# NON-MANUAL DISINFECTION TECHNOLOGIES FOR PREVENTION OF HOSPITAL ASSOCIATED INFECTIONS

A review of effectiveness and cost-effectiveness

A report for the BC Health Technology Assessment Office, on behalf of health authorities and the Ministry of Health. Vancouver. October 29, 2019. Version 3.0

**Acknowledgements**

This study was supported by a financial contribution from the Health Technology Assessment Office (HTAO), Province of British Columbia (BC).

The authors thank Fraser Health and Vancouver Coastal Health for their input to inform the BC context and stakeholders' perspective. We gratefully acknowledge their valuable contribution to this study and thank them for their support.

The views expressed herein are those of the authors and do not necessarily represent the views or official policy of the government of British Columbia.

This report is authored by the Health Technology Assessment Team at the Centre for Clinical Epidemiology and Evaluation at the University of British Columbia and Vancouver Coastal Health Research Institute. The authors declare no conflicts of interest. The authors abide by the Conflict of Interest/Nondisclosure Agreement with BC Ministry of Health.

**Table of Contents**

**List of Tables**

**List of Figures**

**List of Abbreviations**

| | |
|---|---|
| BC | British Columbia |
| BCCSS | BC Clinical & Support Services |
| CADTH | Canadian Agency for Drugs and Technologies in Health |
| CD | *Clostridioides Difficile* |
| CDI | *Clostridioides Difficile* Infection |
| CI | Confidence Interval |
| CNISP | Canadian Nosocomial Infection Surveillance Program |
| CPE | Carbapenemase Producing *Enterobacteriaceae* |
| CPO | Carbapenemase Producing Organisms |
| HAI | Hospital Associated Infections |
| HTA | Health Technology Assessment |
| HQO | Health Quality Ontario |
| HTAC | Health Technology Assessment Committee |
| HVAC | Heating, Ventilation and Air Conditioning |
| MRSA | Methicillin-Resistant *Staphylococcus Aureus* |
| NMD | Non-Manual Disinfection |
| PHAC | Public Health Agency of Canada |
| PICNet | Provincial Infection Control Network |
| UV-C | Ultraviolet–C |
| VRE | Vancomycin-Resistant *Enterococci* |

**Executive summary**

Hospital associated infections (HAIs), refer to infections or colonizations (or both) contracted by patients during their stay at the hospital, which were not present or developing at the time of admission. HAIs are a frequent complication during care delivery and impart a significant clinical and economic burden on the healthcare system. The standard approach for reduction and prevention of HAIs involves an array of interventions, one of which includes decontamination of patient rooms through manual cleaning and disinfection. However, evidence indicates that manual cleaning may be insufficient, resulting in residual contamination of environmental surfaces. Portable no-touch or non-manual disinfection (NMD) devices are proposed to supplement manual cleaning and disinfection procedures for patient rooms and shared spaces.

In British Columbia (BC), NMD technologies are not uniformly adopted within hospitals. Further, previous reviews undertaken by the Canadian Agency for Drugs and Technologies in Health (CADTH) indicate that there is insufficient evidence to support the adoption of these technologies. However, considering the existing limited use of NMDs in BC, a more localized review was done to determine if sufficient evidence exists to warrant proceeding to a full health technology assessment (HTA) regarding the adoption of NMD systems.

The present study was instigated to update the review conducted by CADTH in 2018 and to evaluate local evidence using portable NMD technologies. The purpose of this study was to review and summarize clinical and economic evidence on portable light and gaseous-based NMD devices and to determine if there is sufficient evidence to pursue a full HTA on this topic.

A systematic literature search was implemented in Embase and MEDLINE and limited to studies published between January 2018 to July 2019. Local stakeholders were also contacted to identify any BC-specific evidence of effectiveness of NMD technologies. Representatives from two health authorities were invited to provide any unpublished studies, and information on any province-specific evidence of effectiveness of NMD technologies from ongoing field evaluations. All included studies were assessed for methodological quality and risk of bias. The primary outcome of interest was to evaluate the impact of NMD technologies on the rate of HAIs and identify any evidence on the cost-effectiveness of NMD technologies.

Thirteen studies were included in the final review; no new studies evaluating gaseous-based NMD devices were identified. Three study reports based on a previously implemented intervention were identified through local stakeholder engagement, however, no new references or unpublished evidence on ongoing field evaluation was received. Overall, the study findings regarding the clinical effectiveness were inconsistent and the evidence was rated as low quality and only one study evaluating the cost-effectiveness of ultraviolet NMD technology was identified.

Given the heterogeneity of the included studies, and high risk of bias associated with the study outcomes, a definitive conclusion regarding the clinical effectiveness of portable NMD ultraviolet technologies could not be made. Therefore, at present there is insufficient evidence regarding the clinical effectiveness of portable light-and-gaseous-based NMD devices to proceed to a full HTA. Further research, accounting for local manual cleaning practices, with a robust study design is warranted to better understand the effectiveness of these technologies in practice.

## Chapter 1 Background and Problem

### 1.1 Purpose of this Literature Review

The purpose of this literature review is to summarize evidence on the economic and clinical effectiveness of non-manual disinfection (NMD) systems. This review focused on ultraviolet light-based and gaseous-based NMD technologies.

This report includes evidence on the clinical effectiveness of NMD technologies in addition to manual cleaning and disinfection methods for prevention of hospital associated infections (HAI) compared to conventional manual cleaning and disinfections methods alone. In Canada, the Canadian agency for drugs and technologies in health (CADTH) and health quality Ontario (HQO) have previously reviewed NMD systems. (1-4) A CADTH review in 2015 suggests a more localized review for individual hospitals is warranted to help inform an appropriate decision regarding the adoption of NMD systems. (4) In addition, a Vancouver-based (Vancouver Coastal Health Authority) example concludes that Ultraviolet–C (UV-C) disinfection systems are a successful adjunct to manual cleaning in reducing environmental bioburden while noting that such a system must be carefully chosen for any specific facility. (5) Additional reviews for NMD technologies in other jurisdictions in BC, such as Fraser Health Authority, are ongoing.

This review focused on updating the 2018 CADTH rapid response review (2), while refining the search to only include light and gaseous-based NMD technologies, and to include evaluations undertaken by local health authorities in British Columbia (BC).

### 1.2 Policy Question and Research Objectives

The pretext in BC indicates that NMD technologies are not uniformly adopted within hospitals. Presently, there is some adoption of NMD technologies in BC, but the type of

technology and its use varies across health authorities. However, reviews undertaken by CADTH and other provincial organizations (i.e. HQO) indicate that there is insufficient evidence to support the adoption of these technologies. The present study was instigated as local health care professionals expressed interest and nominated NMD technologies to be reviewed by the Health Technology Assessment Committee (HTAC) in order to have province-specific conclusions and highlight trials in BC using portable UV-C technologies. This first phase of work was commissioned by HTAC to provide BC-specific context and include any new evidence for NMD technologies to determine if a full health technology assessment (HTA) would add value for decision-making purposes regarding the use of NMD technologies in BC.

### 1.2.1 Primary Policy Question or Decision Problem to be Answered in this Review

- Is there any new evidence that establishes the clinical effectiveness of portable light and gaseous-based NMD technologies for reducing and preventing rates of HAIs?
- If yes, is the evidence sufficient to pursue a full HTA on this topic?

### 1.2.2 Primary Research Questions to be Answered in this Review

- What is the clinical effectiveness of portable light- and gaseous-based NMD systems for infection prevention in hospital and healthcare facilities?

## 1.3 Background Information

HAIs, also referred to as nosocomial infections, refer to colonization or infections contracted by patients during their stay at the hospital, which were not present or developing at the time of admission. (6) In Ontario, colonizations or infections that occur within 48-72 hours of a hospital admission or 10 days after discharge can be classified as a HAI. (7) However,

this classification is not standardized across Canada, and in BC the lookback period (i.e., days post discharge) can vary across health authorities.

Environmental surfaces contaminated with microorganisms (including bacteria, viruses and fungi) have been implicated in HAIs. Antimicrobial drugs such as antibiotics are available to treat infections; however, antimicrobial resistance limits the effectiveness of available treatments and increases the importance of prevention of HAIs. (8)

*Clostridioides difficile* infection (CDI), vancomycin-resistant *enterococci* (VRE), methicillin-resistant *Staphylococcus aureus* (MRSA) and carbapenemase-producing organisms (CPO) are among the most common HAIs. (9, 10) HAIs include both infections and colonizations by these microorganisms, where CD can cause infections while MRSA, VRE and CPO can include both colonizations and infections. Infections resulting from these bacteria lead to serious illness and are associated with a prolonged hospital stay, hospital readmission and in some cases death. (11)

These microorganisms survive on surfaces or medical equipment, where they can be transmitted to patients via direct contact with contaminated environmental surfaces or from staff and visitors who may act as carriers. However, it has been estimated that up to half of HAIs can be prevented. (12) HAI prevention and control measures may vary depending on the health care setting, type of infection, and susceptibility of patients (e.g., burn or transplant patients). However, some general prevention measures include but are not limited to: Spatial separation, hand hygiene practices, architecture and layout of health care facilities, antibiotic prophylaxis (e.g., for burn patients), cleaning and disinfection of environmental surfaces and medical devices. (13, 14)

Therefore, implementation of best practices can significantly reduce the risk of some colonizations or infections (8), with protocols for cleaning of hospital surfaces, equipment and proper hand hygiene, essential to prevent the spread of HAIs.

### 1.3.1 Burden of HAI

HAIs are a frequent complication during care delivery and impart a significant clinical and economic burden on the healthcare system. Based on data from 1995 to 2010, Canada had one of the highest national prevalence of HAIs at 11.6%, compared to other developed countries, which range from 3.6% (in Germany) to 12% (in New Zealand). (15) With one in nine hospital patients contracting HAIs, each year in Canada there are over 220,000 cases of HAIs, where 8000 to 12,000 of cases result in death. (9, 16, 17)

Given the high burden of HAIs, several surveillance programs have been established to estimate and track rates of antimicrobial resistance infections or colonizations. The Canadian Nosocomial Infection Surveillance Program (CNISP) is a collaborative effort between several agencies, which aim to identify trends at both a national and regional level, and inform infection prevention and control programs. In Canada, the Public Health Agency of Canada (PHAC) monitors and reports the number of new cases of HAI antimicrobial resistant organisms annually. (18)

At the national level, CDI rates in acute care facilities have fallen from 6.03 per 10,000 patient days in 2012 to 3.85 per 10,000 patient days in 2017 across Canada. (18) Over the same time period (2012-2017), the overall rate of MRSA infections increased from 2.80 cases per 10,000 patient-days to 3.17. However, the rate of MRSA infection acquired within healthcare facilities was reduced by 6%, from 1.74 cases per 10,000 patient-days in 2012 to 1.65 cases in

2017. The rate of VRE infections increased for the first time from 0.26 infections per 10,000 patients-days in 2016 to 0.34. Lastly, the rate of carbapenemase producing *Enterobacteriaceae* (CPE) infections among hospitalize patients has remained at 0.03 infections per 10,000 patient-days since 2012. (18)

In BC, the Provincial Infection Control Network (PICNet), health authorities and related agencies have established surveillance programs for HAIs in acute care facilities. In 2017/2018, among participating facilities there were 8,479 acute care beds, 446,117 acute care admissions and a total of 3,119,299 inpatient days. (19) Over the same time period, within participating facilities there were 1,104 new cases of CDI, 1,447 new cases of MRSA and 134 new cases of CPO. (19) More specifically, the rate of CDI and MRSA per 10,000 inpatient day was 3.8 (95% CI: 3.6-4.0) and 4.6 (95% CI: 4.4-4.9), respectively.

Infections resulting from common bacteria associated with HAIs can lead to serious illness and death. In 2015, the all-cause mortality rate based on data from 61 hospitals across Canada (monitored at 30 days from diagnosis) among patients with MRSA was found to be 10%. (20) Moreover, the mortality rate differs between MRSA blood infections and skin infections. When all-cause mortality is stratified according to the site of infections, the rate among patients with MRSA blood infections and non-blood infections is 20% and 7% respectively. (20) However, the overall trend associated with all-cause mortality among patients with MRSA blood infection shows a reduction of 26% between 2012 and 2016. (18) The attributable mortality rate in Canada among hospital acquired CDI has also decreased by 30%, from 4.6% in 2012 to 3.2% in 2017. Patients with VRE infections also have significant risk of death, with a

crude mortality rate of 39% for VRE blood stream infections in 2015. (20) The all-cause mortality observed among patients with CPE has been 18.3% from 2012 to 2017.

### 1.3.2 Cost to Treat HAIs

Management of patients with HAIs is also associated with an increased economic burden on the healthcare system. (21-23) Based on estimates from 2001, the annual direct cost of management of HAIs in Canada was estimated to be $1 billion dollars. (24, 25) Costs are primarily driven by the substantial resources required to manage and treat infected patients. On average, patients with a HAI spend an additional five days as inpatients. (26) Although few cost estimates are available for management of HAIs in Canada, in 2005 the direct attributable cost of MRSA infections was estimated to be between $54 - $110 million; an estimated average cost of $12,216 per patient. (21) While, the cost of management of VRE infections was estimated to reach $17,949 per patient. (23)

Further, depending on the infection, patients may require a longer hospital stay. For example, evidence suggests that patients with MRSA require an average of 26 days of isolation, in addition to treatment, surveillance and other precautionary measures needed to contain the infection. (21, 27) Similarly, patients with severe CDI are reported to spend an additional 4.11 days in the hospital. (27) In BC, estimates from a study commissioned by PICNet in 2011, indicates that acute care facilities incur approximately $300 million for treatment of HAIs each year. (28) Further, it has been estimated that a 5% reduction in HAI could reduce treatment cost by $63 million dollars over four years. (28)

### 1.3.3 HAI Transmission and Infection Prevention

Pathogens (such as bacteria and viruses) can survive on environmental surfaces for several weeks and in some cases months. (29) Microorganisms responsible for HAIs can be transferred either directly from an infected patient to an environmental surface and then to a following patient, or indirectly from a contaminated environmental surface to a hospital staff/visitor and then to a patient. (30-32) Therefore, environmental surfaces within a healthcare setting play a key role in transmission of HAIs. Environment cleaning is an important step for infection prevention by reducing the amount of pathogens present, and thus reducing the risk of infection by disrupting the route of transfer for microorganisms from one object/person to another. (33) In this context cleaning refers to the physical removal of debris and foreign agents, whereas disinfections indicate killing (or inactivation) of infectious agents. (33)

In BC, the network for infection control (i.e. PICNet) has developed best practice guidelines for environment cleaning within healthcare settings. (34) The guideline provides recommendations on best practices for environment cleaning infrastructure, including cleaning and disinfection products, and best practices for different types of manual cleaning (e.g. general clean, routine daily clean, discharge clean). (34)

Manual cleaning protocols performed by human operators can be complex and require adherence to protocol to ensure a consistent outcome. When implemented in practice, manual cleaning and disinfection varies across different acute care facilities. (35) Evidence indicates that manual cleaning may be insufficient, which results in residual contamination of environmental surfaces. (36-39) The problems observed with conventional cleaning and

disinfection is related to the reliance on human operators to first ensure adequate cleaning before application of disinfectants, followed by the proper selection, preparation and application of disinfection agents and sufficient contact time. (40, 41)

To account for some of the challenges observed in implementing manual cleaning and disinfection of health care facilities, no-touch or NMD systems have been identified as technologies that may help supplement standard cleaning and disinfection procedures to reduce the risk of HAIs.

### 1.4 Overview of Technologies Under Assessment

In addition to standard cleaning and disinfection procedures, no-touch or NMD systems have been identified as a technology that may help reduce the risk of HAIs. No-touch systems refer to portable or fixed technologies that do not require the direct manual application or removal of disinfectant agents to environmental surfaces. (42) Portable systems can be moved throughout a facility for use, while fixed systems are those which are built into the room (e.g., wall-mounted) or built into the heating, ventilation and air conditioning (HVAC) systems.

A variety of NMD technologies are available, including: Hydrogen peroxide vapor or mist (43, 44), ultraviolet light (e.g., mercury bulb, pulsed xenon), high-intensity narrow-spectrum light (45, 46), fogging (47), ozone gas (48, 49), superoxide water (48), and steam vapor. (50, 51) Among available NMD technologies, the use of ultraviolet light and hydrogen peroxide are the most common systems in use and studied.

An overview of portable ultraviolet light and hydrogen peroxide technologies is presented below.

### 1.4.1 Ultraviolet Irradiation

In Canada, two types of portable ultraviolet devices are approved: (1) devices that emit UV-C through a mercury bulb (Figure **1.1**) and (2) devices that use a pulsed Xenon UV light (Figure 1.2). Ultraviolet light is a form of electromagnetic radiation that can kill microorganisms at specific wavelengths (between 200 to 320 nm) by destroying chemical bonds of genetic material. (52) UV-C light is the highest energy type of ultraviolet light (wavelength between 200 to 270 nm) (53), and has been used in healthcare settings to destroy both airborne microorganisms and those on environmental surfaces. (54)

Devices emitting ultraviolet light work by using germicidal lamps that produce a high-intensity UV-C light. UV-C destroys the DNA of bacteria, viruses and other microorganisms, thus preventing them from multiplying and causing infections. (55) Ultraviolet disinfecting devices that use mercury bulbs, emit a continuous dose of UV-C at a strong narrow band of UV-C spectrum (e.g., wavelength of 254nm). The lamps (i.e., Xenon lamps) used in pulsed Xenon ultraviolet devices, produce pulses of light at a broader spectrum, which includes both UV-C and UV-B (wavelengths of 200–320 nm).

To disinfect rooms, portable ultraviolet emitting devices are placed in the room and activated remotely for a prescribed time. The rooms must be vacated and surfaces must be in direct sight of ultraviolet light emitted for decontamination. The recommended length of time for decontamination varies between devices and manufacturers; on average the time required to disinfect one room is estimated at 15-30 minutes for pulsed Xenon UV devices and between 15-35 minutes for mercury UV-C devices. (1, 56) In the new models of the mercury bulb devices,

sensors are placed throughout the room, measuring the amount of UV energy that is reflected back to the device. This information is used by the device to provide a precise and lethal dose of UV-C required for room disinfection from a single position. (56)


**Figure 1.1 An Example of a Mercury bulb UV-C device**

**Figure 1.2 An Example of a Pulsed Xenon UV device**

#### 1.4.1.1 Ultraviolet Device Costs

The purchasing cost of UV disinfecting devices from two leading manufacturers range from $89,500 USD (including a 1-year warranty) for mercury UV-C devices and $102,300 USD, (including a 4-year warranty) for pulsed Xenon UV devices. (1) However, the use of these devices also includes the additional costs of a healthcare aid to move patients, dedicated environmental personnel to operate the device, and maintenance cost of the device.

### 1.4.2 Hydrogen Peroxide Systems

Hydrogen peroxide systems are a gaseous-based system used for disinfection of environmental surfaces and include: (1) aerosolized hydrogen peroxide (aHP) systems and (2) vaporized hydrogen peroxide (vHP) systems. Both systems have been used to eradicate common HAIs (including MRSA, CDI and VRE) and shown to be effective against bacteria, viruses and spores through destruction of the cell wall (Figure 1.3). (57, 58)

The aerosolized system uses a 5%-6% hydrogen peroxide solution and generates aHP using pressure or ultrasonic nebulization. (59-61) The aerosolized droplets are emitted into an enclosed space through a one-way nozzle. The vaporized system produces a 30%-35% hydrogen peroxide vapors (HPV) generated by heat. The HPV is also released into an enclosed space through a high velocity air system to ensure an even distribution within the enclosure. (62, 63) Both systems are computer controlled and can deliver aHP or vHP in rooms remotely. The automated machines ensure even distribution of hydrogen peroxide concentration throughout the room and monitor gas concentration, temperature and relative humidity. Following exposure

an aeration unit converts the hydrogen peroxide into oxygen and water. The estimated time for the decontamination process using hydrogen peroxide systems is between three to five hours.

**Figure 1.3 An Example of a Hydrogen Peroxide Device**

### 1.4.3 Potential Limitations of NMD Technologies

Both hydrogen peroxide and ultraviolet disinfection systems require manual cleaning to be completed prior to use of both systems, and have demonstrated a reduction in bacterial burden when implemented in conjunction with manual cleaning. However, the effectiveness of each NMD technology is influenced by several factors as outlined below.

Hydrogen peroxide systems require approximately 4 times longer for room decontamination when compared to 30 minutes required for manual cleaning. (64) In addition, during operation this system poses a health and safety risk to patients and staff, requiring

complete enclosure of the space with HVAC systems shut off. (52, 58) Repeated exposure to hydrogen peroxide also causes erosion of surfaces and medical equipment. (52) Lastly, different materials (e.g., soft furnishings) and positioning of the devices can influence the effectiveness of hydrogen peroxide systems.

The germicidal effectiveness of ultraviolet systems is also affected by several factors. Namely, pre-cleaning of visibly soiled surfaces is required as ultraviolet light is absorbed by organic material. (65) Further, appropriate positioning of the device is a key consideration as the ultraviolet light intensity is affected by the distance and angle of target surfaces. Ultraviolet devices also have destructive effect on surfaces (e.g., plastics, fabrics and paint) upon repeated exposure. (52, 58) Additional factors that could influence the effectiveness ultraviolet light systems include: surface material, temperature and relative humidity, exposure time, type of microorganism and wavelength of ultraviolet light. (54, 66)

Although environmental services staff will need initial training to operate these devices, a noted advantage of mobile NMD technologies is their ease of use, and minimal need for special training of environmental services personnel, versus the training required for manual disinfection of environmental surfaces. However, regardless of the technology, the additional effort required to prepare the room for non-manual disinfection is significant.

Some challenges identified based on a local implementation of a UV-C disinfection relates to staffing, training, and room turnover times. (67) A noted practical limitation associated with use of both ultraviolet and hydrogen peroxide disinfection systems relates to settings where disinfection of a shared patient room is required. For both NMD technologies the room must be vacant during the implementation of the disinfection procedure, and the

presence of other patients in the room poses a logistical challenge. To account for this, effective and timely coordination between medical staff and environmental cleaning services staff is required, to allow for use of NMD devices in shared patient rooms.

## Chapter 2 Methods

### 2.1 Literature Search

An updated literature search was performed to determine the clinical effectiveness and identify evidence on the cost-effectiveness of portable light- or gaseous-based non-manual disinfection systems for infection prevention in healthcare facilities. An information specialist developed the search strategy. The search strategy used in a previously published CADTH rapid response in 2018 was used to guide the development of an updated search strategy. (2) To ensure the search captured the NMD technologies of interest they were also reviewed by a clinical expert.

The literature search was implemented in Embase and MEDLINE and the search was limited to studies published between, January 2018 to July 2019. A targeted review of two CADTH rapid response reviews on NMD technologies was also performed.

The final search strategy, including all search terms is presented in Appendix A.

### 2.2 Call to Local Stakeholders

Representatives from two local health authorities were contacted to inform locally implemented standard manual cleaning practices. In addition, stakeholders were invited to provide any additional unpublished references, and information on any province-specific evidence of effectiveness of NMD technologies from ongoing field evaluations of NMD technologies. Through local stakeholder engagement 3 study reports on a previously implemented intervention was identified. However, no new references or unpublished evidence of ongoing field evaluations were received.

## 2.3 Literature Screening

One reviewer conducted the initial screening of title and abstract, and obtained the full text of studies that were eligible for a full-text review. Full text articles found to meet the inclusion criteria listed in Table 2.1 were selected for inclusion in the study. The study flow was summarized using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) diagram (see Figure 3.1).

### 2.3.1 Inclusion Criteria

The inclusion criteria are presented in Table 2.1.

**Table 2.1. Inclusion Criteria**

| Patient Population | Intervention | Comparators | Outcomes | Study design |
|---|---|---|---|---|
| **Hospital or healthcare facility rooms** | NMD techniques that incorporate:<br>• light-based systems (e.g., UV-light)<br>• Gaseous-based systems (e.g., hydrogen peroxide vapour) | • Standard manual cleaning procedures<br>• No intervention<br>• No comparator | Rates of HAIs (e.g., CDI, VRE, MRSA)<br>Cost-effectiveness outcomes | • Systematic reviews<br>• Health technology assessments<br>• Randomized controlled trials<br>• Quasi-experimental studies<br>• Economic evaluations |

NMD: Non-manual disinfection; HAI: Hospital associated infection; CDI: *Clostridioides difficile* infection; MRSA: methicillin-resistant *Staphylococcus aureus*; VRE: vancomycin-resistant enterococci; UV: Ultraviolet

### 2.3.2 Exclusion Criteria

- Studies that did not meet the selection criteria listed in Table 2.1;
- Non-English-language publications;
- Abstract/conference proceedings;
- Letters and commentaries.

### 2.3.3 Data Extraction and Quality Assessment

One reviewer extracted data using a standardized form in Microsoft Excel on study characteristics, clinical and economic outcomes. Data pertaining to study setting, design, length of follow-up, NMD device used and disinfection protocols for manual disinfection were abstracted. In addition, information on other infection control measures was collected. Study outcomes collected include: number of HAI cases, infection rates, and incident rate ratio (IRR), where appropriate. Extracted data were crosschecked for errors.

All included studies were assessed for methodological quality and risk of bias. Risk of bias for individual studies was completed using study design-specific tools. Effective Practice and Organization of Care (EPOC) tool for randomized trials, controlled before-after and interrupted time-series studies was used. (68) The National Heart, Lung and Blood Institute quality assessment tool was used for before-after studies with no control group. (69) The AMSTAR-2 checklist was used to assess the quality of systematic reviews. (70)

### 2.3.4 Data Synthesis

The included studies were summarized qualitatively. The study characteristics of full text articles that met the inclusion criteria were summarized in tables. Rate of HAIs were summarized by microorganism were possible. Rate ratios of HAIs between NMD technologies and manual disinfection were taken as reported or calculated from data reported in the study.

### 2.3.5 Subgroup Analysis

No subgroup analysis was planned.

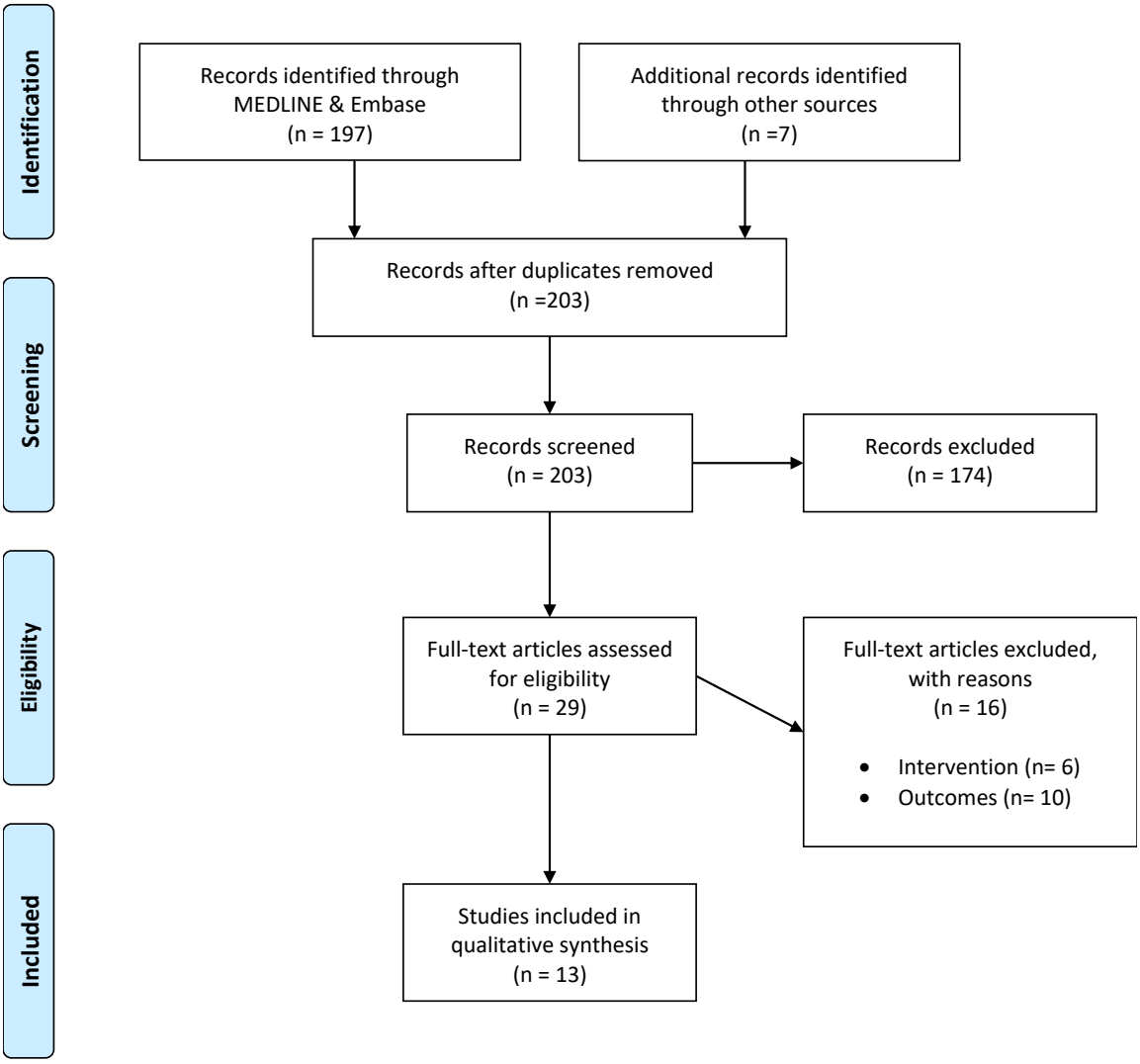
# Chapter 3 Results

## 3.1 Literature Search Results

The combined search of MELDLINE and Embase identified 197 studies. Hand search of previous CADTH reviews (2, 71), identified four studies and request to local stakeholders generated 3 additional studies. (72-74)

After the preliminary screening of title and abstracts, one duplicate was identified and 174 studies, which did not match the inclusion criteria, were excluded. A total of 29 studies were eligible for full text review, 13 of which were included in the review. Among the 13 studies, ten studies evaluated clinical outcomes (73-82), one study evaluated economic outcomes (72), and two studies reported both economic and clinical outcomes (1, 83). In the following sections, the evidence identified from the included studies is presented as clinical evidence (Section 3.2) and economic evidence (Section 3.4).

**Figure 3.1 PRISMA Diagram of Study Selection**



***Previous assessment of identified studies***

Of the thirteen studies included in this review, all studies identified through the updated database search were previously captured in either the 2018 or 2019 CADTH rapid response reviews (Table 3.1). Further, the three studies identified through hand search of the 2018 CADTH review had been evaluated in the HTA conducted by HQO in 2018. The studies identified via stakeholders (i.e., studies conducted by Fraser Health) (72-74), are the only studies that have not been identified and reviewed previously.

**Table 3.1 Overview of The Previous Assessment of Included Studies**

| Method of identification in present study | Author, year | Previous Reviews | | |
|---|---|---|---|---|
| | | CADTH 2018 (2) | CADTH 2019 (71) | HQO review (1) |
| *Updated database search (MEDLINE, Embase; Date: Jan 2018-Jul 2019)* | Raggi et al., 2018 (83) | X | X | |
| | Anderson et al., 2018 (84) | X | | |
| | Brite et al., 2018 (78) | | X | |
| | Marra et al., 2018 (75) | X | X | |
| | HQO, 2018 (1) | X | X | NA |
| | Sampathkumar et al., 2019 (82) | | X | |
| *Hand search of 2019 CADTH Rapid response* | Pavia et al., 2019 (80) | | X | |
| *Hand search of 2018 CADTH Rapid response* | Pegues et al., 2017 (81) | X | | X |
| | Haas et al., 2014 (79) | X | | X |
| | Anderson et al., 2017 (76) | X | | X |
| *Call to local stakeholders* | Fraser Health, 2017 (74) | | | |
| | Fraser Health, 2018 (72) | | | |
| | Fraser Health, 2019 (73) | | | |

CADTH: Canadian Agency for Drugs and Technologies in Health; HQO: Health Quality Ontario

## 3.2 Clinical Evidence

### 3.2.1 Summary of Included Studies

Overall, thirteen studies met the inclusion criteria and were included in the final review. A summary of the study characteristics of the included studies is presented in Appendix B (sections B.1, B.2, and B.3). The included studies which evaluated clinical outcomes comprised one systematic review (75), one HTA (1), two randomized trials (76, 84), three interrupted time-series studies (73, 78, 81) [two of which included controls (73, 81)], two controlled before-after studies (74, 82), three before-after studies without a control. (79, 80, 83)

The NMD technologies in all included studies were light-based UV disinfection technologies; none of the studies evaluating hydrogen peroxide systems met the inclusion criteria. Overall, few studies evaluating hydrogen peroxide systems were identified in the updated review and among the studies that did use this system the primary reason for exclusion was by intervention and study outcomes.

Among the ten primary studies included, five evaluated mercury UV-C devices (76, 80, 81, 83, 84), and five studies evaluated pulsed Xenon UV devices. (73, 74, 78, 79, 82)

***Study setting, target rooms and timing of disinfection***

Eight of the identified studies were conducted within hospitals in the USA, while three were based on a study implemented in BC, Canada. Of the two reviews identified: authors in the USA conducted the systematic review, and authors from Ontario, Canada conducted the HTA. Four studies evaluated the use of the device in all hospital units, while the remaining studies were limited to specific units within the hospital (e.g., vulnerable units, units of leukemia and lymphoma patients, etc.), see Appendix B, sections B.1 and B.2.

The systematic review and HTA evaluated studies conducted within a hospital setting, targeting patient rooms (after discharge or transfer) in units ranging from intensive care unit (ICU) and non-ICU units. In the primary studies included, there was considerable variation across the included studies with respect to the rooms targeted for UV disinfection. In two studies the UV devices were used primarily in rooms of patients on contact precautions (76, 81), four studies included rooms within the targeted units (74, 78, 80, 82), and two studies used the device in ICU, operating rooms, in rooms of long-term stay patients, or areas with high prevalence of infections. (79, 83) Lastly, two studies (73, 77) were secondary analyses of two included studies (i.e., Anderson et al., 2017 (76) and Fraser Health., 2017 (74)), where both evaluated the impact of the intervention on all patients admitted to the hospital.

The timing of UV disinfection was mainly after patient discharge or transfer. However, in the study implemented by Fraser Health (74), a cyclical unit deep clean of all rooms was implemented with the sequence repeated for the duration of the intervention (i.e., 6 months). Similarly, in another study that was restricted to toddler units, a rotating schedule was implemented, where the target rooms were cleaned 2-3 times per week. (80)

***Manual cleaning and disinfection procedure***

All the included studies reported the use of either bleach and/or quaternary ammonium disinfectants. Quaternary ammonium disinfectants were used in four studies (76, 78-80), and bleach was specifically used for CDI in four studies. (76, 78, 81, 82) In one study the cleaning disinfectant used was not stated. (83) Lastly, in one study a bleach-based solution was used for all rooms except for daily cleaning of rooms with pediatric patients. (79)

***UV disinfection procedure***

In all studies, UV disinfection was evaluated as an adjunct to standard manual cleaning. Both the HTA and systematic review also evaluated the use of UV devices in conjunction with manual cleaning. In the HTA, studies were separated according to the type of UV technology used (i.e., mercury UV-C and Pulsed Xenon UV). Overall, the number of UV disinfection cycles reported ranged from 1-7 cycles, and duration per cycle reported was between 5-8 minutes (see Appendix B, section B.3). Of the included studies, five evaluated mercury UV-C devices (76, 80, 81, 83, 84), and five evaluated pulsed Xenon UV devices. (73, 74, 78, 79, 82) with the exception of the randomized trial (76), where the duration was 30 min-55 min (77), the duration of disinfection cycles reported was similar between studies using mercury UV-C devices and those that used the pulsed Xenon UV devices. Additional process measures reported during UV disinfection included, opening drawers and cabinets, exposing high touch objects (e.g., remote controls, telephones), as wells as changing linens and curtains.

### 3.2.2 Summary of Study Outcomes

***Reviews***

The HTA and systematic review have been previously summarized and evaluated in an updated CADTH response review in 2019; these findings are presented in Table 3.2 and Table 3.3, respectively.

In both the HTA and systematic review the rate of HAI was the primary outcomes investigated, including rates of CDI, MRSA, VRE and other MDROs. In the HTA given the heterogeneity observed in the study design, setting, interventions and outcome measures, a quantitative data synthesis was not conducted. Therefore, the authors were not able to make conclusions regarding the effectiveness of UV disinfection technology. In the systematic review,

although clinical heterogeneity was observed in the included studies a quantitative synthesis of the data was conducted using a meta-analysis approach; where all the included studies (except for one) evaluated infections, and not colonization, as the outcome. To address the heterogeneity observed, subgroup analysis based on hospital type, compliance and monitoring and CDI rates was carried out. The authors of the systematic review concluded that the UV disinfection technology might be effective in prevention of CDI and VRE. The authors also evaluated the evidence on hydrogen peroxide vapor systems and CDI, and found no statistically significant reductions in the pooled analysis (Table 3.3).

**Table 3.2 Summary of Results: HTA**

| | HQO, 2018 (1) | |
|---|---|---|
| | **Mercury UV-C Devices** | **Pulsed Xenon UV Devices** |
| Combined HAI and colonization relative rate: | One cluster RCT (low quality evidence)<br>RR (95% CI) = 0.70 (0.55 to 0.98); P = 0.036<br><br>One pre-post study (very low-quality evidence)<br>RR (95% CI) = 0.66 (0.45 to 0.96); P = 0.03 | Three pre-post studies (very low-quality evidence)<br>RR (95% CI) = 1.17 (0.50 to 2.76); P = 0.72<br>RR (95% CI) = 0.71 (0.55 to 0.91); P = 0.01<br>RR (95% CI) = 0.80 (0.73 to 0.88); P < 0.001 |
| CD | One cluster RCT (low quality evidence)<br>RR (95% CI) = 1.0 (0.57 to 1.75); P = 0.997<br><br>Two pre-post studies (very low-quality evidence)<br>RR (95% CI) = 0.49 (0.26 to 0.94); P = 0.03<br>RR (95% CI) = 0.54 (0.27 to 1.09); P = 0.08 | Six pre-post studies (very low quality evidence)<br>RR (95% CI) = 0.37 (0.02 to 6.89); P = 0.51<br>RR (95% CI) = 0.59 (0.41 to 0.86); P = 0.005<br>RR (95% CI) = 0.43 (0.24 to 0.77); P = 0.005<br>RR (95% CI) = 0.78 (0.61 to 1.01); P = 0.06<br>RR (95% CI) = 0.83 (0.7 to 0.97); P = 0.02<br>RR (95% CI) = 0.47 (0.26 to 0.86); P = 0.015 versus 1 year prior |
| MRSA | One cluster RCT (low quality evidence)<br>RR (95% CI) = 0.78 (0.58 to 1.05); P = 0.10<br><br>One pre-post study (very low-quality evidence)<br>RR (95% CI) = 0.99 (0.35 to 2.08); P = 0.98 | Three pre-post studies (very low-quality evidence)<br>RR (95% CI) = 1.26 (0.34 to 4.75); P = 0.75<br>RR (95% CI) = 1.20 (0.75 to 1.91); P = 0.45<br>RR (95% CI) = 0.73 (0.58 to 0.92); P = 0.007 |
| VRE | One cluster RCT (low quality evidence)<br>RR (95% CI) = 0.41 (0.15 to 1.13); P = 0.08<br><br>One pre-post study (very low-quality evidence)<br>RR (95% CI) = 0.88 (0.45 to 1.71); P = 0.70 | Two pre-post studies (very low-quality evidence)<br>RR (95% CI) = 0.50 (0.27 to 0.91); P = 0.02<br>RR (95% CI) = 0.82 (0.70 to 0.95); P = 0.002 |

| HQO, 2018 (1) | | |
|---|---|---|
| | **Mercury UV-C Devices** | **Pulsed Xenon UV Devices** |
| Other HAI rates: | - One RCT found no cases of multidrug-resistant Acinetobacter infection or colonization after both treatment and control (low quality evidence)<br>- 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) | - 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)<br>- One pre-post study found no significant difference in any other HAI rates including VAP, CAUTI, CLABSI (very low-quality evidence) |
| Author's Conclusions: | "We are unable to make a firm conclusion about the effectiveness of this technology on HAIs given the very low quality of evidence" p.3 | |

HAI: Hospital associated infections; CD: *Clostridioides difficile;* VRE: Vancomycin-resistant Enterococcus; MRSA: Methicillin-resistant Staphylococcus aureus; UV: Ultraviolet; HQO: Health Quality Ontario

**Table 3.3 Summary of Results: Systematic Review**

| | Marra et al., 2018 (75) |
|---|---|
| **UV light no-touch technology (UV-C and PX-UV)** | |
| CD | - Overall (11 studies): RR (95% CI) = 0.64 (0.49 to 0.84); $I^2$ = 0%; P = 0.0010<br>- Subgroups based on baseline C. difficile infection rates:<br>High (6 studies): RR (95% CI) = 0.60 (0.43 to 0.86); $I^2$ = 37%; P = 0.005<br>Low (5 studies): RR (95% CI) = 0.70 (0.17 to 2.90); $I^2$ = 0%; P = 0.63<br>- Subgroups based on study design:<br>Controlled trials (2 studies): RR (95% CI) = 0.65 (0.26 to 1.62); $I^2$ = 79%; P = 0.35<br>Non-controlled trials (9 studies): RR (95% CI) = 0.58 (0.41 to 0.83); $I^2$ = 0%; P = 0.003<br>- Subgroups based on types of hospital:<br>Academic hospitals (3 studies): RR (95% CI) = 0.58 (0.37 to 0.91); $I^2$ = 7%; P = 0.02<br>Community hospitals (7 studies): RR (95% CI) = 0.48 (0.30 to 0.77); $I^2$ = 0%; P = 0.002<br>- Subgroups based on studies reporting compliance rates:<br>Yes (7 studies): RR (95% CI) = 0.71 (0.52 to 0.96); $I^2$ = 0%; P = 0.03<br>No (4 studies): RR (95% CI) = 0.48 (0.28 to 0.81); $I^2$ = 0%; P = 0.006 |
| VRE | - Overall (4 studies): RR (95% CI) = 0.42 (0.28 to 0.65); I2 = 0%; P < 0.0001 |
| **HPV no-touch technology** | |
| CD | - Overall (5 studies): RR (95% CI) = 0.52 (0.15 to 1.81); $I^2$ = 0%; P = 0.3 |
| Author's Conclusions: | "Ultraviolet light no-touch disinfection technology may be effective in preventing C. difficile infection and VRE infection" p.20 |

HPV: Hydrogen peroxide vapor; CD: *Clostridioides difficile*; VRE: Vancomycin-resistant Enterococcus; UV: Ultraviolet

***Randomized trials***

The results presented in Table 3.4 are the primary (Anderson et al. 2017) and secondary analysis (Anderson et al. 2018) of a cross over cluster-randomized trial using a mercury UV-C device. In the primary analysis of the this study the rate of HAIs (defined as rate of infection plus colonization) was estimated for patients exposed to target rooms, while in the secondary analysis the hospital-wide rate of HAIs (also defined as rate of infection plus colonization) was evaluated.

Results from the primary analysis indicate that the addition of mercury UV-C disinfection to standard non-bleach manual cleaning protocols (i.e. Reference group: Quaternary ammonium disinfectant except for CD, for which bleach was used), led to a 30% relative rate reduction of combined HAIs among patients exposed to target rooms, when compared to standard cleaning alone. While, the rate ratio observed with the addition of UV-C disinfection to a bleach-based manual disinfection was less effective than all the other interventions considered; 0·91 (95% CI: 0·76 to 1·09); p= 0·303). A similar trend was observed when the results are evaluated by individual microorganisms. The results from the primary analysis also found a non–statistically significant relative reduction in hospital-acquired MRSA colonization or infection rates when UV-C disinfection was added to the non-bleach manual cleaning protocol.

In the secondary analysis, a non-statistically significant difference in risk of hospital-wide HAIs between the standard disinfection versus mercury UV-C disinfection plus standard disinfection was found (a relative rate reduction of 11%). When results were evaluated by individual microorganisms, the hospital-wide risk of CDI was significantly reduced with the

addition of UV-C disinfection to standard non-bleach manual disinfection, while a non-significant increase in the risk hospital-wide MRSA was observed. Similar to the results observed in the primary analysis, in this hospital-wide evaluation, the rate ratio in the mercury UV-C to plus bleach manual cleaning study arm was higher than all the other intervention groups.

**Table 3.4 Randomized Trials: HAI Rate for UV Disinfection Plus Manual Disinfection Versus Manual Disinfection Alone**

| Author, Year | Organisms included | Manual Disinfection [a] | | UV + Manual Disinfection | | Bleach | | UV + Bleach | |
|---|---|---|---|---|---|---|---|---|---|
| | | Rate* | Rate Ratio (95% CI); p value [b] | Rate* | Rate Ratio (95% CI); p value [b] | Rate* | Rate Ratio (95% CI); p value [b] | Rate* | Rate Ratio (95% CI); p value [b] |
| **Anderson et al., 2018 (78)** | **Combined** | **1.81** | | **1.72** | **0·89 (0·79 to 1·00); p= 0·052** | **1.75** | **0·92 (0·79 to 1·08); p= 0·32** | **1.74** | **0·99 (0·89 to 1·11); p= 0·89** |
| | MRSA | 5.66 | | 0.63 | 1·08 (0·89 to 1·30); p= 0·42 | 0.59 | 0·97 (0·76 to 1·24); p= 0·82 | 0.58 | 1·00 (0·87 to 1·14); p= 0·97 |
| | VRE | 0.32 | Reference | 0.32 | 0·56 (0·31 to0·996); p= 0·048 | 0.46 | 0·87 (0·65 to 1·17); p= 0·35 | 0.45 | 1·28 (0·94 to 1·73); p= 0·11 |
| | MDR *Acinetobacter*[d] | 0.02 | | 0.01 | 0·10 (–0·07 to 0·28) | 0.01 | 0·07 (–0·12 to 0·26) | 0.01 | 0·10 (–0·07 to 0·28) |
| | CD | 1.01 | | 0.91 | 0·89 (0·80 to 0·99); p= 0·031 | 0.88 | 0·91 (0·75 to 1·10); p= 0·32 | 0.89 | 0·97 (0·84 to 1·12); p= 0·68 |
| **Anderson et al., 2017 (70)** | **Combined** | **5.13** | | **3.39** | **0·70 (0·50 to 0·98); p= 0·036** | **4.16** | **0·85 (0·69 to 1·04); p= 0·116** | **4.56** | **0·91 (0·76 to 1·09); p= 0·303** |
| | MRSA | 5.03 | | 3.65 | 0·78 (0·58 to 1·05); p= 0·104 | 4.82 | 1·00 (0·82 to 1·21); p= 0·967 | 4.69 | 0·97 (0·78 to 1·22); p= 0·819 |
| | VRE | 6.34 | Reference | 2.94 | 0·41 (0·15 to 1·13); p= 0·084 | 3.19 | 0·43 (0·19 to 1·00); p= 0·049 | 3.90 | 0·36 (0·18 to 0·70); p= 0·003 |
| | MDR *Acinetobacter*[d] | 0.00 | | 0.00 | NA | 10.24 | NA | 0.00 | NA |
| | CD [c] | - | | - | - | 3.16 | Reference | 3.04 | 1·0 (0·57 to 1·75); p= 0·997 |

CD: *Clostridioides difficile;* VRE: Vancomycin-resistant Enterococcus; MRSA: Methicillin-resistant Staphylococcus aureus; MDR: Multidrug-resistant; UV: Ultraviolet

*Rate per 1000 patient days; Cases include both hospital-associated colonization and infection

[a] Quaternary ammonium disinfectant except for CD, for which bleach was used

[b] Based on adjusted intention-to-treat analysis.

[c] for CD manual disinfection was completed using bleach; Reference group was the Bleach group only, different from other organisms

[d] No models were created for multidrug-resistant *Acinetobacter baumanii* given the few numbers of outcomes observed in each study group

***Interrupted time-series***

Three studies estimated the impact of addition of UV disinfection on HAI rates using an interrupted time-series design (Table 3.5). Two studies conducted this with a control arm that was defined as "acute care facilities that were not part of the intervention (73), or hospital units that did not participate in the study (81)". Of the three studies, only one found a significant association between reduction of CDI rates and implementation of UV disinfection. (81)

In the study by Brite et al., which did not have a control group, the addition of UV disinfection to routine manual cleaning of patient rooms was not effective in significantly reducing acquisition of CD and VRE (which included colonization or infection). (78) This study was restricted to stem cell transplant patients. In the analysis conducted by Fraser Health, the combined rate of HAI at a facility level was evaluated. In this analysis a reduction was observed in combined infection rates (-6.42 cases per 10,000) after the cleaning program was started, however this was not statistically significant (p=0.35). (73) This is likely due to small sample size and the short duration (i.e., 6 months) of the trial.

**Table 3.5 Interrupted Time-Series: HAI Rate for UV Disinfection Plus Manual Disinfection Versus Manual Disinfection Alone**

| Author, Year | Organisms included | Rate* | | IRR (95% CI); p value |
|---|---|---|---|---|
| | | Baseline | Intervention | |
| **Brite et al., 2018 (78)** | CD | 1.41 | 1.11 | **Level change:** 0.51 (0.13 to 2.11); P = .356<br>**Trend change:** 1.08 (0.89 to 1.31); P = .413 |
| | VRE | 3.02 | 3.66 | **Level change:** 1.34 (0.37 to 4.80); P = .652<br>**Trend change:** 0.96 (0.81 to 1.14); P = .625 |
| **Pegues et al., 2017 (81)** | CD-intervention | 3.03 | 2.29 | **Adjusted:** 0.49 (0.26–0.94); P = .03 [a]<br>**Unadjusted:** 0.75 (0.55–1.04) |

| Author, Year | Organisms included | Rate* | | IRR (95% CI); p value |
|---|---|---|---|---|
| | | Baseline | Intervention | |
| | CD- control | 0.58 | 0.67 | **Adjusted:** 0.63 (0.38 to 1.06); P=.08 [a]<br>**Unadjusted:**1.16 (0.91 to 1.51); p=.95 |
| **Fraser Health., 2019 (73)** | Combined-Intervention | - | - | **Level change:** -6.42 cases per 10,000 (-19.70 to 6.87); p=.35 [a]<br>**Trend change:** 0.82 cases per 10,000 (-1.99 to 3.64); p=.57 [a] |
| | Combined-Control | - | - | **Level change:** 0.76 cases per 10,000 (-8.63 to 10.15); p=.87 [a]<br>**Trend change:** -0.75 cases per 10,000 (-2.74 to 1.24); p=.46 [a] |

CD: *Clostridioides difficile* ; VRE: Vancomycin-resistant *Enterococcus*

[a] Based on adjusted interrupted time-series analysis

*Rate per 1000 patient days

***Controlled before and after***

Two controlled before after studies evaluated the impact of the addition of pulsed Xenon UV devices to standard manual disinfection (Table 3.6). In the study by Sampathkumar et al., a quasi-experimental design using three units for the intervention (two hematology and bone marrow transplant [BMT] units and one medical-surgical unit) and three similar units as control units was implemented. (82) This study found a reduction in the rate of CD and VRE infections after the intervention, and the rate observed was significantly different than the infection rates in the control units.

In the study conducted by Fraser Health (74), overall there was a reduction in rates of HAIs within the intervention facilities, when compared to the same period in the previous year. The rates of MRSA and CD infections in the non-target units were also reported. However, as the target units used for this intervention were selected because of the high-observed rates of HAI and willingness to participate, by definition the non-target units are not appropriate comparators.

**Table 3.6 Controlled Before and After Studies: HAI Rate for UV Disinfection Plus Manual Disinfection Versus Manual Disinfection Alone**

| Author, Year | Groups (Control/Intervention) | Organisms included | Pre-Intervention | | | | During-intervention | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | *Cases (n)* | Patient days | *Rate*[*] | *P value* | *Cases (n)* | Patient days | *Rate*[*] | *P value* |
| **Sampathkumar et al., 2019 (82)** | Intervention | CD | 59 | 27,707 | 2.13 | 0.17 | 10 | 8,958 | 1.12 | 0.03 |
| | Control | | 48 | 18,405 | 2.61 | | 15 | 5,219 | 2.87 | |
| | Intervention | VRE | 35 | 13,686 | 2.56 | 0.00 | 4 | 4,085 | 0.98[b] | 0.02 |
| | Control | | 65 | 14,129 | 4.60 | | 13 | 4,000 | 3.25 | |
| **Fraser Health, 2017 (74)** | Intervention-ARH | MRSA | 27 | 23,276[a] | 1.16 | - | 20 | 21,978[a] | 0.91 | - |
| | Intervention-BH | | 53 | 21,992[a] | 2.41 | - | 30 | 21,127[a] | 1.42 | - |
| | Intervention-RMH | | 35 | 24,476[a] | 1.43 | - | 27 | 23,077[a] | 1.17 | - |
| | Control-ARH | | 18 | 31,034[a] | 0.58 | - | 12 | 29,268[a] | 0.41 | - |
| | Control-BH | | 25 | 40,984[a] | 0.61 | - | 23 | 38,333[a] | 0.60 | - |
| | Control-RMH | | 7 | 9,589[a] | 0.73 | - | 0 | 0 | 0 | - |
| | Intervention-ARH | CD | 16 | 23,188[a] | 0.69 | - | 9 | 21,951[a] | 0.41 | - |
| | Intervention-BH | | 35 | 22,013[a] | 1.59 | - | 15 | 21,127[a] | 0.71 | - |
| | Intervention-RMH | | 12 | 24,490[a] | 0.49 | - | 25 | 23,148[a] | 1.08 | - |
| | Control-ARH | | 8 | 27,586[a] | 0.29 | - | 4 | 25,000[a] | 0.16 | - |
| | Control-BH | | 29 | 38,667[a] | 0.75 | - | 9 | 36,000[a] | 0.25 | - |
| | Control-RMH | | 3 | 8,824[a] | 0.34 | - | 1 | 9,091[a] | 0.11 | - |

CD: *Clostridioides difficile* ; VRE: Vancomycin-resistant *Enterococcus*; MRSA: Methicillin-resistant *Staphylococcus aureus*; ARH: Abbotsford Regional Hospital; BH: Burnaby Hospital; RMH: Ridge Meadows Hospital

[*]Rate per 1000 patient days

[a] Patient days were not reported in the study and were calculated

[b] Believe there is an error in the paper; the number here represents a calculation based on the numbers reported

***Uncontrolled before and after***

Among the three uncontrolled before-after studies identified (Table 3.7), one was conducted in a pediatric facility and evaluated the impact of introducing the technology on the rate of hospital associated viral infections. The results of this study demonstrated a significant reduction in the rate of viral infections, after the implementation of a mercury UV-C device. (80) In the study by Haas et al, which evaluated the use of pulsed Xenon UV devices, a relative rate reduction in both the combined and individual organisms was observed. (79) Lastly, in the study by Raggi et al, the rates (defined as infection or colonization) pre- and post-intervention were compared, and the overall HAI incidence rate was reduced. (83)

Although these studies demonstrate a reduction in the rates of infection after the implementation of ultraviolet devices, the findings are limited since the underlying trend (i.e., pre-intervention phase) that could have contributed to the outcomes was not accounted for in the evaluation.

**Table 3.7 Uncontrolled Before and After Studies: HAI Rate for UV Disinfection Plus Manual Disinfection Versus Manual Disinfection Alone**

| Author, Year | Organisms included | Pre-Intervention | | | During-intervention | | | *Rate Ratio (95% CI)/ P value* |
|---|---|---|---|---|---|---|---|---|
| | | Cases *(n)* | Patient days | *Rate** | Cases *(n)* | Patient days | *Rate** | |
| **Raggi et al., 2018 (83)** | Combined | 313 | 64,262 | 4.87 | 245 | 62,242 | 3.94 | p=.007 |
| | AB | 22 | 64706 [a] | 0.34 | 10 | 62,500 [a] | 0.16 | p=.03 |
| | KP | 73 | 62,931 [a] | 1.16 | 76 | 62,295 [a] | 1.22 | p=.36 |
| | MRSA | 91 | 64,085 [a] | 1.42 | 61 | 62,245 [a] | 0.98 | p=.02 |
| | PA | 83 | 64,341 [a] | 1.29 | 70 | 60,345 [a] | 1.16 | p=.22 |
| | VRE | 44 | 64,706 [a] | 0.68 | 28 | 62,222 [a] | 0.45 | p=.05 |
| **Pavia et al., 2018 (80)** | Viral infections | 73 | 9,418 | 7.75 | 41 | 9,387 | 4.37 | 0.56 (0.37 to 0.84); p =.003 |
| **Haas et al., 2014 (79)** | Combined | 1320 | 494,382 [a] | 2.67 | 749 | 350,000 [a] | 2.14 | 0.80 (0.73-0.88); p<.001 |
| | VRE | 443 | 492,222 [a] | 0.9 | 257 | 352,055 [a] | 0.73 | 0.82 (0.70-0.95); p=.002 |
| | CD | 390 | 493,671 [a] | 0.79 | 228 | 350,769 [a] | 0.65 | 0.83 (0.70-0.97); p=.02 |
| | MRSA | 224 | 497,778 [a] | 0.45 | 116 | 351,515 [a] | 0.33 | 0.73 (0.58-0.92); p=.007 |
| | MDRO | 260 | 500,000 [a] | 0.52 | 148 | 352,381 [a] | 0.42 | 0.81 (0.66-0.98); p=.04 |

AB: *Acinetobacter baumannii*; KP:*Klebsiella pneumoniae*; PA: *Pseudomonas aeruginosa* CD: *Clostridioides difficile* ; VRE: Vancomycin-resistant *Enterococcus*; MRSA: Methicillin-resistant *Staphylococcus aureus*; MDRO: Multidrug-resistant organism

[*] Rate per 1000 patient days

[a] Patient days were not reported in the study and were calculated

### 3.3 Quality Assessment

The quality assessment of all included studies is summarized in Appendix C.

The quality of both the HTA and systematic review had been recently appraised in the 2019 CADTH rapid response. (71) Therefore, a second appraisal was not conducted in this study (see Appendix C, Section C.1). Generally, it was found that both studies used the appropriate research question and implemented a comprehensive search strategy. Further, both studies described the included studies in sufficient detail and used appropriate techniques in assessing the risk of bias in the studies included. The following was not reported in the studies: a list of excluded studies, source of funding for the included studies, whether review methods were established in a protocol. Overall, the methodology in the HTA was found to be more detailed and comprehensive, than the systematic review.

In the primary analysis of the randomized trial (76), adequate random sequence generation, similar baseline characteristics, and selective outcome reporting were explicit with a low risk of bias. However, the study was at risk of selection bias due to the absence of allocation concealment, and detection bias in the absence of blinding of outcome assessment. In the secondary analysis (77), there was also a lack of clarity regarding the incomplete outcome data during the study, which increases the possibility of attrition bias in the observed estimate (see Appendix C, Section D.1).

The additional studies, with the controlled before and after design, demonstrated a high risk of bias. A primary concern was due to the lack of clarity regarding the comparability of the study groups (both in terms of patient characteristics and baseline outcome measures), prior to the implementation of the intervention. Further, the risk of contamination was unclear in both

studies. Overall, these studies had a high risk of selection and performance bias (see Appendix C, Section D.1).

Among the studies with a before-after design that conducted an interrupted time-series analysis (73, 78, 81) , the outcome was at a high risk of confounding by other events during the study periods. However, as the study outcomes (i.e., rates of HAI) were an objective measure, the intervention was not likely to have an impact on the data collection (see Appendix C, Section D.2).

All of the additional uncontrolled before-after studies had a clearly stated objective. However, two of the studies did not specify the eligibility criteria. (79, 80) Further, blind outcome assessment and loss to follow-up was not accounted for in all three studies. Overall, these studies were at high risk of attrition bias. Further, with the before-after studies design in the absence of a control or appropriate statistical methods to account for confounding variables, it is unclear if the study outcomes observed can be attributable to the intervention implemented. Thus, these studies are at a high risk of detection bias (see Appendix C, Section D.3).

## 3.4 Economic Evidence

### 3.4.1 Summary of Included Studies

Overall, three studies were identified that reported economic evidence. (1, 72, 83)

Raggi et al. conducted a cost savings analysis. The estimated hospital cost savings was determined by the difference in expected versus observed HAI patient stays. (83) Using this approach, 56 fewer HAI patient stays was estimated in the intervention period versus the pre-intervention period (n = 241 versus n = 185). This translated into a reduction of total length of stay by 739.3 patient days during the intervention period with an estimated total cost savings of $1,219,878 USD. The mean cost saving per patient was estimated at $3,355.74 USD. (83)

In the HTA conducted by HQO, an economic literature search was implemented to identify published economic evidence for portable ultraviolet light devices as an adjunct to standard environmental cleaning. (1) The outcomes of interest included incremental cost-effectiveness ratio, incremental costs, and incremental effectiveness. However, the search did not identify any economic evaluations of ultraviolet disinfection devices for cleaning within a hospital. Furthermore, within the same HTA a primary economic evaluation was not conducted, as the clinical evidence was considered very low-quality evidence. However, the authors did conduct a budget impact analysis (BIA) from the perspective of an Ontario hospital to estimate the cost of using portable ultraviolet disinfecting devices as an adjunct to standard environmental cleaning. Based on this analysis the 5-year budget impact was estimated to be $586,023 CAD for Xenon bulb UV devices and $634,255 CAD for mercury UV-C devices (assuming 2 devices per hospital); first-year costs were driven by purchasing the devices, while costs in subsequent years was due to maintenance and operation of the devices. The results

were sensitive to the following; number of devices purchased, frequency of use during daytime, and staff time required per use.

Lastly, an economic assessment was conducted by Fraser Health to evaluate the cost-effectiveness of adopting a portable ultraviolet NMD technology as an adjunct to standard manual environmental cleaning protocol that is currently used within Fraser Health. (72) An overview of this study is provided in Table 3.8. To achieve this objective, a retrospective cost analysis (CA), cost-benefit (CBA), and cost-effectiveness (CEA) analyses were carried out. The clinical effectiveness was informed by a study conducted by Fraser Health (included in this review; (74)), which examined the impact of pulsed Xenon UV devices on HAI rates in three trial sites over a six-month period (Nov. 2016–May 2017). The components included to estimate costs were the cost of the device, operation of the technology, cost associated with MRSA and CDI infections. The costs were estimated for both a purchase and lease option of the device. The cost data estimated from the CA was used in both the CBA and CEA.

The CBA estimated the total monetary benefit delivered by implementing the NMD technology over six months. The monetized benefits were estimated as the number of HAI cases (included CDI and MRSA cases) avoided due to the technology (i.e., number of HAI avoided), multiplied by the incremental cost of that HAI. The results of this CBA indicate that the implementation of this technology over the six-month trial period, delivered between $165,194 CAD (device lease option) and $414,905 CAD (device purchase option) of cost benefit.

In the CEA, four measures of effectiveness were defined: 1) the number of CDI cases avoided, 2) the number of MRSA infection cases avoided, 3) a combination of the number of

CDI cases plus MRSA infection cases avoided, and 4) the number of bed-days avoided. The CEA was conducted for both the purchase and lease options. Overall, the results of this analysis are:

- Expenditure per one CDI case avoided: $10,171 (purchase option) and $12,604 (lease option)
- Expenditure per one MRSA case avoided: $29,301 (purchase option) and $36,310 (lease option)
- Expenditure to avoid one bed-day: $620 (purchase option) and $768 (lease option)

Several limitations associated with this evaluation are noted. Namely, the outcomes used to reflect the benefits associated with the implementation of the technologies were restricted to CDI and MRSA cases. Thus, the potential impact of this intervention on other HAI was not captured in this evaluation. Further, the results of this analysis are only generalizable to the three facility where the trial was implemented, and any deviation from the protocols implemented at these facilities could impact the findings. The authors acknowledge the uncertainty associated with estimation of the incremental cost of care. This uncertainty relates to the difficulty in accurately estimating the cost of care for non-infected individuals. Lastly, some limitations are noted due to the before-after trials design used to estimate the clinical effectiveness of the ultraviolet technology. A primary assumption in using a before-after study design is that any change in the HAI rates observed are due to the intervention. However, the change in rates observed could be influenced by other factors such as different patient characteristics, environmental cleaning practices, or other infection prevention programs

implemented during the study period. The authors tried to address this bias by evaluating the rates observed in non-trial sites.

**Table 3.8 Study Characteristic of Economic Evaluations**

| Overview of study characteristics | |
|---|---|
| **Author, Year** | Fraser Health, 2018 (72) |
| **Setting** | 3 FH acute care facilities (Abbotsford Regional Hospital [ARH], Burnaby Hospital [BH], Ridge Meadows Hospital [RMH]) |
| **Study Design** | A retrospective Cost Analysis (CA)<br>Cost-Benefit analysis (CBA)<br>Cost-Effectiveness Analysis (CEA) |
| **Perspective** | Fraser Health Authority |
| **Population** | Patients in target rooms |
| **intervention** | PX-UV + Manual deep clean |
| **comparator** | Manual deep clean |
| **Costs** | Data was collected from past Fraser Health reports, the trial evaluation, and published literature; CBA and CEA were conducted using purchasing and leasing costs as well as two different costs for CDI infection. (device cost + UV Operator cost + Health Care Aide cost) |
| **Outcomes** | HAI cost avoidance of the technology was measured using the number of HAIs avoided, and multiplying the number of cases of each HAI avoided by the incremental cost of that HAI. |
| | CBA: Avoided HAI costs [(# of CDI cases avoided x incremental cost of a CDI case) + (# of MRSA infection cases avoided x incremental cost of an MRSA infection case) |
| | CEA: Number of HAI avoided; Number of bed days avoided |
| **Time horizon** | 6 months; trial duration |
| **Discounting** | None |
| **Data sources for clinical data** | Controlled before-after study conducted in 3 acute care facilities |
| **Uncertainty** | Sensitivity analysis was performed to determine the range of costs avoided across multiple CDI costs and methods of technology procurement |

## Chapter 4 Conclusion and Implications

The updated review carried out in this study did not identify any new evidence that established the clinical effectiveness of portable light and gaseous NMD technologies. Further, no studies, which evaluated the clinical effectiveness of hydrogen peroxide NMD technologies, were identified. Therefore, the assessment of evidence in this review was restricted to ultraviolet technologies. Overall, given the heterogeneity of the studies, and high risk of bias associated with the study outcomes, a definitive conclusion regarding the clinical effectiveness of portable NMD ultraviolet technologies could not be made at this time. Some aspects that contribute to this finding include an absence of a robust study design (e.g., study follow-up, appropriate allocation concealment, large sample size, appropriate outcome assessment), variability in manual cleaning protocols required prior to use of NMD technologies, and evidence to inform how logistical challenges may limit the effectiveness of NMD technologies in practice.

Among the 13 studies included in this review the evidence in nine of those studies had been previously critically reviewed and evaluated by CADTH (71) and HQO (1). In both reviews the quality of the evidence was considered low. Assessment of this evidence in the present analysis was consistent with conclusions made by CADTH and HQO.

The highest quality evidence identified, was from the only known randomized trial (BETR study; NCT01579370) conducted to evaluate the effectiveness of portable ultraviolet technology. The primary analysis of this trial has been previously reviewed by HQO, and the evidence was rated as low quality. More specifically, several factors have been noted that limit

the clinical relevance of this study, and its use as evidence of clinical effectiveness in a full HTA of portable ultraviolet disinfections systems.

First, the outcomes reported in this study are based on a combined rate of infection and colonization. This is an important consideration, since evidence suggests that a small percentage of microorganism colonization of MDROs and CD lead to infections. (85-88) Thus, in the absence of a subgroup analysis, the impact of this technology on the rates of HAIs (i.e., eventual infections) remains uncertain. Second, in the review conducted by HQO it was noted that the primary analysis of this trial was restricted to evaluation of patients that are subsequently admitted to the target rooms. Hence, information regarding hospital-wide spread of infections through indirect contact was not captured. Since the review by HQO, the secondary analysis of this trial was published and the impact on hospital-wide rates of HAIs were evaluated. This study was included and evaluated in the present study.

In the secondary analysis of the BETR study, all microbial cultures, which represented both colonization and infections were considered in the outcome analysis. Therefore, the first limitation that was noted in the primary analysis was not addressed. In addition, the limitations associated with the study design which reduced the quality of the evidence also remained consistent (e.g., selection and performance bias due to inadequate allocation concealment). Also, the results from this analysis found no significant difference in the hospital-wide risk of target organism acquisition between standard disinfection and the enhanced terminal disinfection strategies with UV. Notably, the results from this trial suggest that the addition of UV disinfection as adjunct to bleach may have a detrimental effect on the risk of infection. (77)

Overall, given the heterogeneity of the evidence identified it was not possible to synthesize the data quantitatively. The variability observed in the identified studies also limits the generalizability of the study outcomes. Namely, most of the studies identified were conducted in the USA, and the settings in which the NMD technology was implemented varied across the studies. This included the type of hospital (e.g., community hospital, tertiary care facility), hospital units (e.g., pediatric, oncology, hematology) and target rooms (e.g., operating room, all rooms or rooms of patients with contact precautions). Furthermore, different studies used different types of ultraviolet devices (mercury UV-C vs. pulsed Xenon UV technology), with various numbers of UV disinfection cycles and duration.

Another important factor, which limits the generalizability of the study findings is the heterogeneity of the specific manual disinfection protocols that precedes the implementation of NMD technologies within hospitals. Therefore, the outcomes from studies where ultraviolet technology was implemented as an adjunct to manual cleaning cannot be compared reliably. Given these limitations, and the dependency of the effectiveness of these technologies on local manual cleaning practices, previous CADTH rapid response reviews have suggested conducting a more localized review (i.e., within individual hospitals). (4)

Therefore, in addition to the previously evaluated evidence, results from a locally implement study by Fraser Health Authority was included and assessed. In this study the addition of a pulsed Xenon UV device to manual cleaning practices, in three Fraser Health facilities associated with high rates of HAIs (CDI and MRSA) was found to reduce rates of MRSA by 24% and CDI by 36%, when compared with the same period in the previous year. (74) However, this trial employed a before-after study design, which limited any conclusions

regarding the study findings, as it was not possible to evaluate the impact of underlying trends, which could influence the rates of HAI observed during the intervention. To account for this limitation a secondary analysis of this intervention was conducted using a controlled interrupted time-series analysis. In this analysis the impact on the combined rate of HAIs was evaluated at each trial site, and was found to be statistically non-significant: -6.42 cases per 10,000 (95%CI: -19.70-6.87; p=.35). (73)

It should be acknowledged that due to the nature of the topic under investigation some aspects of a robust study design are challenging to implement in practice. Notably, it is difficult to conceal the allocation of intervention, as the intervention itself is a physical piece of instrument that needs to be move in and out of the room. An additional challenge relates to protection against contamination bias, where the control/non-intervention group is exposed to the intervention indirectly. This can occur through a temporary change in manual cleaning and disinfection practices by personnel, which does not reflect everyday practice. Lastly, an important challenge in studying the effectiveness of such interventions, relates to the human factors involved in conducting both the manual cleaning and deployment of the UV-C devices. Although protocols are developed to ensure consistency, it is difficult to account for differences that may arise due to variations manual cleaning (and room preparation) habits of individuals that carry out the cleaning.

In summary, germicidal effectiveness of both ultraviolet and hydrogen peroxide technologies against a wide range of microorganisms on environmental surfaces has been established in a number of studies. (52-54, 57, 58) However, the findings from the present study and other reviews of the evidence indicate that the downstream impact of these

technologies in reducing the rates of HAI observed is unclear. In the absence of robust evidence that supports the clinical effectiveness of portable light-and-gaseous-based NMD devices, at present there is uncertainty around the effectiveness of these technologies in practice. Therefore, completion of a full HTA would have considerable limitations at this time. Further research conducted locally, which accounts for some of the limitations noted in the available evidence could help inform the effectiveness of these technologies in practice, and to identify factors that may be limiting their effective implementation within hospitals. A targeted search of ClinicalTrials.gov identified two studies which could inform the questions posed in this study. The studies include:

- "Ultra Violet-C Light Evaluation as an Adjunct to Removing Multi-Drug Resistant Organisms (UVCLEAR-MDRO) (UVCLEAR-MDRO)" (NCT02605499). The results of this study are pending (Study closed February 2018, no results posted).
- "Pulsed UV Xenon Disinfection to Prevent Resistant Healthcare Associated Infection "(NCT03349268). The estimated primary completion date is May 2022.

With the limitations of previous studies noted, and the importance of considering local manual cleaning protocols to inform the effectiveness of these technologies, the Ministry of Health may wish to consider supporting further research conducted locally, which includes: Sufficient follow-up, larger sample size, appropriate outcome assessment (i.e. Primary outcome definition and blinding of outcomes assessors) and consistent manual cleaning protocols, while evaluating factors that may hinder the downstream impact of these technologies in reducing the rates of HAI observed.

**Reference**

1.Portable Ultraviolet Light Surface-Disinfecting Devices for Prevention of Hospital-Acquired Infections: A Health Technology Assessment. Ont Health Technol Assess Ser. 2018;18(1):1-73. Epub 2018/03/01. PubMed PMID: 29487629; PubMed Central PMCID: PMCPMC5824029.
2.CADTH rapid response report: Summary of abstracts. Non-manual room disinfection techniques for infection prevention in healthcare facilities: clinical effectiveness, cost-effectiveness, and guidelines. October 23, 2018. Report No.
3.CADTH rapid response. Non-Manual Techniques for Room Disinfection in Healthcare Facilities: A Review of Clinical Effectiveness and Guidelines. April 30, 2014. Report No.
4.CADTH rapid response. Non-Manual Room Disinfection Techniques for Infection Prevention in Healthcare Facilities: A Review of the Clinical Effectiveness, Cost-Effectiveness, and Guidelines. May 27, 2015. Report No.
5.Spencer M, Vignari M, Bryce E, Johnson HB, Fauerbach L, Graham D. A model for choosing an automated ultraviolet-C disinfection system and building a case for the C-suite: Two case reports. Am J Infect Control. 2017;45(3):288-92. Epub 2016/12/28. doi: 10.1016/j.ajic.2016.11.016. PubMed PMID: 28024852.
6.Prevention of hospital-acquired infection: A practical guide. World Health Organization, 2002.
7.Provincial Infectious Diseases Advisory Committee. Best Practices for Surveillance of Health Care-associated Infections. Public Health Ontario: Provincial Infectious Diseases Advisory Committee, 2014 July 2014. Report No.
8.Public Health Agency of Canada. The Chief Public Health Officer's Report on the State of Public Health in Canada, 2013: Infectious Disease—The Never-ending Threat 2014.
9.Provincial Infection Control Network of British Columbia. About Healthcare-associated Infections 2019 [cited 2019 June 26]. Available from: https://www.picnet.ca/surveillance/about-hai/.
10.Public Health Agency of Canada. The Chief Public Health Officer's Report on the State of Public Health in Canada 2013 – Healthcare-associated infections – Due diligence 2013 [cited 2019 June 26]. Available from: https://www.canada.ca/en/public-health/corporate/publications/chief-public-health-officer-reports-state-public-health-canada/chief-public-health-officer-report-on-state-public-health-canada-2013-infectious-disease-never-ending-threat/healthcare-associated-infections-due-diligence.html.
11.Forster AJ, Taljaard M, Oake N, Wilson K, Roth V, van Walraven C. The effect of hospital-acquired infection with Clostridium difficile on length of stay in hospital. Cmaj. 2012;184(1):37-42. Epub 2011/12/07. doi: 10.1503/cmaj.110543. PubMed PMID: 22143235; PubMed Central PMCID: PMCPMC3255231.
12.Schreiber PW, Sax H, Wolfensberger A, Clack L, Kuster SP. The preventable proportion of healthcare-associated infections 2005-2016: Systematic review and meta-analysis. Infect Control Hosp Epidemiol. 2018;39(11):1277-95. Epub 2018/09/21. doi: 10.1017/ice.2018.183. PubMed PMID: 30234463.
13.Mehta Y, Gupta A, Todi S, Myatra S, Samaddar DP, Patil V, et al. Guidelines for prevention of hospital acquired infections. Indian J Crit Care Med. 2014;18(3):149-63. Epub 2014/04/05. doi:

10.4103/0972-5229.128705. PubMed PMID: 24701065; PubMed Central PMCID: PMCPMC3963198.
14.Public Health Agency of Canada. Routine Practices and Additional Precautions for Preventing the Transmission of Infection in Healthcare Settings. 2016.
15.World Health Organization. Report on the Burden of Endemic Health Care-Associated Infection Worldwide: Clean Care is Safer Care. 2011.
16.The Chief Public Health Officer's Report on the State of Public Health in Canada 2013. Healthcare-associated infections – Due diligence 2013 [cited 2019]. Available from: https://www.canada.ca/en/public-health/corporate/publications/chief-public-health-officer-reports-state-public-health-canada/chief-public-health-officer-report-on-state-public-health-canada-2013-infectious-disease-never-ending-threat/healthcare-associated-infections-due-diligence.html.
17.About Healthcare-associated Infections: Provincial Infection Control Network of British Columbia; [cited 2019 June 25, 2019]. Available from: https://www.picnet.ca/surveillance/about-hai/.
18.Canadian antimicrobial resistance surveillance system: Update 2018. Canadian antimicrobial resistance surveillance system 2018.
19.Provincial Infection Control Network of British Columbia. Annual surveillance report of healthcare-associated infections in BC health care facilities. 2018.
20.Canada PHAo. Antimicrobial resistance surveillance system: Update 2017. 2017.
21.Goetghebeur M, Landry PA, Han D, Vicente C. Methicillin-resistant Staphylococcus aureus: A public health issue with economic consequences. Can J Infect Dis Med Microbiol. 2007;18(1):27-34. Epub 2008/10/17. doi: 10.1155/2007/253947. PubMed PMID: 18923684; PubMed Central PMCID: PMCPMC2542887.
22.Levy AR, Szabo SM, Lozano-Ortega G, Lloyd-Smith E, Leung V, Lawrence R, et al. Incidence and Costs of Clostridium difficile Infections in Canada. Open Forum Infect Dis. 2015;2(3):ofv076. Epub 2015/07/21. doi: 10.1093/ofid/ofv076. PubMed PMID: 26191534; PubMed Central PMCID: PMCPMC4503917.
23.Lloyd-Smith P, Younger J, Lloyd-Smith E, Green H, Leung V, Romney MG. Economic analysis of vancomycin-resistant enterococci at a Canadian hospital: assessing attributable cost and length of stay. J Hosp Infect. 2013;85(1):54-9. Epub 2013/08/08. doi: 10.1016/j.jhin.2013.06.016. PubMed PMID: 23920443.
24.Auditor General of British Columbia. Infection Control: Essential for a Healthy British Columbia The Provincial Overview. Office of the Auditor General of British Columbia, 2007.
25.Canadian union of public employees. Healthcare Associated Infections: A Backgrounder 2009.
26.Stewardson AJ, Allignol A, Beyersmann J, Graves N, Schumacher M, Meyer R, et al. The health and economic burden of bloodstream infections caused by antimicrobial-susceptible and non-susceptible Enterobacteriaceae and Staphylococcus aureus in European hospitals, 2010 and 2011: a multicentre retrospective cohort study. Euro Surveill. 2016;21(33). Epub 2016/08/27. doi: 10.2807/1560-7917.Es.2016.21.33.30319. PubMed PMID: 27562950; PubMed Central PMCID: PMCPMC4998424.

27.Stevens VW, Khader K, Nelson RE, Jones M, Rubin MA, Brown KA, et al. Excess Length of Stay Attributable to Clostridium difficile Infection (CDI) in the Acute Care Setting: A Multistate Model. Infect Control Hosp Epidemiol. 2015;36(9):1024-30. Epub 2015/05/27. doi: 10.1017/ice.2015.132. PubMed PMID: 26006153.
28.Centre for Clinical Epidemiology and Evaluation. Electronic monitoring systems for hand hygiene compliance in british columbia. 2017.
29.Kramer A, Schwebke I, Kampf G. How long do nosocomial pathogens persist on inanimate surfaces? A systematic review. BMC Infect Dis. 2006;6:130. Epub 2006/08/18. doi: 10.1186/1471-2334-6-130. PubMed PMID: 16914034; PubMed Central PMCID: PMCPMC1564025.
30.Otter JA, Yezli S, French GL. The role played by contaminated surfaces in the transmission of nosocomial pathogens. Infect Control Hosp Epidemiol. 2011;32(7):687-99. Epub 2011/06/15. doi: 10.1086/660363. PubMed PMID: 21666400.
31.Weber DJ, Anderson D, Rutala WA. The role of the surface environment in healthcare-associated infections. Curr Opin Infect Dis. 2013;26(4):338-44. Epub 2013/06/08. doi: 10.1097/QCO.0b013e3283630f04. PubMed PMID: 23743816.
32.Boyce JM. Environmental contamination makes an important contribution to hospital infection. J Hosp Infect. 2007;65 Suppl 2:50-4. Epub 2007/08/19. doi: 10.1016/s0195-6701(07)60015-2. PubMed PMID: 17540242.
33.Provincial infectious diseases advisory committee. Best Practices for Environmental Cleaning for Prevention and Control of Infections- 2nd edition. 2012.
34.provincial Infection Control Network of British Columbia. British Columbia best practices for environmental cleaning for prevention and control of infections in all healthcare settings and programs-Appendix A. 2016.
35.Zoutman DE, Ford BD, Sopha K. Environmental cleaning resources and activities in Canadian acute care hospitals. Am J Infect Control. 2014;42(5):490-4. Epub 2014/04/30. doi: 10.1016/j.ajic.2014.01.013. PubMed PMID: 24773787.
36.Carling PC, Briggs JL, Perkins J, Highlander D. Improved cleaning of patient rooms using a new targeting method. Clin Infect Dis. 2006;42(3):385-8. Epub 2006/01/05. doi: 10.1086/499361. PubMed PMID: 16392086.
37.Cooper RA, Griffith CJ, Malik RE, Obee P, Looker N. Monitoring the effectiveness of cleaning in four British hospitals. Am J Infect Control. 2007;35(5):338-41. Epub 2007/06/20. doi: 10.1016/j.ajic.2006.07.015. PubMed PMID: 17577482.
38.French GL, Otter JA, Shannon KP, Adams NM, 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. J Hosp Infect. 2004;57(1):31-7. Epub 2004/05/15. doi: 10.1016/j.jhin.2004.03.006. PubMed PMID: 15142713.
39.Manian FA, Griesenauer S, Senkel D, Setzer JM, Doll SA, Perry AM, et al. Isolation of Acinetobacter baumannii complex and methicillin-resistant Staphylococcus aureus from hospital rooms following terminal cleaning and disinfection: can we do better? Infect Control Hosp Epidemiol. 2011;32(7):667-72. Epub 2011/06/15. doi: 10.1086/660357. PubMed PMID: 21666397.

40.Otter JA, Yezli S, Perl TM, Barbut F, French GL. The role of 'no-touch' automated room disinfection systems in infection prevention and control. J Hosp Infect. 2013;83(1):1-13. Epub 2012/12/01. doi: 10.1016/j.jhin.2012.10.002. PubMed PMID: 23195691.
41.Leas BF, Sullivan N, Han JH, Pegues DA, Kaczmarek JL, Umscheid CA. AHRQ Comparative Effectiveness Technical Briefs. Environmental Cleaning for the Prevention of Healthcare-Associated Infections. Rockville (MD): Agency for Healthcare Research and Quality (US); 2015.
42.Ontario Agency for Health Protection and Promotion (Public Health Ontario) PIDAC. Best Practices for Environmental Cleaning for Prevention and Control of Infections in All Health Care Settings, 3rd Edition. 2018.
43.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. Epub 2014/04/22. doi: 10.1136/bmjopen-2013-004522. PubMed PMID: 24747791; PubMed Central PMCID: PMCPMC3996814.
44.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. Infect Control Hosp Epidemiol. 2009;30(6):507-14. Epub 2009/04/22. doi: 10.1086/597232. PubMed PMID: 19379098.
45.Bache SE, Maclean M, MacGregor SJ, Anderson JG, Gettinby G, Coia JE, 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(1):69-76. Epub 2011/11/23. doi: 10.1016/j.burns.2011.03.008. PubMed PMID: 22103991.
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. J Hosp Infect. 2010;76(3):247-51. Epub 2010/09/25. doi: 10.1016/j.jhin.2010.07.010. PubMed PMID: 20864210.
47.Friedman H, Volin E, Laumann D. Terminal disinfection in hospitals wihh quaternary ammonium compounds by use of a spray-fog technique. Appl Microbiol. 1968;16(2):223-7. Epub 1968/02/01. PubMed PMID: 5645408; PubMed Central PMCID: PMCPMC547383.
48.Sharma M, Hudson JB. Ozone gas is an effective and practical antibacterial agent. Am J Infect Control. 2008;36(8):559-63. Epub 2008/10/18. doi: 10.1016/j.ajic.2007.10.021. PubMed PMID: 18926308.
49.de Boer HE, van Elzelingen-Dekker CM, van Rheenen-Verberg CM, Spanjaard L. Use of gaseous ozone for eradication of methicillin-resistant Staphylococcus aureus from the home environment of a colonized hospital employee. Infect Control Hosp Epidemiol. 2006;27(10):1120-2. Epub 2006/09/29. doi: 10.1086/507966. PubMed PMID: 17006820.
50.Sexton JD, Tanner BD, Maxwell SL, Gerba CP. Reduction in the microbial load on high-touch surfaces in hospital rooms by treatment with a portable saturated steam vapor disinfection system. Am J Infect Control. 2011;39(8):655-62. Epub 2011/06/07. doi: 10.1016/j.ajic.2010.11.009. PubMed PMID: 21641089.
51.Tanner BD. Reduction in infection risk through treatment of microbially contaminated surfaces with a novel, portable, saturated steam vapor disinfection system. Am J Infect Control. 2009;37(1):20-7. Epub 2008/10/07. doi: 10.1016/j.ajic.2008.03.008. PubMed PMID: 18834748.

52.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. doi: 10.1128/cmr.00020-14.
53.Dancer SJ. Floor wars: the battle for 'clean' surfaces. J Hosp Infect. 2013;84(4):339-40. Epub 2013/06/29. doi: 10.1016/j.jhin.2013.01.015. PubMed PMID: 23806838.
54.Rutala WA WD, Healthcare Infection Control Practices Advisory Committee. Guideline for disinfection and sterilization in healthcare facilities. Center for Disease Control and Prevention, 2008.
55.Nerandzic MM, Thota P, Sankar CT, Jencson A, Cadnum JL, Ray AJ, et al. Evaluation of a pulsed xenon ultraviolet disinfection system for reduction of healthcare-associated pathogens in hospital rooms. Infect Control Hosp Epidemiol. 2015;36(2):192-7. Epub 2015/01/31. doi: 10.1017/ice.2014.36. PubMed PMID: 25633002.
56.Tru-D SmartUVC [cited 2019 October 24]. Available from: http://tru-d.com/wp-content/uploads/2019/02/Tru-D-2019-Brochure_Pages.pdf.
57.Han JH, Sullivan N, Leas BF, Pegues DA, Kaczmarek JL, Umscheid CA. Cleaning Hospital Room Surfaces to Prevent Health Care-Associated Infections: A Technical Brief. Ann Intern Med. 2015;163(8):598-607. Epub 2015/08/11. doi: 10.7326/m15-1192. PubMed PMID: 26258903; PubMed Central PMCID: PMCPMC4812669.
58.Rutala WA, Weber DJ. Disinfectants used for environmental disinfection and new room decontamination technology. Am J Infect Control. 2013;41(5 Suppl):S36-41. Epub 2013/05/03. doi: 10.1016/j.ajic.2012.11.006. PubMed PMID: 23622746.
59.Weber DJ, Kanamori H, Rutala WA. 'No touch' technologies for environmental decontamination: focus on ultraviolet devices and hydrogen peroxide systems. Curr Opin Infect Dis. 2016;29(4):424-31. Epub 2016/06/04. doi: 10.1097/qco.0000000000000284. PubMed PMID: 27257798.
60.Orlando P, Cristina ML, Dallera M, Ottria G, Vitale A, Badolati G. Surface disinfection: evaluation of the efficacy of a nebulization system spraying hydrogen peroxide. J Prev Med Hyg. 2008;49(3):116-9. Epub 2009/03/13. PubMed PMID: 19278138.
61.Chan HT, White P, Sheorey H, Cocks J, Waters MJ. Evaluation of the biological efficacy of hydrogen peroxide vapour decontamination in wards of an Australian hospital. J Hosp Infect. 2011;79(2):125-8. Epub 2011/08/10. doi: 10.1016/j.jhin.2011.06.009. PubMed PMID: 21824681.
62.Boyce JM. New approaches to decontamination of rooms after patients are discharged. Infect Control Hosp Epidemiol. 2009;30(6):515-7. Epub 2009/04/22. doi: 10.1086/598999. PubMed PMID: 19379097.
63.Otter JA, Yezli S. A call for clarity when discussing hydrogen peroxide vapour and aerosol systems. J Hosp Infect. 2011;77(1):83-4; author reply 1-3. Epub 2010/10/26. doi: 10.1016/j.jhin.2010.07.023. PubMed PMID: 20970884.
64.Otter JA, Puchowicz M, Ryan D, Salkeld JA, Cooper TA, Havill NL, et al. Feasibility of routinely using hydrogen peroxide vapor to decontaminate rooms in a busy United States hospital. Infect Control Hosp Epidemiol. 2009;30(6):574-7. Epub 2009/05/07. doi: 10.1086/597544. PubMed PMID: 19415969.

65.Andersen BM, Banrud H, Boe E, Bjordal O, Drangsholt F. Comparison of UV C light and chemicals for disinfection of surfaces in hospital isolation units. Infect Control Hosp Epidemiol. 2006;27(7):729-34. Epub 2006/06/30. doi: 10.1086/503643. PubMed PMID: 16807849.
66.Jensen PA, Lambert LA, Iademarco MF, Ridzon R. Guidelines for preventing the transmission of Mycobacterium tuberculosis in health-care settings, 2005. MMWR Recomm Rep. 2005;54(Rr-17):1-141. Epub 2005/12/31. PubMed PMID: 16382216.
67.Charina Rivas RH, Jun Chen Collet, Michelle Chang, Marney Hunt, Julita Sienkiewicz, Jocelyn Srigley, editor Spreading the light? The challenges of introducing Ultraviolet-c disinfection to our environmental cleaning process. IPAC Canada conference; 2017; Charlottetown, PEI.
68.Cochrane Effective Practice and Organisation of Care (EPOC). Suggested risk of bias criteria for EPOC reviews. 2017.
69.National Heart L, and Blood Institute,. Quality assessment tool for before-after (pre-post) studies with no control group. 2014.
70.Shea BJ, Reeves BC, Wells G, Thuku M, Hamel C, Moran J, et al. AMSTAR 2: a critical appraisal tool for systematic reviews that include randomised or non-randomised studies of healthcare interventions, or both. Bmj. 2017;358:j4008. Epub 2017/09/25. doi: 10.1136/bmj.j4008. PubMed PMID: 28935701; PubMed Central PMCID: PMCPMC5833365 at http://www.icmje.org/coi_disclosure.pdf and declare: no support from any organisation for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years, no other relationships or activities that could appear to have influenced the submitted work.
71.CADTH rapid response report: Summary with critical appraisal. Non-Manual Ultraviolet Light Disinfection for Hospital Acquired Infections: A Review of Clinical Effectiveness and Guidelines. April 5, 2019. Report No.
72.William Hall PW, Fuad Ibrahimov. UVGI Economic Assessment. Fraser Health, 2018.
73.William Hall ML, Petra Welsh. UVGI ITS Analysis. Fraser Health, 2019 February 21st, 2019. Report No.
74.Petra Welsh FI. Ultra-violet germicidal irradiation trial at fraser health: Evaluating the efficacy of a deep clean approach utilizing UVGI to reduce HAIs. Fraser Health, 2017 September 5, 2017. Report No.
75.Marra AR, Schweizer ML, Edmond MB. No-Touch Disinfection Methods to Decrease Multidrug-Resistant Organism Infections: A Systematic Review and Meta-analysis. Infect Control Hosp Epidemiol. 2018;39(1):20-31. Epub 2017/11/17. doi: 10.1017/ice.2017.226. PubMed PMID: 29144223.
76.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. Lancet. 2017;389(10071):805-14. Epub 2017/01/21. doi: 10.1016/s0140-6736(16)31588-4. PubMed PMID: 28104287; PubMed Central PMCID: PMCPMC5935446.
77.Anderson DJ, Knelson LP, Moehring RW, Lewis SS, Weber DJ, Chen LF, 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. Infect

Control Hosp Epidemiol. 2018;39(2):157-63. Epub 2018/01/15. doi: 10.1017/ice.2017.268. PubMed PMID: 29331170; PubMed Central PMCID: PMCPMC5935456.
78.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. Infect Control Hosp Epidemiol. 2018;39(11):1301-6. Epub 2018/09/19. doi: 10.1017/ice.2018.215. PubMed PMID: 30226124.
79.Haas JP, Menz J, Dusza S, Montecalvo MA. Implementation and impact of ultraviolet environmental disinfection in an acute care setting. Am J Infect Control. 2014;42(6):586-90. Epub 2014/05/20. doi: 10.1016/j.ajic.2013.12.013. PubMed PMID: 24837107.
80.Pavia M, Simpser E, Becker M, Mainquist WK, Velez KA. The effect of ultraviolet-C technology on viral infection incidence in a pediatric long-term care facility. Am J Infect Control. 2018;46(6):720-2. Epub 2018/03/20. doi: 10.1016/j.ajic.2018.01.014. PubMed PMID: 29550083.
81.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. Infect Control Hosp Epidemiol. 2017;38(1):39-44. Epub 2016/10/07. doi: 10.1017/ice.2016.222. PubMed PMID: 27707423.
82.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. Am J Infect Control. 2019;47(4):406-8. Epub 2018/12/07. doi: 10.1016/j.ajic.2018.09.018. PubMed PMID: 30502111.
83.Raggi R, Archulet K, Haag CW, Tang W. Clinical, operational, and financial impact of an ultraviolet-C terminal disinfection intervention at a community hospital. Am J Infect Control. 2018;46(11):1224-9. Epub 2018/06/24. doi: 10.1016/j.ajic.2018.05.012. PubMed PMID: 29934205.
84.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). Lancet Infect Dis. 2018;18(8):845-53. Epub 2018/06/09. doi: 10.1016/s1473-3099(18)30278-0. PubMed PMID: 29880301; PubMed Central PMCID: PMCPMC6487496.
85.Furuya-Kanamori L, Marquess J, Yakob L, Riley TV, Paterson DL, Foster NF, et al. Asymptomatic Clostridium difficile colonization: epidemiology and clinical implications. BMC Infect Dis. 2015;15:516. Epub 2015/11/18. doi: 10.1186/s12879-015-1258-4. PubMed PMID: 26573915; PubMed Central PMCID: PMCPMC4647607.
86.Huang SS, Platt R. Risk of methicillin-resistant Staphylococcus aureus infection after previous infection or colonization. Clin Infect Dis. 2003;36(3):281-5. Epub 2003/01/23. doi: 10.1086/345955. PubMed PMID: 12539068.
87.Balm MN, Lover AA, Salmon S, Tambyah PA, Fisher DA. Progression from new methicillin-resistant Staphylococcus aureus colonisation to infection: an observational study in a hospital cohort. BMC Infect Dis. 2013;13:491. Epub 2013/10/24. doi: 10.1186/1471-2334-13-491. PubMed PMID: 24148135; PubMed Central PMCID: PMCPMC4015767.
88.Zirakzadeh A, Patel R. Vancomycin-resistant enterococci: colonization, infection, detection, and treatment. Mayo Clin Proc. 2006;81(4):529-36. Epub 2006/04/14. doi: 10.4065/81.4.529. PubMed PMID: 16610573.

# Appendix A Search Strategies

## A.1 MEDLINE

Database: Ovid MEDLINE(R) and Epub Ahead of Print, In-Process & Other Non-Indexed Citations, Daily and Versions(R) <1946 to July 03, 2019>

Search Strategy:

---

1 ((nonmanual* or non-manual* or no-touch or automated or automatic or air or airborn or vaporiz*) adj3 disinfect*).ti,ab,kf. (496)

2 ultraviolet rays/ or hydrogen peroxide/ (128498)

3 high-intensity narrow-spectrum.ti,ab,kf. (10)

4 HINS.ti,ab,kf. (50)

5 hydrogen peroxide.ti,ab,kf. (51396)

6 hydroperoxide.ti,ab,kf. (9187)

7 fogging.ti,ab,kf. (454)

8 UVG.ti,ab,kf. (19)

9 UVGI.ti,ab,kf. [Ultraviolet germicidal irradiation] (63)

10 Ultraviolet C.ti,ab,kf. (520)

11 Ultra-violet C.ti,ab,kf. (9)

12 UV-C.ti,ab,kf. (1338)

13 UVC.ti,ab,kf. (1732)

14 (vaporized adj3 peroxide).ti,ab,kf. (35)

15 VHP.ti,ab,kf. [vaporized hydrogen peroxide ] (195)

16 ((ultraviolet or ultra-violet or UV or LED or light) adj3 (germicide or germicidal or irradiation or irradiate or disinfect*)).ti,ab,kf. (33015)

17 or/1-16 [Non-manual disinfection] (179868)

18 Hospitals/ or hospital units/ or hospital departments/ or health facilities/ (112508)

19 (hospitals or hospital or clinic or clinics or ward or wards or ICU or NICU or PICU or operating room* or operating theater* or operating theatre* or ER or emergency room* or triage or waiting room* or inpatient* or in-patient* or inhospital of healthcare facilit* or health care facilit* or LTCF or LTC or healthcare-associated or healthcare-acquired).ti,ab. (2897775)

20 Nursing homes/ or homes for the aged/ or long term care/ (59082)

21 or/18-20 [Healthcare facilities] (2992438)

22 and/17,21 (4209)

23 exp Environmental Microbiology/ (109610)

24 Fomites/ (389)

25 (surface or surfaces or fomite or fomites or floor* or table* or tile* or chair* or door knob* or bed* or wall or walls or room or rooms or furniture or furnishing* or equipment or washbasin* or toilet* or sink*).ti,ab. (1894517)

26 or/23-25 [Surfaces] (1988460)

27 and/17,21,26 (770)
28 Cross infection/ or infection control/ or disinfection/ (80549)
29 (cross infection or cross infections or hospital infection or hospital infections or nosocomial infection or nosocomial infections or contaminant or contaminants or contamination or hospital epidemiology).ti,ab. (165426)
30 ((transmission or transmissible or infectious) adj2 (disease or diseases or infection or infections)).ti,ab. (90341)
31 decontamination/ or disinfectants/ (16697)
32 (disinfect* or steriliz* or sterilis* or decontaminat* or pathogen control or decontaminant* or germicide*).ti,ab. (68080)
33 (infection* adj2 prevent*).ti,ab. (21955)
34 or/28-33 [Infection control] (388839)
35 and/17,21,34 (694)
36 27 or 35 (1029)
37 limit 36 to yr="2018 - 2019" (130)
38 limit 37 to English language (128)
39 comment/ or editorial/ or letter/ or news/ (1920636)
40 38 not 39 (**123**)

## A.2 Embase

Database: Embase <1974 to 2019 July 03>
Search Strategy:
---

1 ((nonmanual* or non-manual* or no-touch or automated or automatic or air or airborn or vaporiz*) adj3 disinfect*).ti,ab,kw. (500)
2 high-intensity narrow-spectrum.ti,ab,kw. (16)
3 HINS.ti,ab,kw. (63)
4 hydrogen peroxide.ti,ab,kw. (61416)
5 hydroperoxide.ti,ab,kw. (10685)
6 fogging.ti,ab,kw. (514)
7 ultraviolet radiation/ (81287)
8 hydrogen peroxide/ (88053)
9 (vaporized adj3 peroxide).ti,ab,kw. (56)
10 VHP.ti,ab,kw. [vaporized hydrogen peroxide ] (262)
11 UVGI.ti,ab,kw. [Ultraviolet germicidal irradiation] (96)
12 UVG.ti,ab,kw. (28)
13 UVGI.ti,ab,kw. [Ultraviolet germicidal irradiation] (96)
14 Ultraviolet C.ti,ab,kw. (576)
15 Ultra-violet C.ti,ab,kw. (15)
16 UV-C.ti,ab,kw. (1468)
17 UVC.ti,ab,kw. (2152)
18 ((ultraviolet or ultra-violet or UV or LED or light) adj3 (germicide or germicidal or irradiation or irradiate or disinfect*)).ti,ab,kw. (33327)
19 ultraviolet rays.ti,ab,kw. (966)
20 ultraviolet irradiation/ (14047)
21 or/1-20 (220410)
22 health care facility/ (65607)
23 exp hospital/ (1054305)
24 (hospitals or hospital or clinic or clinics or ward or wards or ICU or NICU or PICU or operating room* or operating theater* or operating theatre* or ER or emergency room* or triage or waiting room* or inpatient* or in-patient* or inhospital of healthcare facilit* or health care facilit* or LTCF or LTC or healthcare-associated or healthcare-acquired).ti,ab. (4312875)
25 nursing home/ (49522)
26 home for the aged/ (10596)
27 long term care/ (122021)
28 or/22-27 [Healthcare facilities] (4735610)
29 21 and 28 (8028)
30 environmental microbiology/ (343)
31 fomite/ (434)

32 (surface or surfaces or fomite or fomites or floor* or table* or tile* or chair* or door knob* or bed* or wall or walls or room or rooms or furniture or furnishing* or equipment or washbasin* or toilet* or sink*).ti,ab. (2509719)

33 or/30-32 [Surfaces] (2510095)

34 and/21,28,33 (1501)

35 cross infection/ (18692)

36 infection control/ (80210)

37 disinfection/ (24313)

38 (cross infection or cross infections or hospital infection or hospital infections or nosocomial infection or nosocomial infections or contaminant or contaminants or contamination or hospital epidemiology).ti,ab. (203476)

39 ((transmission or transmissible or infectious) adj2 (disease or diseases or infection or infections)).ti,ab. (125888)

40 (disinfect* or steriliz* or sterilis* or decontaminat* or pathogen control or decontaminant* or germicide*).ti,ab. (77226)

41 (infection* adj2 prevent*).ti,ab. (28905)

42 or/35-41 [Infection control] (493967)

43 and/21,28,42 (1318)

44 34 or 43 (2079)

45 limit 44 to yr="2018 - 2019" (265)

46 limit 45 to English language (263)

47 editorial/ or letter/ or note/ (2360136)

48 46 not 47 (257)

49 limit 48 to conference abstract status (69)

50 48 not 49 (188)

51 remove duplicates from 50 (187)

52 PubMed.cr. (611225)

53 51 and 52 (24)

54 limit 51 to ("pubmed/medline" or publisher) (20)

55 53 or 54 (27) [Possible Duplicates]

56 51 not 55 (160）

# Appendix B Characteristics of Included Studies

## B.1 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 |
|---|---|---|---|---|
| **HQO, 2018 (1)**<br><br>**Canada**<br><br>**Funding:** Public | **Objectives:** To evaluate the effectiveness and budget impact of portable UV light surface disinfecting devices for reducing hospital associated infections.<br><br>**Included studies (n=10):** 1 RCT, 1 ITS, 8 before-after<br><br>**Quality assessment:** Risk of Bias tool for RCTs, EPOC tool for non- RCTs & ITS studies. 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.<br><br>**Databases:** MEDLINE, EMBASE, Cochrane Central Register of Controlled Trials, Cochrane Database of Systematic Reviews, HTA, NHSEED, DARE, and CINAHL<br><br>**Search date:** Inception to January 23, 2017 | **Hospital type:** Community, academic, military, acute care, long-term care<br><br>**Intervention site:** Patient rooms in the ICUs and non-ICUs<br><br>**Year of intervention:** 2011 to 2014 | **UV devices:** pulsed Xenon UV light, Mercury UV-C radiation<br><br>**Intervention:** UV devices used as adjunct to standard hospital room cleaning and disinfection (i.e., manual cleaning) & compared with manual cleaning done in the control groups or in the period before the interventions<br><br>**Length of application:**<br>- RCT: 7 months for each strategy<br>- Non-randomized studies: Before: 3 months to 3 years<br>After: 3 months to 27 months | **Healthcare-acquired infections:**<br>- CD, VRE, MRSA<br>- Other MDROs |

| 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 |
|---|---|---|---|---|
| **Marra et al., 2018 (75)**<br><br>**USA**<br><br>**Funding:** VA Health Services Research and Development award | **Objectives:** To determine the impact of no-touch disinfection methods to decrease health-care associated infections.<br><br>**Included studies (n=20):**<br>- 13 studies on UV light (1 CT, 1 RCT, 11 before-after) published from 2013 to 2017<br>- 7 studies on HP vapor (1 prospective cohort, 6 before-after) published from 2008 to 2016<br><br>**Quality assessment:** Published tool with items on: sample representatives, bias and confounding, description of the intervention, outcomes and follow-up, and statistical analysis. Items are 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".<br><br>**Databases:** PubMed, CINAHL, CDSR, DARE and EMBASE<br><br>**Search date:** Inception to April 2017 | **Hospital type:** Community, academic, military, acute care, long-term care<br><br>**Intervention site:** Patient rooms in the ICUs and non-ICUs<br><br>**Year of intervention:**<br>- UV light: 2011 to 2014<br>- HP vapor: 2005 to 2012 | **NMD devices:**<br>- Type of UV light: pulsed Xenon UV light, UV-C radiation (mercury bulb)<br>- HP vapor disinfection system<br><br>**Interventions:**<br>NMD devices 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<br><br>**Length of application:** NR | **Healthcare-acquired infections:**<br>- CD, VRE |

HQO: Health Quality Ontario; ITS: Interrupted time-series; CT: Controlled trial; RCT: Randomized controlled trial; HP: Hydrogen peroxide; UV: Ultraviolet; CD: *Clostridioides Difficile* ; VRE: Vancomycin-resistant *Enterococcus*; MRSA: Methicillin-resistant *Staphylococcus aureus*; MDRO: Multidrug-resistant organisms; CINAHL: Cumulative Index to Nursing & Allied Health Literature; DARE: Database of Abstracts of Reviews of Effects; NHSEED: National Health Service Economic Evaluation Database; HTA: Health Technology Assessment; ICU: Intensive care unit

## B.2 Characteristics of Included Primary studies

| Author, Year | Hospital Type | Study Design | Length of Follow-Up | NMD device | Hospital Units Evaluated | Timing of Disinfection | Target Rooms |
|---|---|---|---|---|---|---|---|
| **Anderson et al., 2018 (84)** | 9 hospitals (tertiary, community, and Veterans Affairs), 148–950 beds | Randomized trial | 28 months; [April, 2012, to July, 2014] | Mercury UV-C (Tru-D) | All | After discharge or transfer | Secondary analysis of **Anderson et al., 2017 (76)**; **All** patients admitted to a study hospital during the BETR study period were considered |
| **Anderson et al., 2017 (76)** | 9 hospitals (tertiary, community, and Veterans Affairs), 148–950 beds | Randomized trial | 24 months;<br>Each hospital used each strategy for 7 months | Mercury UV-C (Tru-D) | All | After discharge or transfer | Single-patient rooms from which patient with contact precautions is discharged or transferred |
| **Fraser Health., 2019 (73)** | All FH facilities | Interrupted time-series study with control | Before: 25 months<br>Intervention: 7 months<br>Follow-up: 14 months | PX-UV (Xenex LightStrike®) | Intervention: All units at target sites. | Cyclical unit deep clean of all rooms (including ancillary rooms) in all target units; The sequence was repeated for six months at each facility | Secondary analysis of *Fraser Health., 2017 (74);* All patients admitted to trial site were considered |
| **Brite et al., 2018 (78)** | BMT unit; (25 beds, single-patient rooms) of a 474-bed tertiary-care cancer center | Interrupted time-series study | Before: 19 months<br>Washout: 1 month<br>After: 12 months | PX-UV (Xenex Healthcare Services) | BMT unit | After discharge or transfer; daily patient bathroom cleanings | All single patient rooms in BMT unit after discharge |
| **Pegues et al., 2017 (81)** | Tertiary care, 789 | Interrupted time-series study with control | Before: 12 months<br>After: 15 months | Mercury UV-C (Optimum-UV Clorox Healthcare) | Inpatient units of leukemia and lymphoma patients | After discharge or transfer | Rooms of patients on contact precautions for CD, Second priority for MRSA and VRE |
| **Sampathkumar et al., 2019 (82)** | Tertiary care hospital (2059 beds) | Controlled before-after study | Study period: 6 months | PX-UV (Xenex) | 2 hematology and BMT units & 1 medical-surgical unit | After discharge or transfer | Private rooms with private toilets (A few double rooms in the Medical-surgical unit of the intervention arm) |

| Author, Year | Hospital Type | Study Design | Length of Follow-Up | NMD device | Hospital Units Evaluated | Timing of Disinfection | Target Rooms |
|---|---|---|---|---|---|---|---|
| **Pavia et al., 2019 (80)** | Children hospital (97 beds) | Controlled before-after study | Before: 12 months<br>After: 12 months | Mercury UV-C (Clorox Healthcare) | Toddler unit | Rotating schedule (patient rooms: 2-3 treatments per week, Common areas: were treated daily 3 times per week, excluding holidays) | Patient rooms and common areas |
| **Fraser Health., 2017 (74)** | 3 FH acute care facilities (Abbotsford Regional Hospital [ARH], Burnaby Hospital [BH], Ridge Meadows Hospital [RMH]) | Controlled before-after study | Before: 6 months<br>After: 6 months | PX-UV (Xenex) | Vulnerable Units: units with highest rates of CDI & MRSA (ARH: 5 units; BHl: 6 units; RMH: 5 units) | Cyclical unit deep clean of all rooms in all target units; The sequence was repeated for six months at each facility | Single and multi-patient rooms, ancillary rooms |
| **Raggi et al., 2018 (83)** | Community hospital (377 beds) | Before-after study (no control) | Before: 12 months<br>After: 12 months | Mercury UV-C (Skytron) | All units, excluding maternity and nursery units | After discharge or transfer; OR & ER rooms were treated weekly | Inpatient rooms from non-ICU units, including telemetry, medical-surgical, and oncology, with nonstandard transmission precautions had second priority. Non-ICU inpatients rooms with standard precautions had last priority. |
| **Haas et al., 2014 (79)** | Tertiary care academic medical center (643 beds) | Before-after study (no control) | Before: 30 months<br>After: 22 months | PX-UV (Xenex) | All | Daily in the operating rooms; weekly in the dialysis unit; all burn unit discharges. Upon request for rooms of long-stay patients or for discharges in units with high prevalence of MDRO/CD | Operating rooms; long-stay patients; high prevalence of MRDO/CDI; burn unit |

BMT: Bone marrow transplant; PX-UV: Pulsed Xenon UV; UV: Ultraviolet; OR: Operating room; ER: Emergency room; FH: Fraser Health; ICU: Intensive care unit; CDI: *Clostridioides difficile* infection; MRSA: Methicillin-resistant *Staphylococcus aureus*; MDRO: Multidrug-resistant organism

## B.3 Disinfection Protocols for NMD Technologies and Manual Disinfection of Hospital Rooms

| Author, Year | Study design | Number of Devices | NMD Protocol | | | Manual Cleaning Disinfectants | Other Infection Control Measures in Hospital |
|---|---|---|---|---|---|---|---|
| | | | Number of Cycles per Room (Location) | Length of Cycle (Minutes) | Additional Process Measures | | |
| **Anderson et al., 2018 (84)** | Randomized trial | 9 (1–4 per hospital) | 1 (center, near bathroom) | Until sufficient dose is detected (30-55 min) (77) | Opened drawers & cabinets; Staff training | CD: hypochlorite (bleach) Other rooms: quaternary ammonium | Precautions for CD; Staff training for all protocols; standardized Room monitoring with pH pens |
| **Anderson et al., 2017 (76)** | Randomized trial | 9 (1–4 per hospital) | 1 (center, near bathroom) | Until sufficient dose is detected (30-55 min) (77) | Opened drawers & cabinets; Staff training | CD: hypochlorite (bleach) Other rooms: quaternary ammonium | Precautions for CD; Staff training for all protocols; standardized Room monitoring with pH pens |
| **Fraser Health., 2019 (73)** | ITS with control | same as Fraser Health, 2017 | same as Fraser Health, 2017 | same as Fraser Health, 2017 | Same as Fraser Health, 2017 | same as Fraser Health, 2017 | |
| **Brite et al., 2018 (78)** | ITS | NR | Discharge cleaning: 3 (2 positions, 1 in bathroom); Daily bathroom cleaning: 1 | 5 minutes/position | Automated data log & estimated compliance by (1) energy emitted & (2) duration of cleaning (Minimum 5 minutes per position). | CD: hypo-chlorite solution (bleach). Other rooms: quaternary ammonium compound | Used ATP measurements to assess evenness of cleaning on high touch surfaces |
| **Pegues et al., 2017 (81)** | ITS with control | 1 (second added in follow-up) | 3 (foot of bed & near bathroom) | 8 minutes/position | Changed curtains; UV metrics reported; Staff training | CD: Bleach | Hospital-wide CD interventions 2 yrs prior |
| **Sampathkumar et al., 2019 (82)** | Controlled before-after | N | 3 cycles (2 positions, 1 in bathroom) | 5 minutes/position | Opened drawers, cabinets & other high touch objects (e.g. remote, telephone and blood pressure cuffs) positioned appropriately & flipped | Hematology and BMT units: Bleach & bleach wipes (daily & at discharge)<br><br>Medical-surgical units: Bleach (known CD rooms) | Rates of hand hygiene, isolation compliance, & antimicrobial usage were followed on all the units |
| **Pavia et al., 2019 (80)** | Controlled before-after | 1 | 3 (1 in bathroom); +1 in rooms with additional bed | 5 minutes/position | Device was placed on each side of the bed | Quaternary ammonium disinfectants | NR |

| Author, Year | Study design | Number of Devices | NMD Protocol | | | Manual Cleaning Disinfectants | Other Infection Control Measures in Hospital |
|---|---|---|---|---|---|---|---|
| | | | Number of Cycles per Room (Location) | Length of Cycle (Minutes) | Additional Process Measures | | |
| **Fraser Health., 2017 (74)** | Controlled before-after | 3 (1 per facility) | Bathrooms: 1<br>Private: 3<br>Semi-private: 4<br>3-beds: 5-6<br>4-bed: 6-7 | Private: 15-20 minutes<br>Semi-private: 20-25 minutes<br>3-beds: 30-35 minutes<br>4-bed: 35-40 minutes | Linens & curtains replaced for each clean cycle; patient preparation & movement precautions; Patients on Airborne Precautions were not moved from their room, & were not UVGI-disinfected during patient stay | Bleach | |
| **Raggi et al., 2018 (83)** | Before-after study (no control) | NR | NR | NR | NR | NR | No changes to standard terminal disinfection protocols. Additionally, there were no changes in the transmission precautions or disease |
| **Haas et al., 2014 (79)** | Before-after study (no control) | 2 | 3 (1 bathroom; 2 position in the room) | 6 minutes (time was also dependent on room size) | | <u>Adult patient rooms:</u><br>Bleach-based (sodium hypochlorite 0.55%);<br><u>Pediatric patient rooms:</u><br>Quaternary ammonium compound; contact precautions rooms & all discharge cleaning: Sodium hypochlorite 0.55% disinfectant | Used ATP measurements to monitor cleaning; use of checklists for discharge cleaning; randomized double-blind trial of chlorhexidine bathing was conducted on a single unit; weekly intensive cleaning of occupied rooms in high-risk units during the pre-UVD and UVD periods. |

ITS; Interrupted time-series; UVD: Ultraviolet disinfection; CD: *Clostridium difficile*; NR: Not reported

# Appendix C Quality Assessment of Included Studies

## C.1 Quality Assessment of Systematic Reviews (As reported by 2019 CADTH rapid response report (71))

| AMSTAR 2 Checklist (70) | Health Quality Ontario (1) | Marra et al., 2018 (75) |
|---|---|---|
| 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 |

| AMSTAR 2 Checklist (70) | Health Quality Ontario (1) | Marra et al., 2018 (75) |
|---|---|---|
| 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 |

## Appendix D Risk of Bias Assessment of Included Studies

### D.1 Risk of Bias*: Randomized Controlled Trials and Controlled Before-After studies

| | Anderson et al., 2017 (76) | Anderson et al., 2018 (84) | Sampathkumar et al., 2019 (82) | Fraser Health., 2017 (74) |
|---|---|---|---|---|
| Random sequence generation | Low | Low | High | High |
| Allocation concealment | High | High | high | high |
| Baseline outcome measurements similar | High | Unclear | high | high |
| Baseline characteristics similar | Low | Unclear | High | high |
| Incomplete outcome data | low | Unclear | High | unclear |
| Knowledge of the allocated interventions adequately prevented during the study | Unclear | Unclear | low | low |
| Protection against contamination | Low | Low | unclear | unclear |
| Selective outcome reporting | Low | Low | Low | low |
| Other risks of bias | high | high | high | high |

* Effective Practice and Organization of Care (EPOC) tool for randomized trials and controlled before-after studies was used (68)

### D.2 Risk of Bias: Interrupted Time Series Studies

| | Pegues et al., 2017 (81) | Fraser Health., 2019 (73) | Brite et al., 2018 (78) |
|---|---|---|---|
| Intervention independent of other changes | High | High | High |
| Shape of the intervention effect pre-specified | Low | Low | Low |
| Intervention unlikely to affect data collection | Low | Low | Low |
| Knowledge of the allocated interventions adequately prevented during the study | Low | Low | Low |
| Incomplete outcome data adequately | Low | Unclear | Low |
| Selective outcome reporting | High | Low | High |
| Other risks of bias | High | High | High |

* Effective Practice and Organization of Care (EPOC) tool for interrupted time-series studies was used (68)

### D.3 Risk of Bias* Among Uncontrolled Before-After Studies

| | Haas et al., 2014 (79) | Raggi et al., 2018 (83) | Pavia et al., 2019 (80) |
|---|---|---|---|
| Clearly Stated Objective | Y | Y | Y |
| Pre-specified Eligibility Criteria | N | Y | N |
| Representative Patients | Y | Y | Y |
| All Eligible Patients Enrolled | N | N | N |
| Calculated Adequate Sample Size | N | NR | N |
| Intervention Described and Delivered | Y | Y | Y |
| Pre-specified, Valid Outcome Measure | Y | Y | Y |
| Blind Outcome Assessment | N | N | Unclear |
| Loss to Follow-Up Accounted for | NR | NR | Unclear |
| Statistical Methods Appropriate | Y | Y | Y |
| Multiple Outcome Measurement Times | N | N | Y |
| Appropriate Group-Level Analysis | Y | Y | Y |

*Risk of bias assessed using modified version of National Institutes of Health National Heart, Lung and Blood Institute's quality assessment tool for before-after (pre-post) studies with no control group (69)

## Appendix E Excluded Studies

| Author, year | Reason for exclusion | Notes |
|---|---|---|
| Cabral et al., 2019 | Intervention | Note: this was a summary there was not intervention for outcomes to be evaluated |
| Resendiz et al., 2019 | Intervention | UV-C device was not portable |
| Weber et al., 2019 | Outcomes | Outcomes do not include actual HAI rates |
| Donskey et al., 2019 | Outcomes | Study does not report outcomes on the actual HAI rates |
| Zeber et al., 2018 | Outcomes | Outcomes is restricted to bacterial bioburden |
| Cobrado et al., 2018 | Outcomes | Outcome was bioburden on environmental surfaces |
| Yang et al., 2019 | Outcomes | Study did not evaluate impact on HAI rates; instead the outcomes was focused on evaluating impact on bacterial cultures |
| Smolle et al., 2018 | Outcomes | Study evaluated impact of UV-C device on "textiles", however outcomes was focused on evaluation of bioburden and NOT HAI rates |
| Mustapha et al., 2018 | Outcomes | Outcomes was focused on evaluation of bioburden and NOT HAI rates |
| Simmons et al., 2018 | Outcomes | Outcomes was focused on evaluation of bioburden and NOT HAI rates |
| Heredia-Rodriguez et al., 2018 | Intervention | Device used is an Air sterilizer, thus not focusing on "environmental surfaces" |
| Bearman et al., 2018 | Intervention | |
| Allen et al., 2019 | Outcomes | Outcome was reduction in colony forming units (CFU) of bacteria |
| Turner et al., 2019 | Intervention | Outcomes were evaluated after implementation of a bundle of intervention (which included UV-C), therefore unable to attribute outcomes to UV-C |
| Frakking et al., 2018 | Intervention | Intervention implemented as part of a bundled approach, therefore unable to attribute outcomes NMD |
| Ide et al., 2019 | Outcomes | Outcome was focused on bacterial load |