unclear if participants between treatment groups were similar in characteristics, and received similar treatment and care other than the exposure or intervention of interest. It was also unclear if patients were lost to follow-up. Overall, these studies had high risk of bias in selection, performance, and detection.

The included guideline[27] was explicit in terms of scope and purpose, stakeholder involvement (engaging healthcare experts and patient perspective representatives), clarity of presentation, and applicability. The guideline was also explicit in terms of rigour of development, except it was unclear if the guideline had been externally reviewed by experts prior to its publication, and whether there is a procedure for updating the guideline. It was also unclear about editorial independence of the guideline regarding potential influence of the funding body to the content of the guideline and competing interests of the guideline development group members.

Summary of Findings

The main findings and conclusions of the HTA[15] and SR[16] (Table 9), additional primary studies[17-24] (Table 10), and guideline[27] (Table 11) are presented in Appendix 4.

Clinical Effectiveness

Non-manual UV light surface disinfection plus manual disinfection versus manual disinfection alone

Evidence regarding the clinical effectiveness of non-manual UV light surface disinfecting devices used in adjunct to standard hospital room cleaning disinfection (i.e., manual cleaning) compared to manual cleaning alone in reducing HAIs was derived from one HTA,[15] one SR[16] and four additional primary studies.[17-20] The devices were operated after patients were discharged or transferred to other units.

C. difficile infection

The HTA[15] included one RCT and two before-after studies for evaluating the use of mercury UV-C surface disinfecting devices on *C. difficile* infection rates. The RCT found that addition of UV-C room disinfection to standard manual cleaning did not show any reduction in hospital acquired *C. difficile* infection rates. The quality of this evidence was graded as low. Two pre-post studies reported that the use of UV-C devices in addition to manual cleaning was associated with a reduction in *C. difficile* infection rates in hospital. The quality of this evidence was graded as very low. The HTA also included six pre-post studies evaluating the use of pulsed xenon UV devices. All point estimates showed a reduction in hospital acquired *C. difficile* infection rates with the additional use of pulsed xenon UV disinfection, although statistically significant differences were not reached in two studies. The quality of this evidence was graded as very low.

The SR[16] performed a meta-analysis of 11 studies, combining all study designs and types of UV devices. Results of the meta-analysis showed that using UV devices for surface disinfection after standard manual cleaning was associated with statistically significant reduction in *C. difficile* infection rates. In subgroup analyses, the statistically significant reduction in *C. difficile* infection rates was observed in studies having high baseline *C. difficile* infection rates (i.e., ≥ 1.5 / 1,000 patient days), but not in studies having low baseline *C. difficile* infection rates (<1.5 / 1,000 patient days), and in non-controlled studies, but not in controlled trials. Statistically significant reduction in *C. difficile* infection rates was observed regardless of whether or not studies reported compliance rates.

One pre-post study[17] found no significant difference in hospital acquired *C. difficile* infection rates in a bone marrow transplant unit before and after implementation of standard manual cleaning with pulsed xenon UV surface disinfection. In contrast, another non-randomized study with a control group[20] reported a significant reduction in *C. difficile* infection rates in hematology/bone marrow transplant and medical-surgery units having pulsed xenon UV surface disinfection compared to control units.

VRE infection

The HTA[15] included one RCT and one before-after study evaluating the use of mercury UV-C surface disinfecting devices on VRE infection rates. Both studies showed a non-statistically significant reduction in hospital-acquired VRE infection rates with UV-C surface disinfection and standard manual cleaning compared to standard manual cleaning alone. The quality of this evidence was graded as low and very low. The HTA also included two pre-post studies evaluating the use of pulsed xenon UV devices that reported a significant reduction in hospital-acquired VRE infection rates after implementing UV surface disinfection in addition to standard manual cleaning compared to standard manual cleaning alone. The quality of this evidence was graded as very low.

The SR[16] performed a meta-analysis on VRE infection rate using data from four studies, and found that the use of UV surface disinfecting devices after standard manual cleaning was associated with statistically significant reduction in hospital-acquired VRE infection rates.

In three additional primary studies, a significant reduction in VRE infection rates was observed in one study,[20] but not in the other two,[17,19] when evaluating the use of UV surface disinfecting devices (UV-C and pulsed xenon UV) in addition to standard manual cleaning.

MRSA infection

The HTA[15] included one RCT and one before-after study evaluating the use of mercury UV-C surface disinfecting devices on MRSA infection rates. Both studies found no statistically significant difference in hospital-acquired MRSA infection rates with the use of UV-C surface disinfection and standard manual cleaning compared to standard manual cleaning alone. The quality of this evidence was graded as low and very low. The HTA also included three pre-post studies evaluating the use of pulsed xenon UV devices. These studies showed inconsistent results. One study reported a significant reduction in MRSA infection rates for pulsed xenon UV disinfection, while the point estimates of the other two studies favored standard manual cleaning. The quality of this evidence was graded as very low.

One additional pre-post study[19] reported that the rate of MRSA infection was significantly reduced during UV-C disinfection intervention compared to pre-intervention.

Other HAIs

For mercury UV-C room disinfection, the HTA included one RCT and one pre-post study. The RCT found no cases of multidrug-resistant *Acinetobacter* infection or colonization after both treatment and control. The quality of this evidence was graded as low. The pre-post study found reduction in relative rates of infection with *Acinetobacter baumannii or Klebsiella pneumonia* after treated with UV-C disinfection, but the difference did not reach statistical significance. The quality of this evidence was graded as very low. For pulsed xenon UV room disinfection, the HTA included three pre-post studies. One pre-post study found that pulsed xenon UV disinfection significantly reduced Class I, but not Class II surgical site infection. The quality of this evidence was graded as very low. One pre-post study found no significant difference in any other HAI rates including VAP, CAUTI and CLABSI. The quality of this evidence was graded as very low. One pre-post study found that pulsed xenon UV disinfection significantly reduced the rate of multidrug-resistant gram-negative bacteria by 19%. The quality of this evidence was graded as very low.

One additional primary study[19] found that UV-C disinfection was associated with significant reduction in relative rates of infection with *Acinetobacter baumannii*, but not with *Klebsiella pneumonia* or *Pseudomonas aeruginosa*. One pre-post study[18] found that UV-C surface disinfection was associated with a 44% reduction in viral infection among pediatric patients in a pediatric long-term care facility.

Non-manual UV light air disinfection plus manual disinfection versus manual disinfection alone

The clinical effectiveness of non-manual UV light air disinfecting devices used in adjunct to standard hospital room cleaning disinfection (i.e., manual cleaning) compared to normal and manual cleaning alone in reducing HAIs was derived from four identified primary studies.[21-24] The device is either portable or installed in the ceiling, and has a fully shielded

chamber with a UV-C bulb and fans that produce continuous air flow in and out of the irradiation chamber. The devices were operated in the presence of patients and staff.

One pre-post study[21] found a significant reduction in the overall HAI rates after installation of the UV-C air disinfecting devices in patient rooms of special care unit in a long-term acute care hospital. The overall HAI rate reduction was attributed mainly by the reduction of *C. difficile* infection and CAUTI, but not of MRSA, VRE or CLABSI.

One prospective, comparative RCT[22] found no significant differences between UV-C technology between sterilizer rooms and control rooms in an ICU of cardiac surgery in patient colonization rates (any type of bacteria, gram-positive, gram-negative), HAI rates (total, VAP, urinary tract, catheter, blood, surgical site), ICU stay, total hospital stay and 30-day mortality rate.

One non-randomized study with a control group[23] found that UV-C air disinfection in a wing of a long-term care ventilator unit significantly reduced the overall HAI rate (assessed based on antibiotic orders) compared to a control wing. However, no statistically significant differences between groups were observed for infection rates caused by multidrug-resistant organisms such as *Acinetobacter*, MRSA, VRE and *C. difficile.*

One pre-post study (one 6-month pre-period, and three consecutive 6-month post-periods), which evaluated the effect of UV-C air sterilizing device in the heating ventilation and air conditioning system on VAP in a neonatal ICU, found significant decrease in number of VAP cases and the number of antibiotics prescribed among high-risk neonatal patients (< 30 weeks gestation and ventilated for ≥ 14 days). However, these reductions were observed in the third 6-month period of the post-intervention, but not during the first and second 6-month periods. Similarly, the number of high-risk babies also dropped over time and significantly decreased in the third 6-month period of the post-intervention compared to pre-intervention. This situation could not rule out the possibility that VAP might have decreased over time because of reasons other than UV-C air sterilization.

Non-manual UV light disinfection versus accelerated hydrogen peroxide disinfection

No evidence could be identified for the comparative clinical effectiveness of non-manual UV light disinfection versus accelerated hydrogen peroxide disinfection for reducing rates of infection and colonization in healthcare facilities.

Guidelines

Based on the findings of its HTA,[15] the Health Quality Ontario guideline[27] recommends against public funding of portable of portable UV light surface-disinfecting devices for prevention of HAIs, as it was unclear if the technology is better than hospital standard cleaning and disinfection.

Limitations

The quality of evidence derived from primary studies included in the identified HTA and SR, as well as of those additionally identified studies in this report, were considered to be low to very low. Most studies were of pre-post design, of which confounding variables such as patient characteristics, infection control practices, and methods of delivery of care between before- and after-intervention periods were not identified and controlled. As the study investigators and outcomes assessors were not blinded and the hospital manual cleaning protocols were not often described, it was unclear if the reduction of HAIs reported in some

studies was actually associated with implementation of non-manual UV devices. Given substantial clinical and methodological heterogeneity among studies, regarding patient characteristics, settings, hospital types and units, target rooms, types of UV devices, and manufacturer's disinfecting protocols, the authors of the HTA decided not to combine data from included studies, while meta-analysis was conducted by the authors of the SR. Despite the difference in data analysis, both HTA and SR found that the statistically significant reduction in *C. difficile* infection rates associated with UV surface disinfection was observed in non-controlled studies (i.e., pre-post studies), but not in controlled trials. Mixed findings were also observed among additional identified studies regarding the use of non-manual UV devices for surface or air disinfection. The conclusions of studies[18-21,23,24] having some connection with the manufacturers were in favor of the UV devices, while those[17,22] receiving public funding did not find any additional benefit in reducing HAIs compared to standard manual cleaning. As most studies, including those of the HTA and SR, were conducted in the US and no studies were from Canada, the findings could not be generalizable to the Canadian context, as it is difficult to know if the treatment practices and manual cleaning and disinfection protocols are similar among hospitals in US and Canada. This review could not identify any studies comparing non-manual disinfecting methods with accelerated hydrogen peroxide systems for reducing HAIs.

Conclusions and Implications for Decision or Policy Making

Given the study limitations, the clinical effectiveness of non-manual UV light disinfection for reducing HAIs remains inconclusive. In addition, the Health Quality Ontario guideline does not recommend public funding of portable UV light surface-disinfecting devices for prevention of HAIs, as it was uncertain if UV technology used in conjunction with standard manual cleaning and disinfection is better than standard manual cleaning and disinfection alone for preventing HAIs. Future controlled trials with high degree of internal validity and power analysis would reduce the uncertainty regarding the effectiveness of this technology.

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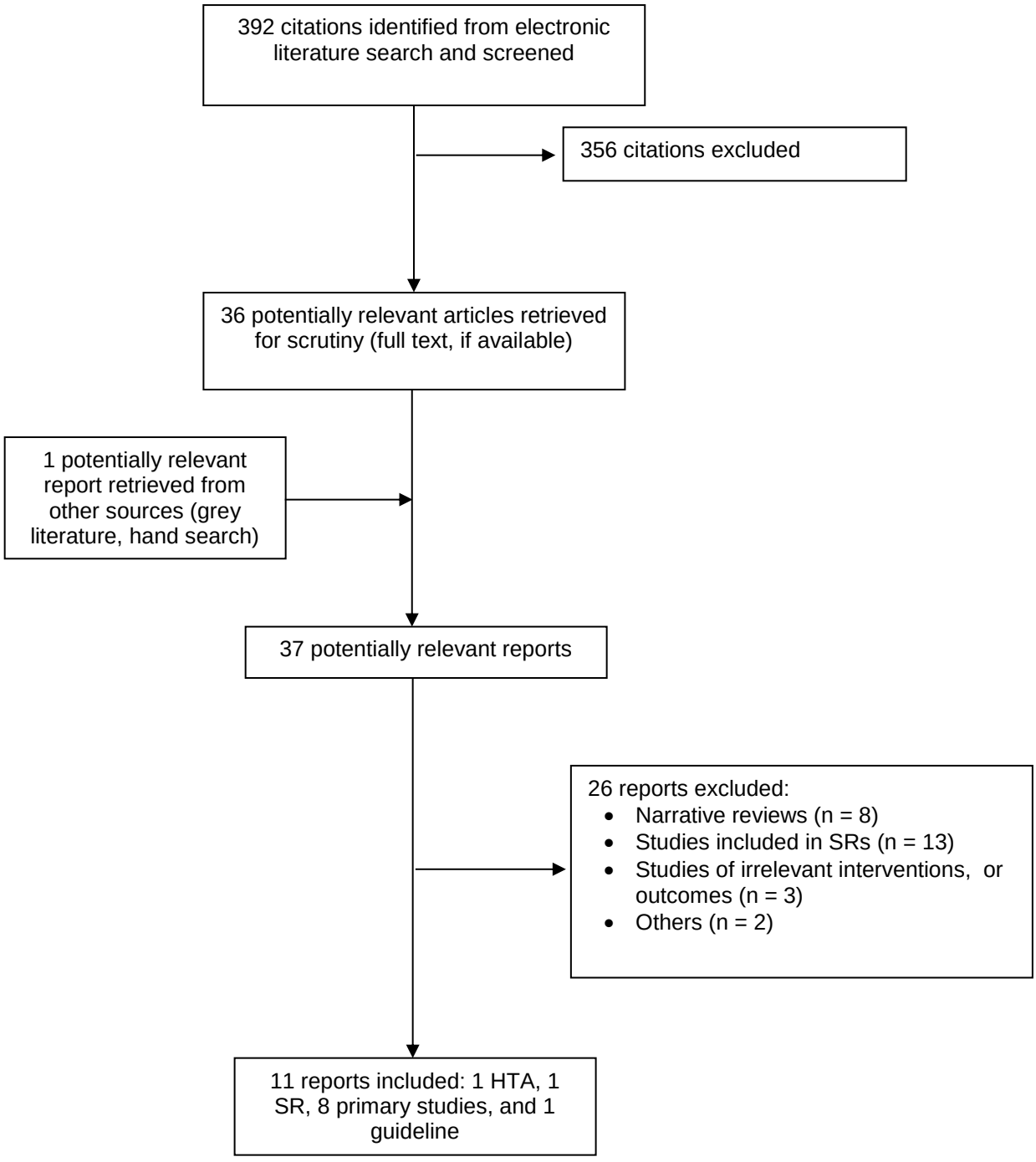
Appendix 1: Selection of Included Studies



Appendix 2: Characteristics of Included Studies

Table 2: Characteristics of Included Systematic Reviews

First Author, Publication Year, Country, Funding	Objectives, Types and Numbers of Primary Studies Included, Quality Assessment Tool, Databases and Search Date	Characteristics	Interventions; Length of Application	Outcomes
Health Quality Ontario[15] Canada Funding: Public	Objectives: To evaluate the effectiveness and budget impact of portable UV light surface-disinfecting devices for reducing hospital-acquired infections. 10 studies included (1 RCT, 1 interrupted time series, 8 before-after) Study quality was assessed using Risk of Bias tool for RCTs, Effective Practice and Organisation of Care (EPOC) tool for non-RCTs and for interrupted time-series studies, and The National Heart, Lung and Blood Institute quality assessment tool for before-after studies with no control groups. The GRADE framework was used to evaluate the quality of the body of evidence for each outcome on the basis of the following considerations: risk of bias, inconsistency, indirectness, imprecision, publication bias, magnitude of effect, and dose-response gradient. MEDLINE, EMBASE, Cochrane Central Register of Controlled Trials, Cochrane Database of Systematic Reviews, Health Technology Assessment, National Health Service Economic Evaluation Database (NHSEED), Database of Abstracts of Reviews of Effects (DARE), and Cumulative Index to Nursing & Allied Health Literature (CINAHL) Search date: Inception to January 23, 2017	Hospital type: Community, academic, military, acute care, long-term care Intervention site: Patient rooms in the ICUs and non-ICUs Year of intervention: 2011 to 2014	UV devices: pulsed Xenon UV light, UV-C radiation (mercury bulb) UV devices were used as adjunct to standard hospital room cleaning and disinfection (i.e., manual cleaning) and compared with manual cleaning done in the control groups or in the period before the interventions Length of application: – RCT: 7 months for each strategy – Non-randomized studies: Before: 3 months to 3 years After: 3 months to 27 months	Healthcare-acquired infections: – *Clostridium difficile* – Vancomycin-resistant *Enterococcus* (VRE) – Methicillin-resistant *Staphylococcus aureus* (MRSA) – Other multidrug-resistant organisms
Marra et al., 2018[16] USA Funding: VA Health Services	Objectives: To determine the impact of no-touch disinfection methods to decrease health-care associated infections. 20 studies included – 13 studies on UV light (1 CT, 1 RCT, 11	Hospital type: Community, academic, military, acute care, long-term care	Interventions: – Type of UV light: pulsed Xenon UV light, UV-C radiation (mercury bulb) – HP vapor disinfection system	Healthcare-acquired infections: – *Clostridium difficile* – Vancomycin-resistant *Enterococcus* (VRE)

First Author, Publication Year, Country, Funding	Objectives, Types and Numbers of Primary Studies Included, Quality Assessment Tool, Databases and Search Date	Characteristics	Interventions; Length of Application	Outcomes
Research and Development award	before-after) published from 2013 to 2017 – 7 studies on HP vapor (1 prospective cohort, 6 before-after) published from 2008 to 2016 Study quality was assessed using a published tool[25,26] having items regarding sample representatives, bias and confounding, description of the intervention, outcomes and follow-up, and statistical analysis. Each item was scored 1 to 4, with 4 being highest quality. Reviewers assessed the scores and provided an overall statement such as "completely adequate", "partially adequate", "inadequate, not stated or impossible to tell" or "not applicable". PubMed, CINAHL, CDSR, DARE and EMBASE Search date: Inception to April 2017	Intervention site: Patient rooms in the ICUs and non-ICUs Year of intervention: – UV light: 2011 to 2014 – HP vapor: 2005 to 2012	The interventions were used as adjunct to standard hospital room cleaning and disinfection (i.e., manual cleaning) and compared with manual cleaning done in the control groups or in the period before the interventions Length of application: NR	

CT = clinical trial; GRADE = Grading of Recommendations Assessment, Development, and Evaluation; HP = hydrogen peroxide; ICUs = intensive care units; NR = not reported; RCT = randomized controlled trial; UV = ultraviolet

Table 3: Characteristics of Included Primary Studies

First Author, Publication Year, Country, Funding	Study Setting and Design	Target rooms and Timing after disinfection	Non-Manual UV Device	Comparators	Clinical Outcomes
Surface disinfection					
Brite et al., 2018[17] USA Funding: New York State Department of Health, Healthcare-associated infection Prevention Project and the MSKCC Core Cancer Center	Bone marrow transplant unit (25 beds, single-patient rooms) of a 474-bed tertiary-care cancer center Interrupted time series Before: 19 months Washout: 1 month After: 12 months	Rooms of patients diagnosed with CDI and other hospital rooms After discharge or transfer	PX-UV device (Xenex) UV disinfection was used after standard terminal (manual) cleaning according to manufacturer's recommendations Length of cycle: 5 minutes Duration: minimum, 5 minutes per position	Standard terminal (manual) cleaning: – *C. difficile*: hypochlorite solution (bleach) – Other rooms: quaternary ammonium	Hospital-acquired colonization or infection with VRE and *C. difficile*
Pavia et al., 2018[18] USA Funding: NR; UV-C device was provided by Clorox Healthcare	Toddler unit of 97-bed children hospital Pre-post Before: 12 months After: 12 months	Five of 12 toddler unit rooms, bathrooms and common areas (2 or 3 treatments per week) Patients were removed from areas prior to UV-C treatment	UV-C device UV disinfection was used after standard (manual) cleaning according to manufacturer's recommendations	Standard terminal (manual) cleaning: quaternary ammonium	Hospital-acquired viral infection rates
Raggi et al., 2018[19] USA Funding: Clean Sweep Group, Inc.	Community hospital (337 beds) Pre-post Before: 12 months After: 12 months	All patient rooms After discharge or transfer	UV-C device (Skytron) UV disinfection was used after standard terminal (manual) cleaning according to manufacturer's recommendations	Standard terminal (manual) cleaning: NR on type of disinfectants	Hospital-acquired infection rates of 5 multidrug resistant bacteria (*Acinetobacter baumannii*, *Klebciella pneumonia*, MRSA, VRE, and *Pseudomonas aeruginosa*)
Sampathkumar et al., 2018[20] USA Funding: NR; PX-UD devices were provided by Xenex	Tertiary care hospital (Mayo Clinic, 2059 beds) Non-randomized design with control Study period: 6 months	UV disinfection: 3 units (2 hematology bone marrow transplant units and a medical surgical unit) Control: 3 similar units After discharge or transfer	PX-UV device (Xenex) UV disinfection was used after standard terminal (manual) cleaning according to manufacturer's recommendations	Standard terminal (manual) cleaning: – All patient rooms in the hematology and bone marrow transplant units were cleaned with hypochlorite solution (bleach) daily.	*C. difficile* infection

First Author, Publication Year, Country, Funding	Study Setting and Design	Target rooms and Timing after disinfection	Non-Manual UV Device	Comparators	Clinical Outcomes
				– Only rooms of patients with known *C. difficile* infection were cleaned with bleach	
Air disinfection					
Ethington et al, 2018[21] USA Funding: NR, UV-C device was provided by American Green Technology	Long-term acute care hospital (123 beds) Pre-post Before: 12 months After: 12 months	Special care unit (16 rooms). All rooms are negative pressure with single beds	UV-C device (Vidashield) used in conjunction with established housekeeping protocols The devices were installed in the ceiling of the occupied patient rooms, hallway and biohazard room. Each device has a fully shielded chamber with a UV-C bulb, and fans that pull air to the irradiation chamber and push the air back to the room.	Normal light and established housekeeping protocols for occupied patient rooms and standard terminal (manual) cleaning at patient discharge	Hospital-acquired infection rates with *C. difficile*, catheter-associated urinary tract infection, central line-associated bloodstream infection, MRSA, VRE
Heredia-Rodriguez et al., 2018[22] Spain Funding: Healthcare Research fund at Instituto de Salud Carlos III, and the Health Management at the Healthcare Regional Ministry of Junta de Castilla y Leon	University hospital RCT Study period: 5 years (January 2011 to January 2016)	Intensive care unit of cardiac surgery (10 single rooms)	Portable UV-C air sterilizer (Medixair) (5 rooms; 522 patients) Each device produces continuous airflow and has a four 25 watts UV low pressure fluorescent lamps that are completely shielded.	Without the device (5 rooms; 575 patients)	– Hospital-acquired infection rates after cardiac surgery – Length hospital stay – 30-day mortality rate
Kane et al., 2018[23] USA Funding: NR	Long-term care ventilator unit (full-time mechanical ventilation patients aged > 18 years) Non-randomized	One wing (40 patients): all rooms had UV-C units Control wing (46 patients): no UV-C units	UV-C device (VidaShield) with fully shielded UV-C bulb has fans that continuously draw air in and out the irradiation chamber.	Standard terminal (manual) cleaning: NR on type of disinfectants After discharge or transfer	Hospital-acquired infection rates (measured based on antibiotic orders)

First Author, Publication Year, Country, Funding	Study Setting and Design	Target rooms and Timing after disinfection	Non-Manual UV Device	Comparators	Clinical Outcomes
	design with control Study period: 6 months		UV disinfection was used in adjunct with standard terminal (manual) cleaning according to manufacturer's recommendations.		
Ryan et al., 2011[24] USA Funding: NYSTAR Center for Advanced Technology in Biomedical and Bioengineering, Department of Pediatrics, SUNY at Buffalo, and eUVGI technology and installation and environmental sample collection from Vigilair Systems	Women and Children's Hospital of Buffalo Pre-post Before: 6 months After: Three consecutive 6 months	Neonatal intensive care unit	UV-C air sterilizer (Enhanced UV germicidal irradiation; Sterile-Aire) installed in the heating ventilation air conditioning system	Before UV-C air sterilizer device installation	– Tracheal microbial load (colonization) – Ventilator-associated pneumonia

CDI = *Clostridium difficile* infection; NR = not reported; PX-UV = pulsed-xenon ultraviolet radiation; RCT = randomized controlled trial; UV = ultraviolet; UV-C = continuous UV radiation; VRE = vancomycin-resistant enterococcus

Table 4: Characteristics of Included Guidelines

First Author, Society/Group Name, Publication Year, Country, Funding	Intended Users/ Target Population	Intervention and Practice Considered	Major Outcomes Considered	Evidence Collection, Selection and Synthesis	Recommendations Development and Evaluation	Guideline Validation
Health Quality Ontario [27], 2018	Intended users: Healthcare professionals and funders Target population: All patients admitted in hospitals	Portable UV light surface-disinfecting devices	Hospital-acquired infections	Systematic methods used to search for evidence were reported The level of evidence and grade of recommendations were assessed using GRADE	The Ontario Health Technology Advisory Committee reviewed the HTAs conducted by Health Quality Ontario and made recommendations to the Minister of Health and Long-Term Care. The committee consisted of volunteer members across the province, including healthcare experts and patient perspective representatives.	No guideline validation was reported

GRADE = Grading of Recommendations Assessment, Development, and Evaluation; HTA = health technology assessment; UV = ultraviolet

Appendix 3: Quality Assessment of Included Studies

Table 5: Quality Assessment of Systematic Reviews

AMSTAR 2 Checklist[12]	Health Quality Ontario [15]	Marra [16] et al., 2018
1. Did the research questions and inclusion criteria for the review include the components of PICO?	Yes	Yes
2. Did the report of the review contain an explicit statement that the review methods were established prior to the conduct of the review and did the report justify any significant deviations from the protocol?	No	No
3. Did the review authors explain their selection of the study designs for inclusion in the review?	Yes	Yes
4. Did the review authors use a comprehensive literature search strategy?	Yes	Yes
5. Did the review authors perform study selection in duplicate?	Unclear	Unclear
6. Did the review authors perform data extraction in duplicate?	Unclear	Unclear
7. Did the review authors provide a list of excluded studies and justify the exclusions?	No	No
8. Did the review authors describe the included studies in adequate detail?	Yes	Yes
9. Did the review authors use a satisfactory technique for assessing the risk of bias (RoB) in individual studies that were included in the review?	Yes	Yes
10. Did the review authors report on the sources of funding for the studies included in the review?	No	No
11. If meta-analysis was performed did the review authors use appropriate methods for statistical combination of results?	NA	Yes
12. If meta-analysis was performed, did the review authors assess the potential impact of RoB in individual studies on the results of the meta-analysis or other evidence synthesis?	NA	No
13. Did the review authors account for RoB in individual studies when interpreting/ discussing the results of the review?	Yes	No
14. Did the review authors provide a satisfactory explanation for, and discussion of, any heterogeneity observed in the results of the review?	Yes	No
15. If they performed quantitative synthesis did the review authors carry out an adequate investigation of publication bias (small study bias) and discuss its likely impact on the results of the review?	NA	Yes
16. Did the review authors report any potential sources of conflict of interest, including any funding they received for conducting the review?	No	Yes

AMSTAR = Assessing the Methodological Quality of Systematic Reviews; NA = not applicable

Table 6: Quality Assessment of Randomized Controlled Trials

JBI Critical Appraisal Checklist for RCT[13]	Heredia-Rodriguez [22] et al., 2018
1. Was true randomization used for assignment of participants to treatment groups?	Yes
2. Was allocation to treatment groups concealed?	Yes
3. Were treatment groups similar at the baseline?	Yes
4. Were participants blind to treatment assignment?	Yes
5. Were those delivering treatment blind to treatment assignment?	Unclear
6. Were outcomes assessors blind to treatment assignment?	Unclear
7. Were treatment groups treated identically other than the intervention of interest?	Yes
8. Was follow up complete and if not, were differences between groups in terms of their follow up adequately described and analyzed?	Yes
9. Were participants analyzed in the groups to which they were randomized?	Yes
10. Were outcomes measured in the same way for treatment groups?	Yes
11. Were outcomes measured in a reliable way?	Yes
12. Was appropriate statistical analysis used?	Yes
13. Was the trial design appropriate, and any deviations from the standard RCT design (individual randomization, parallel groups) accounted for in the conduct and analysis of the trial?	Yes

JBI = Joanna Briggs Institute; RCT = randomized controlled trial

Table 7: Quality Assessment of Non-Randomized Studies

JBI Critical Appraisal Checklist for Non-Randomized Studies[13]	Brite [17] et al., 2018	Ethington [21] et al., 2018	Kane [23] et al., 2018	Pavia [18] et al., 2018	Raggi [19] et al., 2018	Sampathkumar et al., 2018[20]	Ryan [24] et al., 2011
1. Is it clear in the study what is the 'cause' and what is the 'effect' (i.e. there is no confusion about which variable comes first)?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2. Were the participants included in any comparisons similar?	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear
3. Were the participants included in any comparisons receiving similar treatment/care, other than the exposure or intervention of interest?	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear
4. Was there a control group?	No	No	Yes	No	No	Yes	No
5. Were there multiple measurements of the outcome both pre and post the intervention/exposure?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
6. Was follow up complete and if not, were differences between groups in terms of their follow up adequately described and analyzed?	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear
7. Were the outcomes of participants included in any comparisons measured in the same way?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
8. Were outcomes measured in a reliable way?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
9. Was appropriate statistical analysis used?	Yes	Yes	Yes	Yes	Yes	Yes	Yes

JBI = Joanna Briggs Institute

Table 8: Quality Assessment of Guidelines

AGREE II checklist[14]	Health Quality Ontario [27]
Scope and purpose	
1. Objectives and target patients population were explicit	Yes
2. The health question covered by the guidelines is specifically described	Yes
3. The population to whom the guidelines is meant to apply is specifically described	Yes
Stakeholder involvement	
4. The guideline development group includes individuals from all relevant professional groups	Yes
5. The views and preferences of the target population have been sought	Yes
6. The target users of the guideline are clearly defined	Yes
Rigour of development	
7. Systematic methods were used to search for evidence	Yes
8. The criteria for selecting the evidence are clearly described	Yes
9. The strengths and limitations of the body of evidence are clearly described	Yes
10. The methods of formulating the recommendations are clearly described	Yes
11. The health benefits, side effects, and risks have been considered in formulating the recommendations	Yes
12. There is an explicit link between the recommendations and the supporting evidence	Yes
13. The guideline has been externally reviewed by experts prior to its publication	Unclear
14. A procedure for updating the guideline is provided	Unclear
Clarity of presentation	
15. The recommendations are specific and unambiguous	Yes
16. The different options for management of the condition or health issue are clearly presented	Yes
17. Key recommendations are easily identified	Yes
Applicability	
18. The guideline describes facilitators and barriers to its application	Not appplicabble
19. The guidelines provides advice and/or tools on how the recommendations can be put into practice	Yes
20. The potential resource (cost) implications of applying the recommendations have been considered	Yes
21. The guideline presents monitoring and/or auditing criteria	Not applicable
Editorial independence	
22. The views of the funding body have not influenced the content of the guideline	Unclear
23. Competing interests of guideline development group members have been recorded and addressed	Unclear

Appendix 4: Main Study Findings and Author's Conclusions

Table 9: Summary of Findings of Systematic Reviews

Main Study Findings	Author's Conclusions
Health Quality Ontario 2018[15]	
Mercury UV-C room disinfection and standard terminal (manual) cleaning versus standard terminal (manual) cleaning alone • *C. difficile* infection rate: – One cluster RCT (low quality evidence) RR (95% CI) = 1.0 (0.57 to 1.75); *P* = 0.997 – Two pre-post studies (very low quality evidence) RR (95% CI) = 0.49 (0.26 to 0.94); *P* = 0.03 RR (95% CI) = 0.54 (0.27 to 1.09); *P* = 0.08 • Combined HAI and colonization relative rate: – One cluster RCT (low quality evidence) RR (95% CI) = 0.70 (0.55 to 0.98); *P* = 0.036 – One pre-post study (very low quality evidence) RR (95% CI) = 0.66 (0.45 to 0.96); *P* = 0.03 • MRSA infection rate: – One cluster RCT (low quality evidence) RR (95% CI) = 0.78 (0.58 to 1.05); *P* = 0.10 – One pre-post study (very low quality evidence) RR (95% CI) = 0.99 (0.35 to 2.08); *P* = 0.98 • VRE infection rate: – One cluster RCT (low quality evidence) RR (95% CI) = 0.41 (0.15 to 1.13); *P* = 0.08 – One pre-post study (very low quality evidence) RR (95% CI) = 0.88 (0.45 to 1.71); *P* = 0.70 • Other HAI rates: – One RCT found no cases of multidrug-resistant *Acinetobacter* infection or colonization after both treatment and control (low quality evidence) – One pre-post study found reductions in relative rates of infection with *Acinetobacter baumanni or Klebsiella pneumonia* after treated with UV-C disinfection, but the difference did not reach statistical significance (very low quality evidence) **Pulsed xenon UV room disinfection and standard terminal (manual) cleaning versus standard terminal (manual) cleaning alone** • *C. difficile* infection rate: – Six pre-post studies (very low quality evidence) RR (95% CI) = 0.37 (0.02 to 6.89); *P* = 0.51 RR (95% CI) = 0.59 (0.41 to 0.86); *P* = 0.005 RR (95% CI) = 0.43 (0.24 to 0.77); *P* = 0.005 RR (95% CI) = 0.78 (0.61 to 1.01); *P* = 0.06 RR (95% CI) = 0.83 (0.7 to 0.97); *P* = 0.02 RR (95% CI) = 0.47 (0.26 to 0.86); *P* = 0.015 versus 1 year prior • Combined HAI and colonization relative rate: – Three pre-post studies (very low quality evidence) RR (95% CI) = 1.17 (0.50 to 2.76); *P* = 0.72 RR (95% CI) = 0.71 (0.55 to 0.91); *P* = 0.01 RR (95% CI) = 0.80 (0.73 to 0.88); *P* < 0.001 • MRSA infection rate:	*"We are unable to make a firm conclusion about the effectiveness of this technology on HAIs given the very low quality of evidence."*[15] p.3

Main Study Findings	Author's Conclusions
– Three pre-post studies (very low quality evidence) RR (95% CI) = 1.26 (0.34 to 4.75); *P* = 0.75 RR (95% CI) = 1.20 (0.75 to 1.91); *P* = 0.45 RR (95% CI) = 0.73 (0.58 to 0.92); *P* = 0.007 • VRE infection rate: – Two pre-post studies (very low quality evidence) RR (95% CI) = 0.50 (0.27 to 0.91); *P* = 0.02 RR (95% CI) = 0.82 (0.70 to 0.95); *P* = 0.002 • Other HAI rates: – One pre-post study found that pulsed xenon disinfection significantly reduced Class I surgical site infection, but not Class II surgical site infection (very low quality evidence) – One pre-post study found no significant difference in any other HAI rates including VAP, CAUTI, CLABSI (very low quality evidence) – One pre-post study found that pulsed xenon disinfection significantly reduced the rate of multidrug-resistant gram-negative bacteria by 19% (*P* = 0.04) (very low quality evidence)	
Marra et al., 2018[16]	
UV light no-touch technology (UV-C and PX-UV) and standard terminal (manual) cleaning versus standard terminal (manual) cleaning alone • *C. difficile* infection rate: – Overall (11 studies): RR (95% CI) = 0.64 (0.49 to 0.84); I^2 = 0%; *P* = 0.0010 – Subgroups based on baseline *C. difficile* infection rates: High (6 studies): RR (95% CI) = 0.60 (0.43 to 0.86); I^2 = 37%; *P* = 0.005 Low (5 studies): RR (95% CI) = 0.70 (0.17 to 2.90); I^2 = 0%; *P* = 0.63 – Subgroups based on study design: Controlled trials (2 studies): RR (95% CI) = 0.65 (0.26 to 1.62); I^2 = 79%; *P* = 0.35 Non-controlled trials (9 studies): RR (95% CI) = 0.58 (0.41 to 0.83); I^2 = 0%; *P* = 0.003 – Subgroups based on types of hospital: Academic hospitals (3 studies): RR (95% CI) = 0.58 (0.37 to 0.91); I^2 = 7%; *P* = 0.02 Community hospitals (7 studies): RR (95% CI) = 0.48 (0.30 to 0.77); I^2 = 0%; *P* = 0.002 – Subgroups based on studies reporting compliance rates: Yes (7 studies): RR (95% CI) = 0.71 (0.52 to 0.96); I^2 = 0%; *P* = 0.03 No (4 studies): RR (95% CI) = 0.48 (0.28 to 0.81); I^2 = 0%; *P* = 0.006 • VRE infection rate: – Overall (4 studies): RR (95% CI) = 0.42 (0.28 to 0.65); I^2 = 0%; *P* < 0.0001	*"Ultraviolet light no-touch disinfection technology may be effective in preventing C. difficile infection and VRE infection."*[16] p.20

CAUTI = Catheter-associated urinary tract infection; CI = confidence interval; *C. difficile* = *Clostridium difficile*; CLABSI = Central line-associated bloodstream infection; HAI = hospital-acquired infection; IRR = incidence rate ratio; MDRO = multidrug-resistant organisms; MRSA = methicillin resistant *Staphylococcus Aureus*; OR = odds ratio; PX-UV = pulsed xenon ultraviolet radiation; RR = relative risk; SD = standard deviation; UV = ultraviolet; UV-C = continuous ultraviolet radiation; VAP = ventilator-associated pneumonia; VRE = vancomycin-resistant enterococcus

Table 10: Summary of Findings of Included Primary Studies

Main Study Findings	Author's Conclusions
Brite et al., 2018[17]	
Post-intervention (PX-UV) versus pre-intervention in a bone marrow transplant unit • Length of hospital stay (median, SD): 29.48 (16.41) versus 24.33 (12.59) days • Monthly incidence rate of infection – *C. difficile*: 9.3 per 1,000 patient days versus 7.1 per 1,000 patient days; *P* = 0.503 – VRE: 12.2 per 1,000 patient days versus 9.7 per 1,000 patient days; *P* = 0.4389 • Interrupted time series analysis Level change after UV cleaning – *C. difficile*: IRR (95% CI) = 0.51 (0.13 to 2.11); *P* = 0.356 – VRE: IRR (95% CI) = 1.34 (0.37 to 4.80); *P* = 0.652 Trend change after UV cleaning – *C. difficile*: IRR (95% CI) = 1.08 (0.89 to 1.31); *P* = 0.413 – VRE: IRR (95% CI) = 0.96 (0.81 to 1.14); *P* = 0.625 • Hospital-acquired incidence rate of infection – *C. difficile*: 1.411 per 1,000 days versus 1.114 per 1,000 days; *P* = 0.70 – VRE: 3.0236 per 1,000 days versus 3.6588 per 1,000 days; *P* = 0.60 • Manual cleaning, hand hygiene compliance, antibiotic utilization: no difference between two periods	*"Utilization of UV disinfection to supplement routine terminal cleaning of rooms was not effective in reducing hospital acquired VRE and C. difficile among stem cell transplant recipients"*[17] p.1301
Pavia et al., 2018[18]	
Post-intervention (UV-C) versus pre-intervention in a pediatric long-term care facility • Hospital acquired viral infections Unadjusted IRR (95% CI) = 0.56 (0.37 to 0.84); *P* = 0.003	*"The results suggest that UV-C technology is a potentially important component of eliminating the environment as a source of viral infections"*[18] p.720
Raggi et al., 2018[19]	
Post-intervention (UV-C) versus pre-intervention at a community hospital • Overall HAI incidence rates (per 1,000 patient days): 3.94 versus 4.87; *P* = 0.006 • HAI incidence rates with MDRO (per 1,000 patient days) – *Acinetobacter baumannii*: 0.16 versus 0.34; *P* = 0.03 – *Klebsiella pneumonia*: 1.22 versus 1.16; *P* = 0.36 – MRSA: 0.98 versus 1.42; *P* = 0.02 – *Pseudomonas aeruginosa*: 1.16 versus 1.29; *P* = 0.22 – VRE: 0.45 versus 0.68; *P* = 0.05 • Emergency department admissions: 297.9 minutes versus 296.2 minutes; P = 0.18 • Direct cost saving: $1,219,878 over a 12-month period calculated from the reduction of hospital length of stay	*"The UV-C disinfection was associated with a statistically significant facility-wide reduction of multidrug-resistant HAIs and generated substantial direct cost savings without adversely impacting hospital operations"*[19] p.1224
Sampathkumar et al., 2018[20]	
PX-UV disinfection in 3 units (2 hematology and bone marrow transplant units and a medical-surgery unit) versus 3 control units (same type of patients) • *C. difficile* infection rates (per 10,000 patient days): – Before intervention (21 months): 21.3 versus 26.1; *P* = 0.17 – Intervention (6 months): 11.2 versus 28.7; *P* = 0.03 • VRE infection rates in hematology and bone marrow transplant units only (per 10,000 patient days): – Before intervention (21 months): 25.6 versus 46.0; *P* = 0.002	*"The addition of UV disinfection to terminal cleaning has resulted in a reduction in C. difficile infection in our hospital that has sustained over several months. During the pilot phase on units with a VRE*

Main Study Findings	Author's Conclusions
– Intervention (6 months): 12.3 versus 32.5; *P* = 0.02	*surveillance program, we also saw a reduction in VRE acquisition."*[20] p.3
Ethington et al., 2018[21]	
Post-intervention (UV-C air sterilizer) versus pre-intervention in ICU • Overall HAI rates (case per month): 3.5 versus 8.8; *P* < 0.001 • HAI rates with specific organism (case per year) – *C. difficile*: 1 versus 8; *P* = 0.01 – MRSA: 6 versus 13; *P* = 0.107 – VRE: 6 versus 7; *P* = 0.764 – CAUTI: 9 versus 20; *P* = 0.012 – CLABSI: 9 versus 16; *P* = 0.226	*"Continuous shielded UV-C reduced airborne bacteria and may lower the number of HAI, including those caused by contact pathogens."*[21] p.482
Heredia-Rodriguez et al., 2018[22]	
UV-C air sterilizer rooms versus control rooms in ICU of cardiac surgery • Patient colonization rates (%) – Any type of bacteria: 40.4 versus 43.1 – Gram-positive: 21.6 versus 24.3 – Gram-negative: 18.8 in both groups • HAI rates (%) – Total: 14.0 versus 15.5; *P* = 0.45 VAP: 4.6 versus 5.0; *P* = 0.77 – Urinary tract: 2.9 versus 2.6; *P* = 0.78 – Catheter: 1.4 versus 1.6; *P* = 0.71 – Blood: 2.4 versus 2.8; *P* = 0.78 – Surgical site: 2.8 versus 3.5; *P* = 0.56 • Stay in the ICU (mean days, SD): 4.6 ± 8.2 versus 4.6 ± 7.3; *P* = 0.98 • Total hospital stay (mean days, SD): 18.3 ± 5.5 versus 19.2 ± 18.6; *P* = 0.38 • 30-day mortality rate (%): 3.83 versus 6.4; *P* = 0.053	*"Novel UV-C technology had not been shown to significantly reduce nosocomial infections or mortality rates in cardiac surgery patients"*[22] p.299
Kane et al., 2018[23]	
UV disinfecting (UV-C air sterilizer) wing versus control wing in long-term care ventilator unit • Overall infection rate based on antibiotic ordered: 12.5 ± 2.12 per 1,000 patient days versus 17.5 ± 2.81 per 1,000 patient days; *P* = 0.022 • Types of infection-causing organisms: *Acinetobacter*, MRSA, VRE and *C. difficile* • Infection rates caused by those organisms: No statistically significant difference between groups (*P* > 0.05). The authors suggested that the non-significant difference was due to relatively small sample size (n = 81), which is underpowered.	*"Findings suggest that continuous exposure to UV-C treated air reduces HAI. Shielded UV-C units in patient rooms may be an effective non-staff intervention dependent method for reducing HAI."*[23] p.44
Ryan et al., 2011[24]	
Post-intervention (UV-C air sterilizer) versus pre-intervention in neonatal ICU • Tracheal colonization decreased 45% (*P* = 0.004) • Number of high-risk babies (<30 weeks gestation and ventilated for ≥ 14 days) – Pre (6 months): 31 (57%) – Post (first next 6 months): 25 (44%) – Post (second next 6 months): 24 (33%) – Post (third next 6 months): 18 (35%)* • High risk babies with at least one VAP – Pre (6 months): 74% – Post (first next 6 months): 56%	*"Enhanced ultraviolet germicidal irradiation (eUVGI) decreased heating ventilation and air conditioning system microbial colonization and was associated with reduced newborn intensive care unit environment and tracheal microbial colonization. Significant reduction in VAP*

Main Study Findings	Author's Conclusions
– Post (second next 6 months): 54% – Post (third next 6 months): 39% • Number of VAP per high risk patient with any VAP – Pre (6 months): 1.7 – Post (first next 6 months): 1.3 – Post (second next 6 months): 1.5 – Post (third next 6 months): 1.1* • Number of antibiotics per high-risk patient – Pre (6 months): 2.6 – Post (first next 6 months): 1.7 – Post (second next 6 months): 1.9 – Post (third next 6 months): 1.0* **P* < 0.011 compared to pre-intervention	*and antibiotic use were also associated with eUVGI in this single-center study."*[24] p.607

CAUTI = Catheter-associated urinary tract infection; CI = confidence interval; *C. difficile* = *Clostridium difficile*; CLABSI = Central line-associated bloodstream infection; HAI = hospital-acquired infection; IRR = incidence rate ratio; MDRO = multidrug-resistant organisms; MRSA = methicillin resistant *Staphylococcus Aureus*; OR = odds ratio; PX-UV = pulsed xenon ultraviolet radiation; SD = standard deviation; UV = ultraviolet; UV-C = continuous ultraviolet radiation; VAP = ventilator-associated pneumonia; VRE = vancomycin-resistant enterococcus

Table 11: Summary of Findings of Included Guidelines

Recommendations
Health Quality Ontario 2018[27]
"Health Quality Ontario, under the guidance of the Ontario Health Technology Advisory Committee, recommends against publicly funding portable ultraviolet light surface-disinfection devices for prevention of hospital-acquired infections"[27] p.1