Health Quality Ontario

Let's make our health system healthier

ONTARIO HEALTH TECHNOLOGY ASSESSMENT SERIES

Portable Ultraviolet Light Surface-Disinfecting Devices for Prevention of Hospital-Acquired Infections: A Health Technology Assessment

KEY MESSAGES

What Is This Health Technology Assessment About?

Hospital-acquired infections are infections that patients develop while in the hospital that were neither present nor developing when patients were admitted. In Canada about 10% of adults with short-term hospitalization have hospital-acquired infections. We studied the effectiveness and budget impact of portable ultraviolet light surface-disinfecting devices for reducing hospital-acquired infections.

What Did This Health Technology Assessment Find?

We can't be certain of the effectiveness of ultraviolet light disinfection in reducing hospital-acquired infections, given the very low to low quality of evidence. We estimated that the typical cost for a hospitals that purchases two portable devices would be $586,023 over 5 years for devices that use the pulsed xenon technology and $634,255 over 5 years for devices that use the mercury technology. Our budget impact estimates change the most if we vary our assumptions about the number of portable ultraviolet light disinfecting devices purchased per hospital, frequency of daytime use, and staff time required per use.

Published February 2018
Volume 18, Number 1

Ontario
Health Quality Ontario

HEALTH TECHNOLOGY ASSESSMENT AT HEALTH QUALITY ONTARIO

This report was developed by a multidisciplinary team from Health Quality Ontario. The lead clinical epidemiologist was Milica Nikitovic-Jokic and the secondary clinical epidemiologist was Conrad Kabali, the health economist was Chunmei Li, and the medical librarian was Caroline Higgins.

The medical editor was Elizabeth Jean Betsch; others involved in the development and production of this report were Harrison Heft, Kellee Kaulback, Ana Laing, Claude Soulodre, Sarah McDowell, Andreé Mitchell, Vivian Ng, Anil Thota, Nancy Sikich, and Irfan Dhalla.

We are grateful to the following experts for providing consultations on the report:

Michael Gardam	Medical Director of Infection Prevention and Control at Women' College Hospital, Associate Professor of Medicine, University of Toronto
Allison McGeer	Director of Infection Control, Mount Sinai Hospital Professor, Dalla Lana School of Public Health, University of Toronto
Dominik Mertz	Associate Professor, Division of Infectious Diseases, Department of Medicine, McMaster University Medical Director Infection Control, Hamilton Health Sciences

The statements, conclusions, and views expressed in this report do not necessarily represent the views of the consulted experts.

Citation

Health Quality Ontario. Portable ultraviolet light surface-disinfecting devices for prevention of hospital-acquired infections: a health technology assessment. Ont Health Technol Assess Ser [Internet]. 2018 Feb;18(1):1-73. Available from: http://www.hqontario.ca/evidence-to-improve-care/journal-ontario-health-technology-assessment-series

ABSTRACT

Background

Hospital-acquired infections (HAIs) are infections that patients contract while in the hospital that were neither present nor developing at the time of admission. In Canada an estimated 10% of adults with short-term hospitalization have HAIs. According to 2003 Canadian data, between 4% and 6% of these patients die from these infections. The most common HAIs in Ontario are caused by *Clostridium difficile.* The standard method of reducing and preventing these infections is decontamination of patient rooms through manual cleaning and disinfection. Several portable no-touch ultraviolet (UV) light systems have been proposed to supplement current hospital cleaning and disinfecting practices.

Methods

We searched for studies published from inception of UV disinfection technology to January 23, 2017. We compared portable UV surface-disinfecting devices used together with standard hospital room cleaning and disinfecting versus standard hospital cleaning and disinfecting alone. The primary outcome was HAI from *C. difficile*. Other outcomes were combined HAIs, colonization (i.e., carrying an infectious agent without exhibiting disease symptoms), and the HAI-associated mortality rate. We used Grading of Recommendations Assessment, Development, and Evaluation (GRADE) to rate the quality of evidence of included studies. We also performed a 5-year budget impact analysis from the hospital's perspective. This assessment was limited to portable devices and did not examine wall mounted devices, which are used in some hospitals.

Results

The database search for the clinical review yielded 10 peer-reviewed publications that met eligibility criteria. Three studies focused on mercury UV-C–based technology, seven on pulsed xenon UV technology. Findings were either inconsistent or produced very low-quality evidence using the GRADE rating system. The intervention was effective in reducing the rate of the composite outcome of HAIs (combined) and colonization (but quality of evidence was low). For the review of economic studies, 152 peer-reviewed publications were identified and screened. No studies met the inclusion criteria. Under the assumption that two devices would be purchased per hospital, we estimated the 5-year budget impact of $586,023 for devices that use the pulsed xenon technology and of $634,255 for devices that use the mercury technology.

Conclusions

We are unable to make a firm conclusion about the effectiveness of this technology on HAIs given the very low to low quality of evidence. The budget impact estimates are sensitive to assumptions made about the number of UV disinfecting devices purchased per hospital, frequency of daytime use, and staff time required per use.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

OBJECTIVE

This health technology assessment evaluated the effectiveness and budget impact of portable ultraviolet (UV) light surface-disinfecting devices for reducing hospital-acquired infections (HAIs).

BACKGROUND

Hospital-Acquired Infections

Health care–associated infections are infections that patients contract while in a health care setting (e.g., hospital, long-term care facility, emergency department, outpatient clinic, physicians' offices, community health centre) that were neither present nor developing at the time the patient was admitted. Infections that are acquired in the hospital itself are referred to as HAIs, also known as nosocomial infections. Infections are generally classified as being associated with a hospital or health care facility if they occur within 48 to 72 hours after hospitalization or visiting a health care facility, or if they appear within 10 days following discharge from hospital.[1,2]

Hospital-acquired infections can be caused by a range of microorganisms including bacteria, viruses, or fungi that are present in the hospital environment. The most commonly monitored HAIs in Canada include *Clostridium difficile*, methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant *Enterococcus* (VRE), and carbapenemase-producing *Enterobacteriaceae* (CPE).[3-5] These HAIs can result in serious illness and sometimes death, with longer hospital stays and readmission.[6] As such, HAIs are considered a serious adverse outcome in the delivery of care to patients across the health care system.

Clinical Need and Target Population

Health Care–Acquired Infections in Ontario

In Canada approximately 10% of adults with acute hospitalizations are estimated to have a nosocomial infection.[3] Based on 2003 data, an estimated 200,000 Canadians acquire a health care–associated infection annually, with an estimated 8,000 to 12,000 persons dying as a result of their infection.[3] In fiscal year 2015/16, the *C. difficile* infection rate for Ontario hospitals was 0.26 per 1,000 inpatient days, ranging from 0.0 to 2.94 per 1,000 inpatient days between July and August 2016.[4,7] The MRSA bacteremia rate for fiscal year 2015/16 was 0.018 per 1,000 inpatient days, ranging from 0.0 to 0.235 per 1,000 days across Ontario hospitals, and the VRE bacteremia rate was 0.006 per 1,000 inpatient days, ranging from 0.0 to 0.068 per 1,000 inpatient days[4] (internal data from Health System Performance at Health Quality Ontario; Data source: Health Analytics Branch, Ministry of Health and Long-Term Care, 2016). Data from the Canadian Nosocomial Infection Surveillance Program (CNISP), which are not limited to bacteremia, used 2014 national data to calculate health care–acquired MRSA infection incidence rates of 0.17 per 1,000 patient days and VRE infection incidence rates of 0.045 per 1,000 patient days.[8]

Hospital-acquired infections increase health care costs through prolonged hospital stays or readmissions.[9-11] The direct cost of caring for a patient with an HAI in Canada has been estimated to range from $2,000 to $20,000.[12]

Hospital-Acquired Infection Transmission

Pathogens that cause HAIs can be transmitted from one patient to another through direct or indirect contact. While person-to-person touch is an important mode of transmission, contaminated surfaces in health care settings can contribute to the transmission of microorganisms implicated in HAIs.[13-15] Bacteria can thrive on many objects, such as bed rails, call buttons, telephones, door handles, mattresses, taps, bathroom fixtures, and chairs. Bacteria and viruses can survive on these surfaces for long periods, with *C. difficile* spores surviving in the health care environment for up to 5 months, and MRSA and VRE surviving on dry surfaces for several weeks to months.[16]

Transmission of pathogens from environmental surfaces to patients can occur from direct infection (i.e., from an infected patient to an object and then to a subsequent patient) or indirectly (i.e., from an object to the hands of hospital staff, health care providers, or visitors to a subsequent patient). Most infections are transmitted from a prior room occupant who was infected or colonized. A prior room occupant who is infected or colonized (microorganism is present in the person, but has not invaded the tissue, or caused cellular injury, so the person shows no signs or symptoms of illness) with these pathogens has been shown to increase the risk of infection in subsequent room occupants by two times or more.[17]

Current Hospital Room Cleaning and Disinfection of Surfaces

Decontamination of patient rooms through cleaning and disinfection is a key method for comprehensive infection prevention and control and is critical in reducing and preventing the transmission of pathogens in the health care environment.[18] Cleaning is defined by the physical removal of foreign material or surface debris, while disinfection refers to killing or inactivation of microorganisms that can cause infection.[18]

Public Health Ontario and the Provincial Infectious Diseases Advisory Committee (PIDAC) have developed best practices for environmental cleaning in health care settings.[1,19] Standard environmental cleaning and disinfection protocols are heterogeneous and vary according to the type of room being cleaned. Examples can include routine daily room cleaning, daily cleaning of rooms of patients with additional contact precautions (i.e., additional barrier precautions for patients with known infection or colonization, often in separate isolation units) or thorough cleaning and decontaminating of a room after patients with contact precautions were discharged or transferred.

Despite best practice recommendations, how manual cleaning and disinfection is performed in Ontario hospitals varies (expert communication, Dec 2016).[20] Evidence also suggests that manual cleaning and disinfection may be suboptimal, resulting in residual contamination.[21] Additionally, manual cleaning and disinfection protocols can be complex and require disinfectants that are fast, broad spectrum, safe for humans and the environment, but also compatible with materials and medical devices.[22] Adequate disinfection also requires tailoring the method of disinfection to the microorganisms being targeted, such as the use of sporicidal agents (e.g., sodium hypochlorite [bleach]) to inactivate spore-forming bacteria like *C. difficile.* In addition to the type of disinfectant used, effective disinfection requires appropriate application, which includes adequate cleaning prior to application, sufficient contact time between the disinfectant and the surface being cleaned, and appropriate concentrations of disinfectant used, all of which can be difficult to achieve.[22]

Given the limitations of standard manual cleaning and disinfection of hospital rooms for prevention of HAIs, several no-touch ultraviolet (UV) light systems have been developed to supplement current hospital cleaning and disinfection practices.[23,24]

Portable Ultraviolet Surface-Disinfection Devices Under Review

Devices emitting UV light are no-touch, automated disinfection systems that are used to kill pathogens associated with infectious disease and infections.[25] These devices work primarily through the use of lamps that produce high-intensity ultraviolet C (UV-C) light, a form of electromagnetic radiation (UV-C wavelengths of 100–280 nm on the electromagnetic spectrum). UV-C is germicidal; it destroys the DNA of bacteria, viruses, and other microorganisms, preventing them from multiplying, repairing the damaged DNA, and causing infections and disease.[26] Ultraviolet surface-disinfecting devices are not intended to replace other environmental cleaning practices, but rather to be used as a complementary method to enhance disinfection after surfaces are manually cleaned and disinfected.

There are two main types of portable UV devices for surface disinfection that have been approved for sale in Canada: those that emit a continuous dose of UV-C light through a mercury bulb, and those that use a pulsed xenon light.[25]

Pulsed Xenon Ultraviolet Devices

Pulsed xenon UV devices use xenon lamps to produce a flash of full germicidal light across the entire disinfecting spectrum (wavelengths of 200–320 nm; including both UV-B and UV-C spectrum), which is delivered in millisecond pulses.[27]

The core protocol is to place the device in vacant patient rooms, running it once in the bathroom and once on each side of the hospital bed (personal communication, Xenex Disinfection Service, Feb 2017). Surfaces must be in the line of sight to be decontaminated, and disinfection is therefore limited by shadowed areas and depends on the reflectivity of room walls and surfaces. The amount of UV-C light reaching organisms and the effectiveness of the light is dependent on the dose and intensity, the distance from the object being disinfected, the type of surfaces, and the type of microorganisms present.[28] Rooms are vacated and doors are closed during the disinfection process, and devices must be built with sensors that automatically stop the irradiation if the door is opened or any other movement is detected. Some manufacturers offer a protective curtain, which can be placed between patient beds to allow for partial disinfection of shared patient rooms (personal communication, Xenex Disinfection Service, Feb 2017).

The recommended length of time to run the device varies between devices and manufacturers. The most commonly studied pulsed xenon UV device is developed by Xenex and takes approximately 5 to 15 minutes per run. The entire process of disinfecting a single room is estimated at 15 to 20 minutes.

Mercury Ultraviolet C Devices

Mercury UV-C devices use low-pressure mercury gas bulbs that primarily emit a strong narrow band of the UV-C spectrum (e.g., at 254 nm). These devices use a dose targeted for the type of bacteria on surfaces (i.e., vegetative bacteria or spores). Various mercury UV-C devices exist, all of which differ on the number of lamps used and the type of output produced (e.g., standard- or maximum-output mercury lamps). As with the pulsed xenon UV devices, rooms must be vacated before disinfection, and effectiveness is limited by shadowed areas of the room. To

maximize exposure to areas outside of direct line of sight, the device is typically placed in the centre of the room, with the bathroom door left open (personal communication, Tru-D, Mar 2017). Some manufacturers recommend multiple cycles from different locations, while others, such as the Tru-D Smart UVC system, disinfect rooms from a single location by using sensors to measure the amount of UV-C reflected back to the device.[29] These devices stop automatically when all of the sensors meet the target dose set for the type of bacteria in the room.[29] Similar to the pulsed xenon devices, mercury UV devices are generally built to stop operation if the door is opened or movement is detected in the room. Devices vary in the time to disinfect room, generally requiring upward of 45 minutes for a single cycle.

Ultraviolet Surface Disinfection in Hospitals

The UV room disinfection devices currently available are mobile (on casters) and can be used anywhere disinfection is desired. Given the need for the room to be empty before running the device, primary application has been targeted for cleaning rooms after patient discharge or transfer, specifically rooms of patients with contact precautions. Other proposed applications include bathrooms and shower areas, emergency departments, or operating theatres.

Several reviews of environmental studies have demonstrated reductions of common pathogens (e.g., MRSA, CPE, VRE, and *C. difficile*) on both porous and nonporous hospital surfaces with the use of both mercury UV-C and pulsed xenon UV devices.[22,28] These results, however, cannot be directly extrapolated to improved patient outcomes (i.e., reduced HAI rate).

Regulatory Information

These technologies do not require approval by Health Canada; they are not classified as medical devices because they do not come into contact with patients during use.

At least two portable UV disinfecting products have been approved for sale across Canada (personal communication, Xenex Disinfection Service). This includes the Xenex Light Strike Pulsed Xenon Light Germ Zapping Robot and the Tru-D UVC device, which uses mercury bulbs.

Ontario Context

Numerous UV room disinfecting devices have entered the North American market. The current use and dissemination of UV disinfecting devices in Ontario remains unclear. According to experts, several devices have used or are being used in Ontario hospitals, although dissemination has been slow (expert consultation, December 2016).

The Xenex Light Strike Pulsed Xenon Light Germ Zapping Robot device is currently being used in Ontario by at least two hospitals, primarily in the intensive care (ICU) and oncology units (personal communication, Xenex Disinfection Service, Feb 2017). A third hospital confirmed pilot testing the device in 2013, but discontinuing use because of problems with implementation. The pulsed xenon UV device is being tested in a trial in Saskatchewan focused on VRE.

According to the manufacturer, the Tru-D disinfecting device is currently being used by three hospitals in Ontario (personal communication, Tru-D, March 29).

In Ontario, *C. difficile* constitutes the largest proportion of HAI (expert consultation, May 2017). For this reason, we decided to focus primarily on *C. difficile* in this review.

CLINICAL EVIDENCE

Research Question

What is the effectiveness of portable ultraviolet (UV) light surface-disinfecting devices as an adjunct to standard cleaning and disinfection protocols in reducing hospital-acquired infections versus standard cleaning and disinfection protocols alone?

Methods

Research questions are developed by Health Quality Ontario in consultation with patients, health care providers, clinical experts, and other health system stakeholders.

Literature Search

We performed a literature search on January 23, 2017, to retrieve studies published from inception to the search date. We used the Ovid interface to search the following databases: MEDLINE, Embase, Cochrane Central Register of Controlled Trials, Cochrane Database of Systematic Reviews, Health Technology Assessment, National Health Service Economic Evaluation Database (NHSEED), Database of Abstracts of Reviews of Effects (DARE); and we used the EBSCO host interface to search the Cumulative Index to Nursing & Allied Health Literature (CINAHL).

Search strategies were developed by medical librarians using controlled vocabulary (i.e., Medical Subject Headings) and relevant keywords. The final search strategy was peer-reviewed using the PRESS Checklist.[30] Database auto-alerts were created in MEDLINE, Embase, and CINAHL and monitored for the duration of the health technology assessment.

We performed targeted grey literature searching of sites for health technology assessment agencies and clinical trial registries. See Appendix 1 for Literature Search Strategies, including all search terms.

Literature Screening

A single reviewer used DistillerSR management software to conduct an initial screening of titles and abstracts, and obtained the full text of studies that appeared eligible for the review, according to the inclusion criteria. The author then examined the full-text articles and selected studies that were eligible for inclusion.

Types of Studies

We looked at randomized controlled trials (RCTs), cohort studies, and interrupted time series (also known as before-after) studies that compared UV surface disinfection.

We did not include non–systematic reviews, editorials, case reports, or commentaries.

Types of Participants

Given this device is not applied directly to patients, a patient population of interest was not specified. We included all studies assessing the intervention in the hospital setting. All types of hospital units were included (e.g., intensive care units [ICUs], burn units, and pediatric units).

Studies evaluating the use of the device outside the hospital setting (e.g., long-term care homes) were excluded.

Types of Interventions

Intervention

We included studies of portable UV surface-disinfecting devices used as an adjunct to standard hospital room cleaning and disinfection. Both pulsed xenon disinfecting devices and mercury bulb UV-C devices were included.

We excluded studies using UV germicidal irradiation air-cleaning technologies as well as UV for water irradiation.

Comparator

We included studies comparing the intervention to standard hospital cleaning and disinfecting methods (i.e., manual cleaning).

We excluded studies comparing UV with alternative devices used for no-touch room disinfection (e.g., hydrogen peroxide fogging) or where the manual cleaning and disinfection methods varied between the intervention and comparator arm of the study.

Types of Outcome Measures

- Hospital-acquired infection rates (infection only or composite outcome of infection and colonization); all HAIs were included, with a focus on but not limited to:
    - *Clostridium difficile*
    - Methicillin-resistant *Staphylococcus aureus* (MRSA)
    - Vancomycin-resistant *Enterococcus* (VRE)
    - Carbapenemase-producing *Enterobacteriaceae* (CPE)
- Patient colonization rates only
- HAI-related mortality rate

We excluded studies looking at only reduced microbial contamination outcomes (i.e., reduction of surface contamination).

Data Extraction

We extracted relevant data on study characteristics and on risk-of-bias items to collect information about:

- Source (e.g., citation information, contact details, study type)
- Methods (e.g., study design, study duration and years, participant or room allocation, allocation sequence concealment, blinding, reporting of missing data, reporting of outcomes, and whether or not the study compared two or more groups)
- Intervention and comparator (e.g., type of device, manufacturer, number of devices in hospital, protocol for disinfection, manual disinfection techniques and protocols used, other hospital disinfection initiatives under way)
- Study patient characteristics (e.g., patient age, comorbidities, infection risk)

- Outcomes (e.g., outcomes measured, number of participants for each outcome, number of participants missing for each outcome, outcome definition and source of information, unit of measurement, upper and lower limits [for scales], and time points at which the outcome was assessed)
- Study patient characteristics (e.g., patient age, comorbidities, infection risk)

We contacted authors of the studies to provide clarification as needed.

Statistical Analysis

We performed a qualitative synthesis of the included studies using text and tabular summaries of data. Results for studies using pulsed xenon UV disinfecting devices were summarized separately from those using mercury bulb UV-C disinfecting devices. We had planned to quantitatively synthesize studies using a priori meta-analysis; however, this analysis was not performed given substantial heterogeneity in study design, interventions, comparators, and outcome measures across the studies. Rate ratios of HAI between the manual cleaning and disinfection arms and the UV disinfection arms were taken as reported in the studies, or were otherwise calculated from data reported in the study using Review Manager Version 5.3 software.

Quality of Evidence

Risk of bias for individual studies was assessed using the Cochrane Risk of Bias tool for RCTs and the Effective Practice and Organisation of Care (EPOC) tool for non-RCTs and for interrupted time-series studies.[31,32] The National Heart, Lung and Blood Institute quality assessment tool was used for before-after studies with no control group.[33]

The quality of the body of evidence for each outcome was evaluated according to the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) framework.[34] We started with the assumption that RCTs are high quality, whereas observational studies are low quality. We then rated the studies on the basis of the following considerations: risk of bias, inconsistency, indirectness, imprecision, publication bias, magnitude of effect, and dose-response gradient. The overall quality was determined to be high, moderate, low, or very low using a step-wise, structured methodology. The quality level determination reflects our certainty about the evidence.

Expert Consultation

In December 2016 and January 2017, we consulted Ontario experts about UV disinfecting devices. Expert advisors included physicians and experts in the specialty areas of infectious disease prevention and control. The role of the expert advisors was to place the evidence in the context of Ontario and to provide advice on the use of UV disinfecting devices and guidelines on current standard cleaning and disinfection practices.

Results

Literature Search

The literature search yielded 1,538 citations published between inception and January 23, 2017 after removing duplicates. We reviewed titles and abstracts to identify potentially relevant articles. We obtained the full texts of these articles for further assessment. Ten studies (one

cluster RCT, one time-series analysis, and eight uncontrolled before-after studies) met the inclusion criteria.

Two of the identified studies used the same dataset for their analyses; however, both were included in the review because different comparisons and subgroups were evaluated.[35,36] The most recent study was used in the GRADE assessment when the same outcome was assessed.

We hand-searched the reference lists of the included studies, along with health technology assessment websites and other sources, to identify additional relevant studies. No citations were added.

Figure 1 presents the flow diagram for the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA).

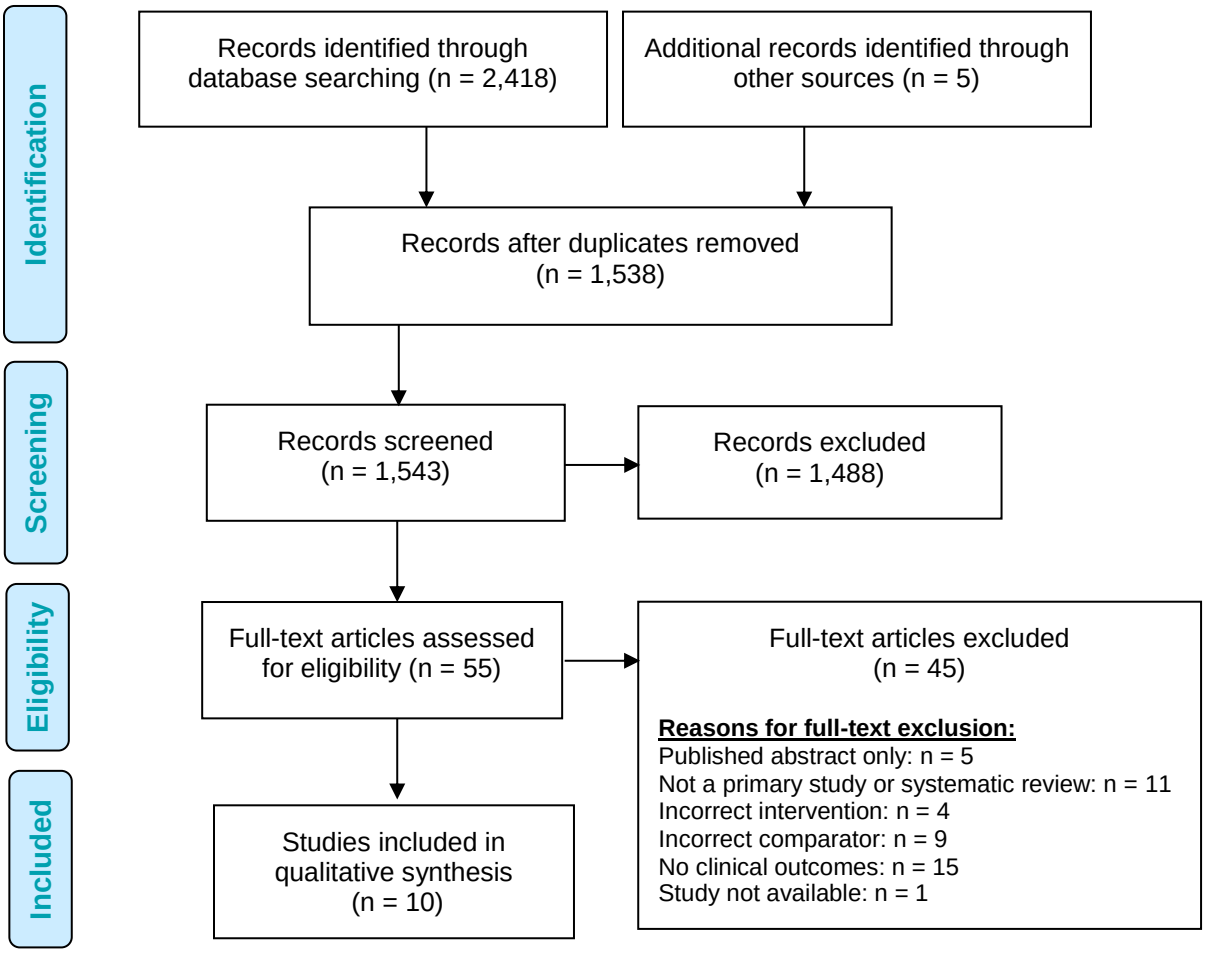

Figure 1: PRISMA Flow Diagram—Clinical Search Strategy

Source: Adapted from Moher et al.[37]

Summary of Included Studies

The 10 included studies are summarized in Tables 1 and 2. Overall, substantial clinical and methodologic heterogeneity made meta-analysis inappropriate.

Study Design

Three studies evaluated the use of mercury UV-C devices (one cluster RCT, one time-series analysis with a control group, and one uncontrolled before-after study). Each of the mercury UV-C studies used a device by a different manufacturer (Tru-D, Optimum-UV Clorox Healthcare, or IRiS 3200m) (Table 1). The remaining seven studies evaluated pulsed xenon UV devices using an uncontrolled before-after study design. Six of these studies used the Xenex device and one did not state the specific device or manufacturer used.

Six of the studies reported direct conflicts of interest with, or funding received from, the manufacturer of the device[38-42] or the manual cleaning agent.[43] Three of the studies had coauthors who were employed by the manufacturer.[38,40,42]

Setting, Target Rooms

All studies were conducted in hospitals within the United States. Four studies limited the use of the device and assessment of HAIs to specific units within the hospital (i.e., inpatient rooms of leukemia and lymphoma patients,[44] inpatient rooms and operating rooms of a burn centre,[39] operating rooms,[38] or acute care units),[41] while the remainder evaluated use of the device throughout all hospital units (Table 1).

Ultraviolet disinfection was primarily used after patient discharge or transfer in nine studies. One study used the device when rooms were vacated for procedures and when operating rooms were cleaned daily.[39] One study used the device exclusively for nightly disinfection of operating rooms (Table 1).[38]

Specific rooms targeted for UV disinfection within hospitals varied greatly across studies. Two studies used the device for all patient rooms[39,40]; two studies used the device for all ICU room discharges and transfers, and for non-ICU rooms only if patients had contact precautions[41,42;41,42]; three studies used the device primarily for rooms of patients with contact precautions, but also used the device for other rooms and areas as appropriate or available[35,36,45]; two studies used the device solely for rooms of patients with contact precautions (Table 1).[43,44]

Manual Cleaning and Disinfection Procedures

Various manual cleaning definitions were reported in each of the studies (Table 2). Only the RCT by Anderson et al[43] provided detailed information regarding the standardization of room disinfection strategies after patient discharge or transfer. Four studies did not specify the cleaning agents used for standard cleaning or disinfection of rooms.[38,39,41,42] Five studies specifically used bleach for cleaning of *C. difficile* in occupied rooms,[39,40,42-44] and one used an unspecified chlorine-based product.[45] Anderson et al[43] used quaternary ammonium for occupied rooms in which *C. difficile* had not been found. Nagaraja et al[33] and Haas et al[32] used bleach-based solutions for all rooms except for daily cleaning of rooms with pediatric patients.[35,36] Levin et al[45] used a pH7Q Ultra hospital-grade disinfectant.

Ultraviolet Disinfection Procedures

In addition to a standard manual cleaning arm (bleach for *C. difficile* discharge and quaternary ammonium for all discharges), the cluster RCT by Anderson et al[43] evaluated four enhanced cleaning study arms: UV alone, UV plus usual manual cleaning, bleach alone, and bleach plus UV. Given comparisons between the bleach alone and bleach plus UV disinfection arms were not adjusted, results for only the usual manual cleaning arm and the usual manual cleaning plus UV arm were included in our review.

Among the mercury UV-C studies, the length of time to run the device varied with the specific device being evaluated (average time range 8–55 minutes, Table 2). For the pulsed xenon UV studies, the device was generally run three times per patient room for between 5 and 12 minutes per run. For both studies using the xenon UV device in the operating room, the device was run twice for 10 minutes each time (Table 2).

Five studies reported on the actual use of the device, which ranged from 22% to 80% of eligible discharges (data not shown).[33,38,40-42]

Definitions of Hospital-Acquired Infection

The outcomes assessed by each study and the definitions used to classify HAIs are summarized in Appendix 3, Table A4. Three of the studies included either infection or colonization with the target organisms as their outcome definition,[39,41,43] although one study required that the organism had contributed to increased length of hospital stay.[41] Results from these studies were summarized in our results as HAIs, but differences in measured outcomes were noted where applicable. No studies reported on colonization with organisms separately from infection.

Four studies limited the assessment of HAIs to patients within the specific hospital units for which the UV device was used.[38,39,41,44] The cluster RCT by Anderson et al[43] evaluated outcomes only among patients who were exposed to a seed room (i.e., a room containing a patient with proven current or history of infection or colonization with one or more of the target organisms). The remainder of the studies evaluated hospital-wide HAI rates.

Patient Characteristics

Only Anderson et al[40] summarized characteristics of patients residing within rooms that were disinfected with UV-C after manual cleaning and disinfection. The study included a total of 21,395 patients exposed to seed rooms across four study arms. Overall, patient demographics and comorbidities were similar for all cleaning strategies.

Table 1: Study Designs Evaluating Use of UV-Disinfecting Devices Versus Usual Care

Author, Year	Hospital Type, Number of Beds	Study Design	Length of Follow-Up	UV Device, Manufacturer	Hospital Units Evaluated	Timing of Disinfection	Target Rooms
Anderson et al, 2017[43]	9 hospitals (tertiary, community, and Veterans Affairs), 148–950 beds	Cluster-randomized crossover trial	Overall: 2 y Each hospital used each strategy for 7 mo	Mercury UV-C, Tru-D	All	After discharge or transfer	Single-patient rooms from which patient with contact precautions is discharged or transferred
Pegues et al, 2017[44]	Tertiary care, 789	Interrupted time series	Before: 12 mo After: 15 mo	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 *C. difficile* Second priority for MRSA and VRE
Green et al, 2017[39]	Burn centre, 16 ICU beds	Uncontrolled, before-after	Before: 1 y, 3 mo After: 3 mo Post-intervention control: 3 mo	PXUV, Xenex	All burn centre units	After discharge or transfer Rooms vacated for procedure ORs, showers, ancillary areas daily	All patient rooms and ORs
Catalanotti et al, 2016[38]	Community, > 200	Uncontrolled, before-after	Before: 14 mo After: 20 mo	PXUV, Xenex	All surgical procedures	Nightly disinfection	All ORs (n = 13)
Vianna et al, 2016[42]	Community, 126 medical-surgical beds, 80 psych beds	Uncontrolled, before-after	Before: 10 mo After: 10 mo	PXUV, not stated	ICU, non-ICU, and whole facility	After discharge or transfer	All ICU discharges and transfers Non-ICU rooms for *C. difficile* discharges
Napolitano et al, 2015[41]	Community or medical centre, 420	Uncontrolled, before-after	Before: 5 mo After: 6 mo	Mercury UV-C, IRiS 3200m with SteriTrak	Acute care units	After discharge or transfer	All ICU rooms Non-ICU rooms with contact precaution
Miller et al, 2015[40]	Urban long-term acute care, NR	Uncontrolled, before-after	Before: 1 y After: 27 mo	PXUV, Xenex	All	After discharge or transfer Communal living areas weekly	All patient rooms after discharge
Nagaraja et al, 2015[36] and Haas et al, 2014[35a]	Tertiary care adult and pediatric, 643	Uncontrolled, before-after	Before: 1 y[36] and 30 mo[35] After: 1 y[36] and 22 mo[35]	PXUV, Xenex	All	After discharge or transfer OR at night, dialysis unit weekly	Primarily contact-precaution rooms All burn unit discharges, and sometimes long-stay patient discharges in units with high HAI prevalence
Levin et al, 2013[45]	Acute care community, 140	Uncontrolled, before-after	Before: 1 and 3 y After: 1 y	PXUV, Xenex	All	After discharge or transfer OR at night, ER in mornings, and other areas as appropriate	Prioritized by: discharge contact precaution rooms, ICU rooms, and other discharges

Abbreviations: ER, emergency room; HAI, hospital-acquired infection; ICU, intensive care unit; MRSA, methicillin-resistant *Staphylococcus aureus*; NR, not reported; OR, operating room; PXUV, pulsed xenon ultraviolet; UV, ultraviolet; VRE, vancomycin-resistant *Enterococcus.*

[a]Studies by Haas et al[35] and Nagaraja[36] et al used same hospital dataset for analysis.

Table 2: Disinfection Protocols for UV Disinfecting Devices and Manual Disinfection of Hospital Rooms

Author, Year	Number of Devices	UV Disinfection Protocol			Manual Cleaning Disinfectants	Other Infection Control Measures in Hospital
		Number of Cycles per Room (Location)	Length of Cycle (Minutes)	Additional Process Measures		
Mercury Bulb UV Devices						
Anderson et al, 2017[43]	1–4 per hospital	1 (centre, near bathroom)	Until sufficient dose is detected; 20 for median vegetative cycle and 55 for spore	Opened drawers and cabinets Staff training	*C. difficile*: hypochlorite (bleach) Other rooms: quaternary ammonium	Precautions for *C. difficile* Staff training for all protocols standardized Room monitoring with pH pens
Pegues et al, 2017[44]	1 (second added in follow-up)	3 (foot of bed and near bathroom)	8	Changed curtains UV metrics reported Staff training	Bleach	Hospital-wide *C. difficile* interventions 2 y prior
Napolitano et al, 2015[41]	NR	1 (NR)	Average 8 for vegetative and 19 for spore cycle	Room staged Dedicated technicians Data and job monitoring	NR	NR
Pulsed Xenon UV Devices						
Green et al, 2017[39]	NR	Patient room: 4 Shower/ancillary: 2 OR: 2	Patient room: 5 Shower/ancillary: 5 OR: 10	NR	Hospital-approved disinfectants (including bleach if *C. difficile*)	Routine infection control measures
Catalanotti et al, 2016[38]	2 used at same time	1 per device (close to surfaces)	10 per device	Dedicated housekeeper	NR, dedicated housekeeper only in intervention period	NR
Vianna et al, 2016[42]	NR	3 (each side of bed, bathroom)	5	Staff tracking of rooms	Standard cleaning (bleach for *C. difficile* isolation rooms)	Antimicrobial stewardship program initiated in pre-UV period
Miller et al, 2015[40]	NR	Unclear (multiple positions)	Unclear	NR	Sodium hypochlorite solution (bleach)	Contact precautions and hand hygiene Multidisciplinary *C. difficile* prevention team in both arms
Nagaraja et al, 2015[36] and Haas et al, 2014[35a]	2	3 (twice in room, once in bathroom)	Bathroom: 6 Single room: 12 Semi-private: 6	Drawers opened and items placed in path of light Device run in bathroom while cleaning room	Daily and discharge adults: bleach-based disinfectants Daily pediatric: quaternary ammonium compound Contact precautions and discharge pediatric: sodium hypochlorite	*C. difficile* initiative New EVS contractor Pre-period: mercury UV-C used in select ICU and burn units Post-period: cleaning monitored
Levin et al, 2013[45]	2	3 (twice in room, once in bathroom)	7	NR	Hospital-grade disinfectant (pH7Q Ultra) *C. difficile:* Chlorine product	Hand hygiene Contact precautions for *C. difficile* No new policies during UV year

Abbreviations: EVS, environmental services; ICU, intensive care unit; NR, not reported; OR, operating room; UV, ultraviolet.
[a]Studies by Haas et al[35] and Nagaraja et al[36] used same hospital dataset for analysis.

Clostridium Difficile *Infection Rate*

Nine studies reported on hospital-acquired *C. difficile* infection rates (three evaluated mercury UV-C devices and six evaluated pulsed xenon UV devices) (Table 3). Eight of the studies used a bleach product to manually disinfect rooms of patients discharged with *C. difficile*, and one did not specify the type of disinfectant used.

Overall baseline rates of hospital-acquired *C. difficile* ranged from 0.79 per 1,000 patient days to 3.16 per 1,000 patient days.

Mercury Ultraviolet C Devices

The RCT by Anderson et al[43] that used mercury UV-C devices found no difference in hospital-acquired *C. difficile* infection rates among patients exposed to seed rooms. The study compared disinfection with bleach plus UV-C versus disinfection with bleach alone (Table 3). We assessed the quality of this evidence as low (Table 4).

Two before-after studies reported a reduction in hospital-acquired *C. difficile* infection rates when compared with manual cleaning and disinfection alone (Table 3), although one of the studies was statistically underpowered (Table 4). We assessed the quality of this evidence as very low (Table 4).

Pulsed Xenon Ultraviolet Devices

Among the six studies evaluating the use of pulsed xenon UV devices (Table 3), two studies (Haas et al[35] and Nagaraja et al[36]) used the same hospital dataset with various follow-up periods and subgroups. Given Nagaraja et al[36] focused only on *C. difficile* rates and published most recently, only total results from this study were used in the GRADE quality of evidence assessment.

Overall, all point estimates showed a reduction in hospital-acquired *C. difficile* rates with the addition of pulsed xenon UV disinfection, although two studies were statistically underpowered. The quality of this body of evidence was assessed as very low (Table 4).

In subgroup analysis, Vianna et al[42] found a reduction in relative rates of *C. difficile* in both ICU and non-ICU settings. However, the reduction was statistically significant only when limited to the non-ICU setting (RR 0.60 [95% CI 0.41–0.89]; $P = .01$) and not the ICU setting alone (RR 0.50 [95% CI 0.19–1.57]; $P = .26$). Conversely Nagaraja et al found a statistically significant reduction only when limiting analysis to the ICU setting (RR 0.30 [95% CI 0.15–0.57]; $P < .001$), with no significant differences observed for non-ICU, oncology, or pediatric settings.

Table 3: Reduction in Hospital-Acquired *C. Difficile* Infection Rates for UV Disinfection Plus Manual Disinfection Versus Manual Disinfection Alone

Author, Year	Number of Cases/Number of Patient Days		Infection Rate/1,000 Days		Rate Ratio (95% CI)[a]
	Manual Disinfection	UV + Manual Disinfection	Manual Disinfection	UV + Manual Disinfection	
Mercury UV Devices					
Anderson et al, 2017[43]	36/11,385[b,c]	38/12,509[b,c]	3.16[b,c]	3.04[b,c]	1.0 (0.57–1.75); *P* = .997[d]
Pegues et al, 2017[44]	87/28,672	66/28,884	3.03	2.28	Adjusted: 0.49 (0.26–0.94); *P* = .03[e] Unadjusted: 0.75 (0.55–1.04)
Napolitano et al, 2015[41]	22/17,933[b]	12/18,184[b]	1.23[b]	0.66[b]	0.54 (0.27–1.09); *P* = .08
Pulsed Xenon UV Devices					
Green et al,2017 [39]	4/2,186[b,f]	0/653[b]	1.82[b,f]	0[b]	0.37 (0.02–6.89); *P* = .51
Vianna et al, 2016[42]	82/99,356	43/87,966	0.83	0.49	0.59 (0.41–0.86); *P* = .005
Miller et al, 2015[40]	23/11,917	22/26,506	1.93	0.83	0.43 (0.24–0.77); *P* = .005
Nagaraja et al, 2015[36]	148/139,677	110/132,574	1.06	0.83	0.78 (0.61–1.01); *P* = .06
Haas et al, 2014[35g]	390/494,382	228/350,000	0.79	0.65	0.83 (0.7–0.97); *P* = .02
Levin et al, 2013[45]	*1 y prior* 33/34,870 *3 y prior* 101/109,673	15/33,687	1 y prior 0.95 3 y prior 0.92	0.44	Vs. 1 y prior: 0.47 (0.26–0.86); *P* = .015 Vs. 3 y prior: 0.48 (0.28–0.83); *P* = .009

Abbreviations: *C. difficile, Clostridium difficile;* CI, confidence interval; GRADE, Grading of Recommendations Assessment, Development, and Evaluation; SD, standard deviation; OR, operating room; PXUV, pulsed xenon ultraviolet; UV, ultraviolet.

[a]Rate ratio, confidence intervals, and *P* values were otherwise calculated from the number of cases and patient days reported in study. When no events were observed in either pre- or post-group, 0.5 was added to each cell to calculate rate ratios.

[b]Cases include both hospital-associated colonization and infection.

[c]Denominator represents number of exposure days.

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

[e]Based on mixed-effects Poisson regression analysis.

[f]Manual disinfection rates calculated from combined 3-year and 1-year pre-periods and a 1-year post-period.

[g]Uses same data as Nagaraja et al[36] with a longer pre- and post-study follow-up period. Data from this study not included in GRADE quality of evidence assessment.

Table 4: GRADE Evidence Profile for Hospital-Acquired *C. Difficile* Infection Rate

Number of Studies (Design)	Risk of Bias	Inconsistency	Indirectness	Imprecision	Publication Bias	Upgrade Considerations	Quality
Comparison of Mercury UV Devices Plus Standard Disinfection Vs. Standard Disinfection Alone							
1 (RCT)	Serious limitations (−1)[a]	No serious limitations	Serious limitations[b]	Serious limitations (−1)[c]	Undetected	None	⊕⊕ Low
2 (observational)	Very serious limitations (−2)[d]	No serious limitations	No serious limitations[e]	No serious limitations	Undetected	None	⊕ Very Low
Comparison of Pulsed Xenon UV Devices Plus Standard Disinfection Vs. Standard Disinfection Alone							
5 (observational)	Very serious limitations (−2)[f]	Serious limitations (−1)[g]	No serious limitations[h]	No serious limitations[i]	Undetected	None	⊕ Very Low

Abbreviations: *C. difficile, Clostridium difficile;* GRADE, Grading of Recommendations Assessment, Development, and Evaluation; RCT, randomized controlled trial; UV, ultraviolet

[a]See Appendix 2, Table A1, for risk-of-bias assessment.

[b]Included study assessed both incident colonization and infection as outcome measure, rather than infection rate alone. But this was already penalized as misclassification of outcome in the risk-of-bias domain.

[c]Study was powered for combination of outcomes and not *C. difficile* alone. Estimate of effect ranges from clinically meaningful reduction to clinically meaningful increase in *C. difficile* infection rates.

[d]See Appendix 2, Table A2, for risk-of-bias assessment.

[e]Both included studies were reflective of the research question, although one study included both colonizations and infections contributing to increased length of stay in outcome assessment while the other study evaluated only infections. We judge evidence as having no serious indirectness but note variability in outcome definitions, use of manual disinfectants (one study did not specify disinfectant used), and hospital units evaluated (one study focused on inpatient units of leukemia and lymphoma patients, the other study on all acute care units).

[f]See Appendix 2, Tables A2 and A3, for risk-of-bias assessment.

[g]Direction and magnitude of effect varied across studies, with three studies showing large reduction in infection rates and two studies finding no effect.

[h]One of five studies evaluated both colonization and infection with *C. difficile* whereas the other four studies specifically evaluated infection rates. We judge evidence as having no serious indirectness but note variability in hospital settings and patients evaluated as well as measures.

[i]Largest study found no difference between groups. The other three large studies had long patient follow-up period; none of the studies documented no effect. Only smallest study had confidence intervals that included no effect as well as large benefits and harms. Overall, we judged evidence as having borderline imprecision and did not rate down quality of evidence.

Combined Hospital-Acquired Infection Rate

Five studies reported on HAI rates for a combined number of pathogens (Table 5). All studies included *C. difficile* and MRSA in their estimates, and four of the five studies included VRE. Other pathogens included in the assessment of the combined HAIs varied across studies.

Baseline combined HAI rates ranged from 1.51 per 1,000 person-years to 9.15 per 1,000 person-years.

Mercury Ultraviolet C Devices

The cluster randomized trial by Anderson et al[43] showed that mercury UV-C disinfection as an adjunct to manual cleaning and disinfection led to a 30% relative rate reduction in the incidence rate of infection plus colonization with one or more of the combined organisms among patients exposed to seed rooms when compared with standard cleaning and disinfection alone. The quality of the body of evidence was assessed as low (Table 6).

A single uncontrolled before-after study[41] showed a 34% relative rate reduction in the combined HAIs during the follow-up period with the addition of UV disinfection. The quality of this body of evidence was assessed as very low (Table 5).

Pulsed Xenon Utraviolet Devices

Three studies[35,39,42] found conflicting results on the effect of pulsed xenon UV disinfection on the combined HAIs (Table 6). Green et al[39] evaluated both infection and incident colonizations in a burn centre with high baseline HAI rates and found no significant difference in the combined HAI rates after the device was added to manual cleaning and disinfection. This study[39] had large imprecision in its estimate, likely owing to the small number of total patient exposure days. Two studies, however, found a relative rate reduction in the combined HAI rates ranging from 20% to 29% when compared with manual disinfection alone.[35,42] The study by Vianna et al[42] found a 61% reduction in intensive care (baseline HAI rate 6.77/1,000 patient years; rate ratio [RR] 0.39 [95% confidence interval (CI) 0.19–0.79; *P* = .009]), with a 22% relative rate reduction observed when limited to HAIs outside intensive care (baseline HAI rate 1.26/1,000 patient years; RR 0.78 [95% CI 0.59–1.04; *P* = .09]). The quality of the body of evidence for the combined HAI rates for pulsed xenon UV devices was assessed as very low (Table 6).

Table 5: Reduction in Combined Hospital-Acquired Infection Rates for UV Disinfection Plus Manual Disinfection Versus Manual Disinfection Alone

Author, Year	Organisms Included	Number of Cases/Number of Patient Days		Infection Rate (per 1,000 Days)		Rate Ratio (95% CI)[a]
		Manual Disinfection	UV + Manual Disinfection	Manual Disinfection	UV + Manual Disinfection	
Mercury UV Devices						
Anderson et al, 2017[43]	*Clostridium difficile*, MRSA, VRE, MDR *Acinetobacter*	115/22,426[b,c]	76/22,389[b,c]	5.13[b,c]	3.39[b,c]	0.70 (0.50–0.98); *P* = .036[d]
Napolitano et al, 2015[41]	*C. difficile*, MRSA, VRE, *Acinetobacter baumannii*, *Klebsiella pneumoniae*	66/17,933[b]	44/18,184[b]	3.7[b]	2.4[b]	0.66 (0.45–0.96); *P* = .03
Pulsed Xenon UV Devices						
Green et al, 2017[39]	*C. difficile*, MRSA, ESBL *Enterobacteriaceae*, MDR *Pseudomonas aeruginosa, Stenotrophomonas maltophilia*	20/2,186[b,e]	7/653[b]	9.15[b,e]	10.72[b]	1.17 (0.50–2.76); *P* = .72
Vianna et al, 2016[42]	*C. difficile*, MRSA, VRE	150/99,356	94/87,966	1.51	1.07	0.71 (0.55–0.91); *P* = .01
Haas et al, 2014[35]	*C. difficile,* MRSA, VRE, MDR gram-negative bacteria	1,320/494,382	749/350,000	2.67	2.14	0.80 (0.73–0.88); *P* < .001

Abbreviations: CI, confidence interval; ESBL, extended-spectrum β-lactamase; MDR, multidrug resistant; MRSA, methicillin-resistant *Staphyloccocus aureus*; VRE, vancomycin-resistant *Enterococcus*, UV, ultraviolet.

[a]As reported in article, otherwise rate ratio, confidence intervals, and *P* values were calculated from number of cases and patient days reported in study.

[b]Cases include both hospital-acquired colonization and infection.

[c]Denominator represents number of exposure days.

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

[e]Calculated from combined 3-year and 1-year pre-periods and a 1-year post period.

Table 6: GRADE Evidence Profile for Combined Hospital-Acquired Infection Rate

Number of Studies (Design)	Risk of Bias	Inconsistency	Indirectness	Imprecision	Publication Bias	Upgrade Considerations	Quality
Comparison of Mercury UV-C Devices Plus Standard Disinfection and Standard Disinfection Alone							
1 (RCT)	Very serious limitations (−2)[a]	No serious limitations	Serious limitations[b]	No serious limitations	Undetected	None	⊕⊕ Low
1 (observational)	Very serious limitations (−2)[c]	No serious limitations	No serious limitations[b]	No serious limitations	Undetected	None	⊕ Very Low
Comparison of Pulsed Xenon UV Devices Plus Standard Disinfection and Standard Disinfection Alone							
3 (observational)	Very serious limitations (−2)[d]	No serious limitations[e]	No serious limitations (−1)[f]	No serious limitations[g]	Undetected	None	⊕ Very Low

Abbreviations: GRADE, Grading of Recommendations Assessment, Development, and Evaluation; HAI, hospital-acquired infection; RCT, randomized controlled trial; UV, ultraviolet.

[a]See Appendix 2, Table A1, for risk-of-bias assessment.

[b]Included study assessed both incident colonization and infection as outcome measure, rather than infection rate alone. But this was already penalized as misclassification of outcome in the Risk of Bias domain.

[c]See Appendix 2, Table A1, for risk-of-bias assessment.

[d]See Appendix 2, Table A2, for risk-of-bias assessment.

[e]Direction and magnitude of effect was similar for two of three studies, whereas third study by Green et al[39] found a non–statistically significant increase in HAI rates. Given study by Green et al was likely under-powered and had overlapping confidence intervals with the other two studies, we did not downgrade for inconsistency.

[f]One of the three studies evaluated both colonization and infection with target organisms, whereas the other two specifically evaluated infection rates; we judge the evidence as having no serious indirectness but note variability in hospital settings and patients evaluated as well as outcome measures (variation in target organisms included and in definition of infection).

[g]Largest two studies reported large reductions in HAIs, with confidence intervals excluding no effect. Smallest study found nonsignificant results and included both clinically meaningful benefits and harms. We judged evidence to have borderline imprecision.

Methicillin-Resistant Streptococcus aureus *Infection Rate*

Five studies reported on hospital-acquired MRSA infection rates (two evaluated mercury UV-C devices and three evaluated pulsed xenon UV devices) (Table 7). Overall baseline rates of hospital-acquired MRSA infection ranged from 0.34 per 1,000 patient days to 5.03 per 1,000 patient days.

Mercury Ultraviolet C Devices

Among studies evaluating mercury UV-C devices, the RCT by Anderson et al[43] found a non–statistically significant relative reduction in hospital-acquired MRSA colonization or infection rates based on low quality of evidence (Table 8). Results from this study did find a statistically significant relative rate reduction of 33% in a separate per-protocol analysis (RR 0.67 [95% CI 0.48–0.94; *P* = .019]).

Based on very low quality of evidence, one uncontrolled before-after study found no difference in the relative rate of hospital-acquired MRSA with the use of UV-C disinfection when compared with manual cleaning and disinfection alone (Table 7).

Pulsed Xenon Ultraviolet Devices

Inconsistent results were observed among the three studies evaluating the use of pulsed xenon UV devices for prevention of MRSA infection. The point estimates for the two studies were in favour of standard manual cleaning over the addition of pulsed xenon UV disinfection, but the studies were statistically underpowered. In contrast, one study found a statistically significant relative rate reduction of 27% for pulsed xenon UV disinfection when compared with standard disinfection alone. The quality of evidence for this body of evidence was assessed as very low (Table 8).

Table 7: Reduction in Hospital-Acquired MRSA Infection Rates for UV Disinfection Plus Manual Disinfection Versus Manual Disinfection Alone

Author, Year	Number of Cases/Number of Patient Days		Infection Rate/1,000 days		Rate Ratio (95% CI)[a]
	Manual Disinfection	UV + Manual Disinfection	Manual Disinfection	UV + Manual Disinfection	
Mercury UV Devices					
Anderson et al, 2017[43]	73/14,524[b,c]	54/14,780[b,c]	5.03[b,c]	3.65[b,c]	0.78 (0.58–1.05); *P* = .10[d]
Napolitano et al, 2015[41]	7/17,933	7/18,184	0.39	0.38	0.99 (0.35–2.8); *P* = .98[b]
Pulsed Xenon UV Devices					
Green et al, 2017[39]	8/2,186[b,e]	3/653[b]	4.6[b,e]	3.7[b]	1.26 (0.34–4.75); *P* = .75
Vianna et al, 2016[42]	34/99,356	36/87,966	0.34	0.41	1.20 (0.75–1.91); *P* = .45
Haas et al, 2014[35]	224/494,382	116/350,000	0.45	0.33	0.73 (0.58–0.92); *P* = .007

Abbreviations: CI, confidence interval; OR, operating room; MRSA, methicillin-resistant *Staphylococcus aureus*; UV, ultraviolet.
[a]Rate ratio, confidence intervals, and *P* values were otherwise calculated from number of cases and patient days reported in study.
[b]Cases include both hospital-acquired colonization and infection.
[c]Denominator represents number of exposure days.
[d]Based on intention-to-treat analysis.
[e]Manual disinfection rates were calculated from combined 3-year and 1-year pre-periods and a 1-year post-period.

Table 8: GRADE Evidence Profile for Hospital-Acquired MRSA Infection Rate

Number of Studies (Design)	Risk of Bias	Inconsistency	Indirectness	Imprecision	Publication Bias	Upgrade Considerations	Quality
Comparison of Mercury UV-C Devices Plus Standard Disinfection Vs. Standard Disinfection Alone							
1 (RCT)	Serious limitations (−1)[a]	No serious limitations	Serious limitations (−1)[b]	No serious limitations[c]	Undetected	None	⊕⊕ Low
1 (observational)	Very serious limitations (−2)[d]	No serious limitations	No serious limitations[b]	Serious limitations (−1)[e]	Undetected	None	⊕ Very Low
Comparison of Pulsed Xenon UV Devices Plus Standard Disinfection Vs. Standard Disinfection Alone							
3 (observational)	Very serious limitations (−2)[d]	Serious limitations (−1)	No serious limitations[g]	Serious limitations (−1)[h]	Undetected	None	⊕ Very Low

Abbreviations: GRADE, Grading of Recommendations Assessment, Development, and Evaluation; MRSA, methicillin-resistant *Staphylococcus aureus*; RCT, randomized controlled trial; UV, ultraviolet.

[a]See Appendix 2, Table A1, for risk-of-bias assessment.

[b]Included study assessed both incident colonization and infection as outcome measure, rather than infection rate alone.

[c]Study was powered for combination of outcomes and not MRSA alone. Estimate of effect ranges from clinically meaningful reduction to clinically meaningful increase in MRSA infection rates.

[d]See Appendix 2, Table A2, for risk-of-bias assessment.

[e] Effect estimate had wide confidence intervals ranging from large reduction in MRSA rates to large increase in MRSA rates.

[f]Direction and magnitude of effect varied greatly across 3 studies.

[g]One included study assessed both incident colonization and infection as outcome measure, rather than infection rate alone. We judge evidence as having no serious indirectness but note variability in hospital settings and patients was evaluated as well in outcome measures.

[h]Largest study found significant reduction in MRSA rates while the other two studies found no significant difference in rates of MRSA between group: confidence intervals included both a large benefit and harm with the intervention.

Vancomycin-Resistant Enterococcus *Infection or Colonization Rate*

Four studies reported on hospital-acquired VRE infection rates (two evaluated mercury UV-C devices and two pulsed xenon UV devices) (Table 9). Of the two studies evaluating mercury UV-C devices, one reported the composite outcome of colonization and infection.[43] Overall baseline rates of hospital-acquired VRE ranged from 0.34 per 1,000 patient days to 6.34 per 1,000 patient days.

Mercury Ultraviolet C Devices

The RCT by Anderson et al[43] did not find a relative reduction in combined hospital-acquired VRE infection and colonization rates among patients exposed to seed rooms that were disinfected with mercury UV-C devices compared with standard manual disinfection alone—although the results were statistically underpowered (Table 9). This body of evidence was assessed as low quality (Table 10).

Based on very low quality of evidence, one uncontrolled before-after study found a small but non–statistically significant reduction in hospital-acquired VRE rates with the use of UV-C disinfection when compared with manual cleaning and disinfection alone (Table 10).

Pulsed Xenon Ultraviolet Devices

Both studies evaluating the use of pulsed xenon UV devices were adequately powered but had several other limitations. Both studies found a relative rate reduction in hospital-acquired VRE rates when the UV device was added to manual cleaning and disinfection (18%–50% reduction in relative rate) (Table 9). The GRADE for this body of evidence was assessed as very low (Table 10).

Table 9: Reduction in Hospital-Acquired VRE Infection Rates for UV Disinfection Plus Manual Disinfection Versus Manual Disinfection Alone

Author, Year	Number of Cases/Number of Patient Days		Infection Rate/1,000 Days		Rate Ratio (95% CI)[a]
	Manual Disinfection	UV+Manual Disinfection	Manual Disinfection	UV+Manual Disinfection	
Mercury UV devices					
Anderson et al, 2017[43]	37/5,838[b,c]	17/5,780[b,c]	6.34[b,c]	2.94[b,c]	0.41 (0.15–1.13); *P* = .08[d]
Napolitano et al, 2015[41]	18/17,933	16/18,184	1.0	0.88	0.88 (0.45–1.71); *P* = .70[b]
Pulsed Xenon UV Devices					
Vianna et al, 2016[42]	34/99,356	15/87,966	0.34	0.17	0.50 (0.27–0.91); *P* = .02[e]
Haas et al, 2014[35]	443/494,382	257/350,000	0.90	0.73	0.82 (0.70–0.95); *P* = .002

Abbreviations: CI, confidence interval; OR, operating room; UV, ultraviolet; VRE, vancomycin-resistant *Enterococcus.*

[a]Rate ratio, confidence intervals, and *P* values were calculated from number of cases and patient days reported in study.

[b]Cases include both hospital-acquired colonization and infection.

[c]Denominator represents number of exposure days.

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

[e]Rate ratio and confidence intervals calculated from rate data provided in article. Note that study found no statistically significant reduction between groups (*P* = .07) based on the Wilcoxon rank sum test.

Table 10: GRADE Evidence Profile for Hospital-Acquired VRE Infection Rate

Number of Studies (Design)	Risk of Bias	Inconsistency	Indirectness	Imprecision	Publication Bias	Upgrade Considerations	Quality
Comparison of Mercury UV-C Devices Plus Standard Disinfection Vs. Standard Disinfection Alone							
1 (RCT)	Serious limitations (−1)[a]	No serious limitations	No serious limitations[b]	Serious limitations (−1)[c]	Undetected	None	⨁⨁ Low
1 (observational)	Very serious limitations (−2)[d]	No serious limitations	No serious limitations[b]	Serious limitations (−1)[e]	Undetected	None	⨁ Very Low
Comparison of Pulsed Xenon UV Devices Plus Standard Disinfection Vs. Standard Disinfection Alone							
2 (observational)	Very serious limitations (−2)[d]	Serious limitations (−1)[f]	No serious limitations[g]	Serious limitations[h]	Undetected	None	⨁ Very Low

Abbreviations: GRADE, Grading of Recommendations Assessment, Development, and Evaluation; RCT, randomized controlled trial; UV, ultraviolet; VRE, vancomycin-resistant *Enterococcus.*

[a]See Appendix 2, Table A1, for risk-of-bias assessment.

[b]Included study assessed both incident colonization and infection as outcome measure, rather than infection rate alone. This was not considered to be a serious source of indirectness.

[c]Study was powered for combination of outcomes and not VRE alone. Estimate of effect ranges from very large reduction to increase in methicillin-resistant *Staphylococcus aureus* infection rates.

[d]See Appendix 2, Table A2, for risk-of-bias assessment.

[e]Study had wide confidence intervals, ranging from large reduction in VRE rates to large increase in VRE rates.

[f]Magnitude of effect varied greatly between studies, with minimal overlap in confidence intervals.

[g]We judge evidence as having no serious indirectness but note variability in hospital settings and patients was evaluated as well as in outcome measures.

[h]Confidence intervals did not cross no effect; however, confidence intervals were wide in both studies, likely owing to insufficient sample size.

Other Hospital-Acquired Infection Rates

Five studies reported on an additional 11 HAIs (Table 15). Only one study reported on each individual outcome.

Mercury Ultraviolet C Devices

The RCT by Anderson et al[43] found no cases of multidrug-resistant *Acinetobacter* infection or colonization among patients exposed to seed rooms with or without the use of UV disinfection.

The study by Napolitano et al[41] found reductions in the relative rates of hospital-acquired *Acinetobacter baumanni* or *Klebsiella pneumoniae* after the use of mercury UV disinfection versus a pre-period without UV disinfection, but the study was not adequately powered.

Pulsed Xenon Ultraviolet Devices

One study evaluated the effect of pulsed xenon UV disinfection in the operating room on surgical site infections.[38] This study found a relative rate reduction in Class I surgical site infections (RR 0.55, 95% CI 0.33–0.92), but the evaluation on Class II surgical site infections was unreliable owing to imprecise point estimates. The quality of evidence was rated as very low.

Haas et al[35] found a 19% relative reduction in the rate of multidrug-resistant gram-negative bacteria. Although adequately powered, this study had very serious limitations related to risk of bias (Appendix 2, Table A2).

The study by Green et al[39] was severely underpowered; point estimates had confidence interval that were too wide (Table 11).

Table 11: Reduction in Other Hospital-Acquired Infection Rates for UV Disinfection Plus Manual Disinfection Versus Manual Disinfection Alone

Author, Year	Organism	Number of Cases/Number of Patient Days		Infection Rate/1,000 Days		Risk Ratio (95% CI)[a]
		Manual Disinfection	UV + Manual Disinfection	Manual Disinfection	UV + Manual Disinfection	
Mercury UV Devices						
Anderson et al, 2017[43]	Multidrug-resistant *Acinetobacter*	0/156[b]	0/199[b,c]	0	0	Not applicable (can't be calculated)
Napolitano et al, 2015[41]	*Acinetobacter baumannii*	7/17,933	2/18,184	0.39	0.11	0.28 (0.06–1.36); *P* = .11
	Klebsiella pneumoniae	8/17,933	0/18,184	0.44	0	0.06 (0.003–1.00); *P* = .05
Pulsed Xenon UV Devices						
Catalanotti et al, 2016[38]	SSI Class I	31/6,439[d]	29/10,883[d]	0.048	0.026	0.55 (0.33–0.92); *P* = .02
	SSI Class II	13/4,811[d]	26/7,825[d]	0.026	0.33	1.23 (0.63–2.39) *P* = .054
Green et al, 2017[39]	ESBL	2/2,186[e]	1/653[e]	0.91	1.5	1.67 (0.15–18.43); *P* = .67
	MDR *Pseudomonas aeruginosa*	2/2,186[e]	0/653[e]	0.91	0	0.67 (0.03–13.91); *P* = .79
	Stenotrophomonas maltophilia	4/2,186[e]	3/653[e]	1.83	3	2.51 (0.56–11.19); *P* = .23
	CLABSI	10/1,899[e]	1/542[e]	5.3	1.84	0.35 (0.04–2.73); *P* = .31
	CAUTI	9/1,956[e]	1/558[e]	4.6	1.79	0.39 (0.05–3.07); *P* = .37
	VAP	4/1,466[e]	3/381	2.7[e]	7.87	2.89 (0.65–12.84); *P* = .16
Haas et al, 2014[35]	MDR gram-negative bacteria	260/500,000	148/352,381	0.52	0.42	0.81 (0.66–0.98); *P* = .04

Abbreviations: CI, confidence interval; CLABSI, central line–associated bloodstream infection; CAUTI, catheter-associated urinary tract infection; ESBL, extended-spectrum β-lactamase; MDR, multidrug resistant; SSI, surgical site infection; UV, ultraviolet; VAP, ventilator-associated pneumonia.
[a]Rate ratio, confidence intervals, and *P* values were calculated from the number of cases and patient days reported in study. When no events were observed in either pre- or post-group, 0.5 was added to each cell to calculate rate ratios.
[b]Number of incident infection or colonization cases per number of exposure days.
[c]Based on intention-to-treat analysis.
[d]Number of infections per number of procedures.
[e]Number of infections per number of device days.

Hospital-Acquired Infection Mortality Rates

Mercury Ultraviolet C Devices

No studies evaluating the use of mercury UV disinfection devices reported on HAI mortality rates.

Pulsed Xenon Ultraviolet Devices

Only the study by Levin et al[45] commented on deaths attributable to *C. difficile*, but there were too few deaths to allow for meaningful interpretation. The GRADE for this body of evidence was assessed as very low (Table 12).

Table 12: GRADE Evidence Profile for Hospital-Acquired *C. Difficile* Infection–Related Mortality Rate, Comparison of Pulsed Xenon UV Devices Plus Standard Disinfection Versus Standard Disinfection Alone

Number of Studies (Design)	Risk of Bias	Inconsistency	Indirectness	Imprecision	Publication Bias	Upgrade Considerations	Quality
1 (observational)	Very serious limitations (−2)[a]	No serious limitations	No serious limitations	Serious limitations (−1)[b]	Undetected	None	⊕ Very Low

Abbreviations: GRADE, Grading of Recommendations Assessment, Development, and Evaluation; UV, ultraviolet.
[a]See Appendix 2, Table A2, for risk-of-bias assessment.
[b]Study did not meet optimal information size, with confidence intervals that spanned both a large clinical benefit and harm.

Discussion

Summary of Findings and Clinical Relevance

We are uncertain about the effectiveness of portable ultraviolet light disinfection devices when combined with standard hospital room cleaning because of low to very low quality of evidence. The highest quality of evidence came from the only cluster RCT evaluating the use of a mercury UV-C device for disinfection of rooms after patients with contact precautions were discharged or transferred. This study found UV disinfection to be effective at reducing the combined rate of HAI and colonization for multiple organisms (GRADE: low), but did not find a relative rate reduction on *C. difficile* infections and colonization (GRADE: low). While the point estimates for relative rates on VRE and MRSA favoured UV room disinfection plus manual cleaning and disinfection, we are uncertain about these estimates because they are imprecise (GRADE: low).

Clinical relevance of this study is limited for several reasons. First, the authors combined both infection and colonization with target organisms as their outcome measure. It was noted that 54% of all outcomes reported were infection, but no data stratified by infection alone could be obtained. Combining both infection and colonization likely improved statistical power, but it remains uncertain whether impact on HAIs alone would be clinically relevant. Because only a small proportion of *C. difficile* or multidrug-resistant organism colonizations lead to eventual infection,[46-49] the clinical impact on outcomes such as morbidity, mortality, and excess length of stay are more difficult to ascertain. Second, the study evaluated infections only among patients admitted to rooms previously occupied by patients with infection or colonization with one or more target organisms. While providing valuable information on the spread of organisms to subsequent patients admitted to the target room, the effect of room disinfection after patient discharge or transfer on hospital-wide infections through other forms of indirect contact was not reported. Study authors stated that secondary analyses evaluating incidence of hospital-wide target organisms will be presented elsewhere; however, these data are currently unpublished.

Similarly, several before-after studies found pulsed xenon UV disinfection devices reduced total combined HAIs, with inconsistent effects on *C. difficile*, MRSA, and VRE rates. The quality of the body of evidence for each outcome assessed from these studies was very low; we therefore have considerable uncertainty about these study results. One limitation is the difficulty of controlling for important confounding variables that could differ between the pre- and post-intervention periods, including the severity of illness among patients admitted, quality of medical care received, other infection control practices employed (e.g., hand-hygiene compliance), and antibiotic prescribing practices. Additionally, manual cleaning and disinfection techniques were often not described. Finally, because study investigators were not blinded to the study treatments used, we cannot know if standard cleaning and disinfection practices and protocols were enhanced when UV disinfection device protocols were implemented within the hospital.

Generalizability of Results to Ontario

Several factors need to be considered before generalizing results from this systematic review to Ontario.

The studies included in this review were all performed in the United States and focused primarily on high-risk settings. Rates of baseline HAI for each of the organisms evaluated were considerably different from averages in Ontario and Canadian hospitals.[4,8] It is therefore uncertain if the magnitude of effect found within the studies would be observed in Ontario.

Similarly, it is difficult to ascertain if manual cleaning and disinfection practices within the included studies reflect Ontario best practices. Beyond stating the type of disinfectant used, most studies provided limited information on the methods used for, and compliance with, environmental cleaning practices.

Comparison With Other Reports and Systematic Reviews

A 2014 Canadian Agency for Drugs and Technologies in Health (CADTH) rapid response[50] identified no high-quality systematic reviews or RCTs that evaluated the clinical effectiveness and safety of UV light decontamination in health care. Similarly, the Agency for Healthcare Research and Quality (AHRQ) developed a technical brief on environmental cleaning for prevention of health care–associated infections in 2015.[22] While the authors made no direct conclusions on UV-disinfecting devices, they noted that comparative-effectiveness studies directly comparing modalities were limited.

Results from this review are in line with prior guidelines set by the National Health Service[49] and the Centers for Disease Control and Prevention, [48] which stated that the effectiveness of these devices is yet to be demonstrated and that more research is required.[51,52] We note, however, that each of these reviews and guidelines are now outdated; 8 of the 10 studies identified in our review were published in or after 2015.

Limitations

The methods used within our review and the availability of evidence have several limitations. In addition to the limitations noted above for individual studies, we were unable to combine data from the various studies given the substantial clinical and methodologic heterogeneity between studies. The studies varied largely in the settings evaluated, including the type of hospital (e.g., tertiary care, community hospitals, long-term acute care), the types of hospital units (e.g., ICU, burn centre, units of leukemia and lymphoma patients), and the types of rooms that were targeted (all rooms, operating rooms, rooms of patients with contact precautions). Additionally, the type of manufacturer, the timing of disinfection, and the protocols used for both UV and manual disinfection varied between studies.

Another limitation is that all studies evaluated the effectiveness of UV disinfection devices in addition to standard cleaning, but they did not describe in detail how standard cleaning was done. For example, it would have been more informative to assess “Is doing standard cleaning twice as good as, better than, or not as good as using a UV device?"

Given these limitations, substantial uncertainty about the most effective and appropriate use of these UV surface-disinfection devices remains.

Potential Ontario Implementation Considerations

Beyond the generalizability of results related to variations in hospital infection rates and manual cleaning and disinfection methods, several implementation considerations will affect the effectiveness of UV surface-disinfecting devices within Ontario hospitals.

Most studies included in our review focused on hospitals or units with single-patient rooms. In Ontario, however, most hospital rooms are multibed rooms shared by two or more patients. The need to vacate rooms to use the device could limit use within many Ontario hospitals. The Xenex pulsed xenon UV disinfection device allows for isolation of bed spaces within multibed rooms with the use of UV black-out curtains; however, an Ontario study found that hanging the

curtains was not feasible and was time-consuming.[53] Clinical experts have also suggested that curtains might not be a reasonable or acceptable option because patients in the shared space must remain isolated and informed during the period of UV disinfection.

Many of the included studies looked at feasibility of deployment and reported actual use of the device ranging from 22% to 80% of all eligible discharges.[36,41,43-45] In addition to multipatient rooms, reasons cited for not using the device included few devices, communication or notification failures, or urgent need for the room.

Last, it is unclear from this review how many devices would be needed per hospital to achieve the expected reductions in HAIs, and how adding UV disinfection would affect overall room cleaning and turnover times.

Ongoing Studies

Review of the grey literature identified one ongoing study that has potential relevance to this review/research question. The study is titled “Ultra Violet-C Light Evaluation as an Adjunct to Removing Multi-Drug Resistant Organisms (UVCLEAR-MDRO)” and registered in ClinicalTrials.gov. The estimated completion date is March 2018.

Conclusions

Mercury Ultraviolet C Room Disinfection

In comparison with standard manual cleaning and disinfection protocols alone, we found the addition of mercury UV-C room disinfection to result in:

- No reduction in *C. difficile* infection relative rate (low quality of evidence from one cluster RCT)
- Statistically significant reduction in the combined HAI and colonization relative rate (low quality of evidence from one cluster RCT)
- Non–statistically significant reduction in individual hospital-acquired MRSA or VRE infection and colonization relative rates (low quality of evidence from one cluster RCT)
- Statistically significant reduction (one study) or a non–statistically significant reduction (one study) in *C. difficile* infection relative rates (very low quality of evidence from two observational studies)
- Statistically significant reduction in the total combined HAI and colonization relative rate (very low quality of evidence from one observational study)
- No reduction in MRSA (one study) or non–statistically significant reduction in VRE (one study) relative rates (very low quality of evidence from two observational studies)

Pulsed Xenon Ultraviolet Room Disinfection

Based on very low quality of evidence from observational studies, pulsed xenon UV surface disinfection (when used as an adjunct to standard manual cleaning and disinfection) was associated with:

- Statistically significant reduction (three studies) or non–statistically significant reduction (two studies) in *C. difficile* infection rates
- Statistically significant reduction in total combined HAI relative rates in most large studies (two studies)

- Statistically significant reduction (one study) or a non–statistically significant increase (two studies) in MRSA infection rates
- Statistically significant reduction in VRE infection rate (two studies)
- Nonsignificant reduction in hospital-acquired *C. difficile* mortality rate (one study)

ECONOMIC EVIDENCE

Research Question

What is the published economic evidence for portable ultraviolet (UV) light irradiation as an adjunct to standard environmental cleaning compared with environmental cleaning alone for hospital room surface disinfection?

Methods

Literature Search

We performed an economic literature search on January 24, 2017, for studies published from inception to the search date. To retrieve relevant studies, the search was developed using the clinical search strategy with an economic filter applied.

Database auto-alerts were created in MEDLINE, Embase, and the Cumulative Index to Nursing & Allied Health Literature (CINAHL) and were monitored for the duration of the health technology assessment. We performed targeted grey literature searching of sites for health technology assessment agencies, clinical trial registries, and Tufts Cost-Effectiveness Analysis Registry. See Clinical Evidence, Literature Search, above for further details on methods used, and Appendix 1 for literature search strategies, including all search terms.

Literature Screening

A single reviewer reviewed titles and abstracts and, for those studies likely meeting the inclusion criteria, we obtained full-text articles.

Inclusion Criteria

- English-language full-text publications
- Studies reporting on hospital-associated infections (HAIs)
- Studies reporting on portable UV disinfecting devices as an adjunct to standard hospital cleaning
- Cost-utility, cost-effectiveness, or cost-benefit analyses

Exclusion Criteria

- Narrative reviews, letters or editorials, abstracts, posters, unpublished studies

Outcomes of Interest

- Incremental cost-effectiveness ratio, incremental costs, and incremental effectiveness.

Data Extraction

We extracted relevant data on the following:

- source (i.e., name, location, year)
- population and comparator
- interventions
- outcomes (i.e., health outcomes, costs, and cost effectiveness)

Study Applicability and Methodologic Quality

We determined the usefulness of each identified study for decision-making by applying a modified applicability checklist for economic evaluations that was originally developed by the National Institute for Health and Care Excellence (NICE) in the United Kingdom. The original checklist is used to inform development of clinical guidelines by NICE.[54] We retained questions from the NICE checklist related to study applicability and modified the wording of the questions to remove references to guidelines and to make questions Ontario specific. The number of studies judged to be directly applicable, partially applicable, or inapplicable to the research question are summarized.

Results

Literature Search

The literature search yielded 152 citations published from inception to January 24, 2017, after removing duplicates. We excluded a total of 128 articles on the basis of information in the title and abstract. We then obtained the full text of 24 potentially relevant articles for further assessment. We did not find any studies that met the inclusion criteria. Figure 2: PRISMA Flow Diagram—Economic Search Strategy presents the flow diagram for the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA).

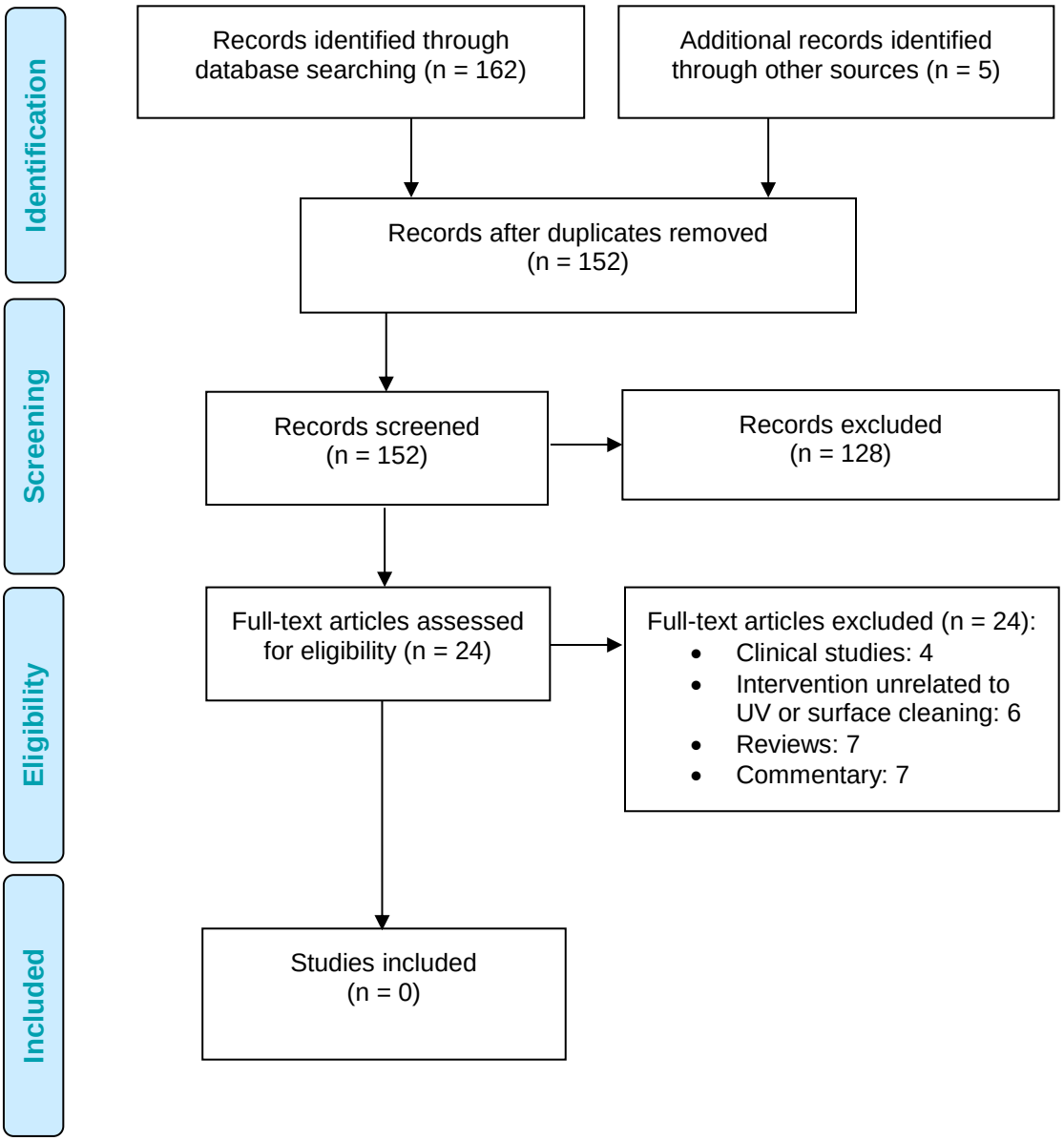

Figure 2: PRISMA Flow Diagram—Economic Search Strategy

Source: Adapted from Moher et al.[37]
Abbreviation: UV, ultraviolet.

Discussion

Our literature search did not identify any economic evaluations of UV disinfecting devices as a cleaning method in hospitals. Further research into the cost-effectiveness of UV disinfecting devices is needed.

Several observational studies reported using UV disinfecting devices could lead to cost savings by reducing the number of infections. Fornwalt et al[55] estimated $290,990 in potential savings from prevention of seven surgical site infections and one death during a 12-month period, at $20,785 per infection. Miller et al[40] stated that $300,000 would be saved by avoiding 29 *Clostridium difficile* infections during a 15-month period, at $13,500 per case. Catalanotti et al[38]

estimated $478,055 would be saved by preventing 23 potential Class I surgical site infections and one death during a 21-month period, at $20,785 per infection. However, these estimates are very crude and do not take into account the cost of acquiring and operating UV disinfecting devices.

Conclusions

We did not find any published cost-effectiveness studies of UV disinfecting devices for cleaning in hospitals.

PRIMARY ECONOMIC EVALUATION

We did not conduct a primary economic evaluation for ultraviolet (UV) disinfecting devices because the clinical evidence available did not provide precise enough estimates for the economic evaluation to be informative.

The observational studies found in the clinical evidence review are considered very low quality evidence and therefore could not be used for an economic evaluation. Also, clinical experts suggested results of observational studies might not be generalizable to Ontario. Most of the studies were in high-incidence settings, and it is unclear whether the reduction in infection would apply in lower-incidence settings like Ontario.

Anderson et al[43] conducted the first randomized controlled trial (RCT) to evaluate the effect of enhanced room disinfection after patient discharge or transfer on HAIs from multidrug-resistant organisms. The researchers compared three enhanced strategies (UV plus quaternary ammonium, UV plus bleach, and bleach alone) with quaternary ammonium. Several characteristics of this study limit the data's usefulness for an economic evaluation:

- The RCT examined the effect of UV disinfection on incidence rates only among patients in "seed" rooms (rooms previously occupied by patients with colonization or infection) and reported the findings as cases per 10,000 exposure days. The data available in Ontario are limited to cases per patient days or number of admissions, but not per exposure day; thus, using these findings for an economic model proved to be impossible.
- The RCT reported the combined reduction in infection and colonization, but did not report the reduction in infection or colonization separately. Given colonization and infection have very different costs and outcomes, results reported by the RCT could not be used without making a variety of assumptions.
- Reduction of individual incidence rates of *C. difficile*, MRSA, and VRE was not statistically significant when UV was added. However, when all infections were pooled, reduction of incidence rate when UV disinfection was used was statistically significant. See the Clinical Evidence section for more details.

BUDGET IMPACT ANALYSIS

We conducted a budget impact analysis from the perspective of an Ontario hospital to estimate the cost of using portable ultraviolet (UV) disinfecting devices as an adjunct to standard environmental cleaning (i.e., manual cleaning). All costs were reported in 2017 Canadian dollars (CAD).

Objectives

The objective of this study was to estimate the 5-year budget impact of using portable UV disinfecting devices as an adjunct to standard environmental cleaning from an Ontario hospital perspective.

Methods

The budget impact is estimated as the cost difference between two scenarios: the reference scenario (without UV disinfecting devices) and the new scenario (with UV disinfecting devices). Because UV disinfecting devices are used as an adjunct to standard cleaning, cost of standard cleaning would remain the same. Therefore, the budget impact is just the additional cost of purchasing and operating the UV devices.

Target Setting

The target setting for UV disinfecting devices is hospitals. Devices might be used in several places, including contact precaution rooms after patients are discharged, intensive care units (ICUs), other medical/surgical wards, and operating rooms where HAIs are more likely to occur.

Perspective

We conducted the analysis from an Ontario hospital perspective.

Resource Use and Costs

This analysis included costs of the UV device, warranty, maintenance, and staff time required to operate the devices (Table 13). We did not include costs related to any potential reduction of HAIs, given our uncertainty about the effectiveness of UV. Cost inputs were obtained from standard Ontario sources, published literature, and the manufacturers.

Ultraviolet Device Cost

We obtained the costs of UV disinfecting devices from the manufacturers. Obtaining the costs of all commercially available UV disinfecting devices is beyond the scope of the project; we therefore contacted only two leading manufacturers[57] (one for xenon devices and one for mercury bulb devices) to obtain cost details. Costs were provided in US dollars (USD). We converted costs into CAD using an exchange rate of 1.325.[58] We applied a 5% federal tax for purchasing medical devices and services through a hospital in Canada. A mercury bulb device costs $124,517 CAD ($89,500 USD, including a 1-year warranty) and a xenon bulb device costs $142,325 CAD ($102,300 USD, including a 4-year warranty) (email communications from the manufacturers, Sept 1, 2017, and Sept 14, 2017). The annual warranty ranges between $11,500 to $13,356, which covers the costs of bulb replacement, device parts, and technical support. For the mercury bulb device, there is also a leasing option at a cost of $53,424 per year ($38,400 USD).

For the base case, we assumed that two devices would be purchased by a hospital. This is consistent with most observational studies in the United States.[38,45,56] According to the manufacturer, a hospital usually purchases one to two devices initially to test in some areas of the hospital (e.g., isolation ward, operating rooms), and sometimes purchases more later if staff decide to use UV disinfection for the entire hospital. Therefore, we tested a range of one to seven devices per hospital in sensitivity analysis.

Table 13: Cost Inputs

Parameter	Value (2017 CAD)	Source
Purchasing cost of device	Mercury: $124,517 Xenon: $142,325	Manufacturers (price converted from USD to CAD using an exchange rate of 1.325[58] included federal tax of 5%)
Annual warranty/maintenance cost	Mercury: $13,356 Xenon: $11,500	
Annual leasing cost	Mercury: $53,424 Xenon: unavailable	
Hourly cost of hospital environmental service worker	$28.60	Humber River Hospital Careers Center[59] (included 30% employee benefit)
Annual cost of UV device operator (for sensitivity analysis)	$60,000	Assuming full-time hourly wage (52 weeks per year, 40 hours per week) + 30% employee benefit

Abbreviations: CAD, Canadian dollars; USD, United States dollars; UV, ultraviolet.

Labour Cost

We estimated the labour cost of operating UV devices by multiplying the time required from a hospital staff member by the hourly cost of labour (Table 14). The cost of labour includes wages paid to employees, as well as the cost of employee benefits and payroll taxes paid by an employer. The cost of a hospital environmental service (EVS) worker is estimated to be $28.60 per hour ($22 for the hourly wage[59] plus 30% employee benefits[60]).

For each use, we estimated that a minimum of 20 minutes would be required to move the UV device into a room for disinfection, set up the room (e.g., staging the furniture and clinical equipment within the space to receive maximum UV exposure; placing the UV device at the optimal location; placing safety signs and a motion sensor at the entrance), and activate the machine (Table 14).

- For the base case, we assumed that any trained EVS worker can use the device.
- In sensitivity analysis, we assumed that a dedicated UV device user/operator would be needed, as this was the experience of some Canadian hospitals. According to Spencer et al[61] at Vancouver General Hospital, where UV devices were pilot tested, EVS workers would manually clean a room and enter the completed job into a computer, which would generate a call to the dedicated UV device operator. This system not only allows EVS workers to continue with the next job, but also enables the UV operator who understands the overall cleaning needs of the hospital to prioritize areas with the most opportunity to improve their HAI rates. This system could be especially helpful when multiple areas in a hospital need to be cleaned with UV devices at the same time.

The time required for UV devices to run depends on the complexity of the room (e.g., large vs. small, difficult shapes, patient room vs. operating room), type of cleaning needed (e.g., spore

vs. bacteria, or *C. difficile* vs. MRSA/VRE) and type of UV device (mercury vs. xenon) (Table 14).

- With a mercury bulb device, 15 to 25 minutes is required for a vegetative cycle (e.g., for MRSA and VRE), 20 to 40 minutes for a spore cycle (e.g., for *C. difficile*), 60 to 75 minutes for an operating room (personal communication, March 30, 2017). We assumed that an EVS worker can clean other areas while the UV device is running, because the disinfection process requires only a single cycle/placement and the time interval is sufficiently long.
- With a xenon bulb device, a total of 18 minutes is required per room (three 5-minute cycles at different locations plus 2–3 minutes for positioning for patient rooms[42,62]; or two 8- or 10-minute cycles for operating rooms[38,55]). Because the device requires multiple cycles/positions, an operator needs to stay nearby and move the device to a new location every 5 minutes. In the base case, we assumed that an EVS worker can perform other tasks (e.g., clean the bathroom) during this 5-minute interval. For sensitivity analysis, we assumed that 5 minutes is too short to allow staff to perform other duties.

Other costs, such as training for cleaning personnel to use the UV devices (approximately 2 hours of staff time), are minimal and therefore were not included.

Table 14: Time and Per-Room Cost of Various Post-Discharge or Transfer Cleaning Strategies

Variable	Isolation Room (*Clostridium difficile*)	Isolation Room (MRSA/VRE)	Operating Room
Time required per room (minutes)			
Staff to move and set up device and room	20[a]	20[a]	20[a]
UV device to disinfect room			
• Xenon	18[b]	18[b]	16–20[b]
• Mercury	20–40[c]	15–25[c]	60–75[c]
Total additional time			
• Xenon	38	38	36–40
• Mercury	40–60	35–45	80–95
Additional labor cost per room			
Base case (20 minutes for both xenon and mercury)[d]	$9.53 (20 minutes x $28.60/hour)		
Sensitivity analysis (more time needed for xenon)[e]	$18.11(38 minutes x $28.60/hour)		

Abbreviations: *C. difficile, Clostridium difficile*; MRSA, methicillin-resistant *Staphylococcus aureus;* UV, ultraviolet; VRE, vancomycin-resistant *Enterococcus*.
[a]We assumed total 20 minutes would be needed to move UV device to room for disinfection and set it up.
[b]Xenon bulb UV: for patient rooms, 18 minutes is required (three 5-minute cycles at three locations within the room; 1 minute for operator to move device); for operating rooms, 16–20 minutes is required (two 8- or 10-minute cycles).
[c]Mercury bulb UV: for patient rooms, 15–25 minutes for bacteria and 20–40 minutes for spores; 60–75 minutes for operating rooms.
[d]For base case, we assumed that operator can perform other tasks while UV device is running.
[e]For sensitivity analysis, we assumed that operator needs to stay nearby to move xenon bulb device.

Frequency of Use

Given the literature, clinical expert opinion, and manufacturer input, UV disinfecting devices are primarily used for the following applications:

- Cleaning patient rooms after discharge or transfer, particularly those occupied by patients who were on contact precaution (isolation units), and patients in ICUs or surgical wards where HAIs are more likely to occur
- Nighttime disinfection of operating rooms, endoscopy suites, equipment supply rooms, and other high-use rooms that are typically vacant at night

Ultraviolet devices are used for post-discharge or transfer cleaning rather than daily cleaning because the room must be empty of patients and staff during UV treatment. For the same reason, it is challenging to use UV devices to clean multibed rooms (vacated by one patient but still occupied by others), which are common in Canadian hospitals. Although some manufacturers provide rolling screens or blackout curtains to block the UV light and create isolation, it is very time-consuming to set them up (according to clinical experts with experience using UV devices). It is also inconvenient for patients on the other side of the room (e.g., they could need to receive care or go to the bathroom while the room is being treated with UV).

For these reasons, the number of rooms that can be cleaned with UV per day depends on 1) the number of isolation room discharges or transfers per day, 2) the number of private (single-bed) rooms in the hospital, and 3) the availability of staff during nights. Given staff limitations, some hospitals might be unable to use UV devices during nights. Therefore, we estimated the frequency of use on the basis of published literature,[38,40-42,56] clinical expert opinion (email communication, March 18, 2017), and manufacturer input (personal communication, March 3, 2017; email communication, March 29, 2017). We estimated that, with full implementation and training, a UV device can be used for about eight patient rooms daily during the day. In sensitivity analysis, we assumed that, in addition to daytime, a device could also be used about six times nightly for operating rooms, equipment rooms, and so forth. The additional staff time needed is calculated below:

- **Base case (daytime only):** 973 h/device yearly = 8 rooms/device daily x 365 d/y x 20 min/room = 0.47 full-time employee (assuming 52 wk/y and 40 h/wk)
- **Sensitivity analysis (both daytime and nighttime):** 1,703 h/device yearly = (8 + 6) rooms/device daily x 365 d/y x 20 min/room = 0.82 full-time employee (assuming 52 wk/y and 40 h/wk)

Analysis

To fully understand how budget impact varies with different assumptions about parameters, we conducted several sensitivity analyses:

- Number of devices needed varied from one to seven
- Cost of the UV device varied by ± 20%
- Leasing the UV devices (vs. buying in the base case)
- A dedicated UV operator (vs. any EVS worker in the base case)
- Frequency of use during daytime varied by ± 50% (4–16 rooms/device daily)
- Nighttime usage (hospital has staff available to run the UV devices both daytime and nighttime vs. daytime only in the base case): six times/device nightly
- Staff time required per use varied by ± 50%
- Operator cannot perform other tasks while xenon UV device is running (vs. operator can perform other tasks in the base case)

Main Assumptions

- Cost savings related to any potential reduction of HAIs were not included, given our uncertainty about the effectiveness of UV disinfection
- Costs of training staff to use UV devices are minimal and therefore not included
- With proper maintenance, a UV device can last more than 5 years

Expert Consultation

Throughout development of this analysis, we solicited advice from clinicians with expertise in HAI prevention and control or in using UV disinfecting devices in a hospital. The role of expert advisors was to review the structure and inputs of the economic analysis to confirm that the information we used reasonably reflects the clinical setting.

Results

Base Case

The base case results of our analysis are presented in Table 15. If a hospital decided to purchase two UV disinfecting devices, the 5-year budget impact was estimated to be $586,023 for xenon bulb devices and $634,255 for mercury bulb devices. About 53% to 56% of the total 5-year budget impact was associated with the cost of the device and warranty, and the remaining costs were associated with increased staff time for operating the devices. If a hospital decided to buy the devices, the first year's cost would be more substantial than subsequent years.

Table 15: Base Case Results of Budget Impact Analysis

Type of Cost (in 2017 CAD)	Year 1	Year 2	Year 3	Year 4	Year 5	Total (5 Years)
Mercury bulb device						
UV device cost	249,034	0	0	0	0	249,034
Maintenance/warranty cost	0	26,712	26,712	26,712	26,712	106,848
Staff/operating cost	55,675	55,675	55,675	55,675	55,675	278,373
Total budget impact	**304,708**	**82,387**	**82,387**	**82,387**	**82,387**	**634,255**
Xenon bulb device						
UV device cost	284,650	0	0	0	0	284,650
Maintenance/warranty cost	0	0	0	0	23,000	23,000
Staff/operating cost	55,675	55,675	55,675	55,675	55,675	278,373
Total budget impact	**340,324**	**55,675**	**55,675**	**55,675**	**78,675**	**586,023**

Abbreviations: CAD, Canadian dollars; UV, ultraviolet.

Sensitivity Analysis

Results of the sensitivity analyses are presented in the Tornado diagram (Figure 3: Tornado Diagram Evaluating Influence of Key Parameters on Net Budget Impact). The net budget impact was most sensitive to the number of devices purchased by the hospital, frequency of use during daytime, and staff time required per use. Four factors had a moderate impact on the results: assumption regarding nighttime usage of the UV devices, leasing the devices instead of buying (mercury bulb device only), assumption regarding whether staff can perform other tasks during the UV cycle (xenon bulb device only), and cost of the UV device. Results were not sensitive to assumptions regarding who operates the UV devices (any EVS worker vs. a dedicated operator).

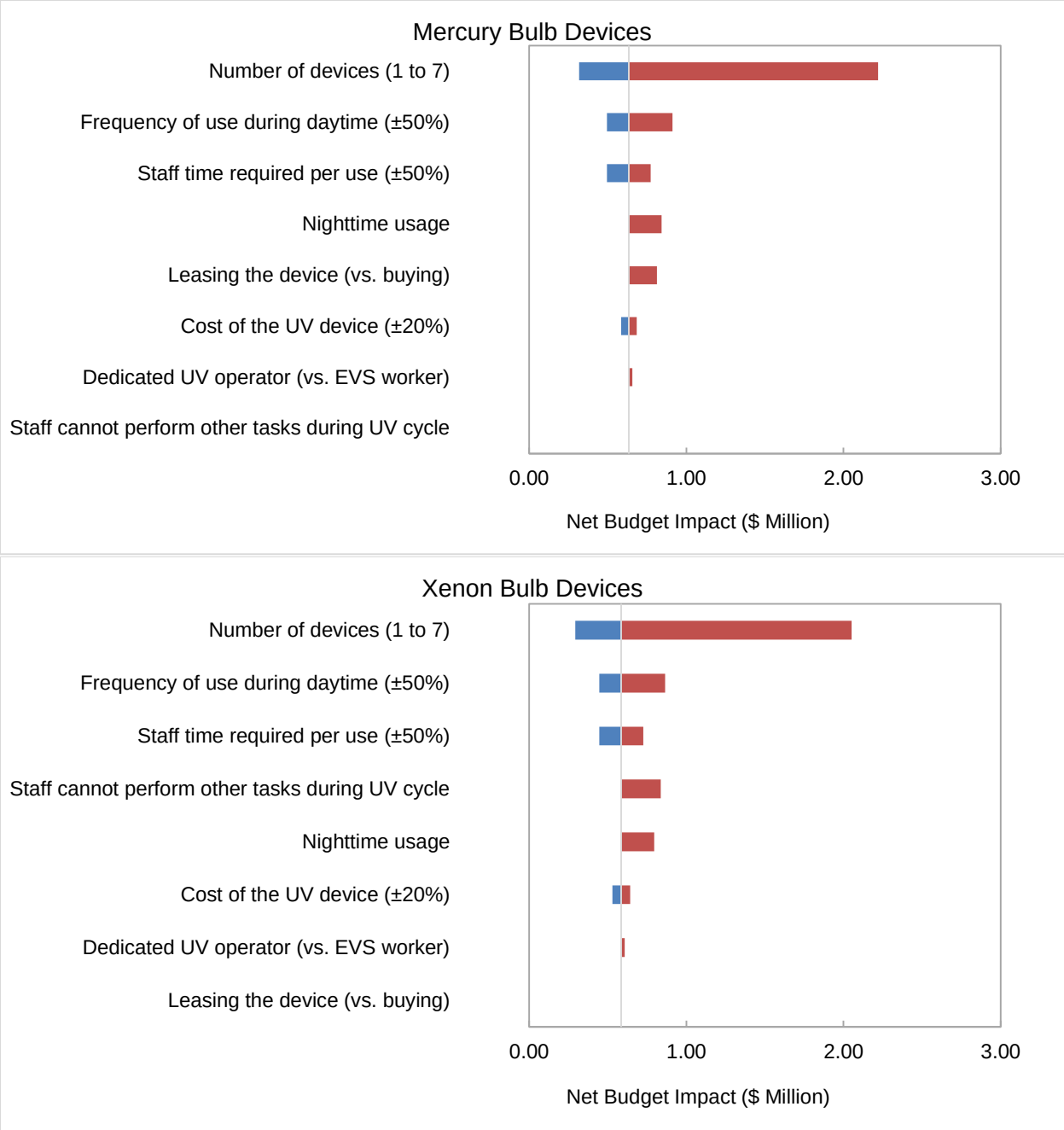

Figure 3: Tornado Diagram Evaluating Influence of Key Parameters on Net Budget Impact

Abbreviations: EVS, environmental services; UV, ultraviolet.

Discussion

Our analysis showed that adopting UV disinfecting devices would lead to a budget impact between $586,023 (pulsed xenon) and $634,255 (mercury) over 5 years if a hospital purchases two devices. A few clinical studies reported that using UV devices could lead to cost savings from reduced HAIs. However, none of these studies have taken into account the cost of acquiring and operating UV devices. If a hospital is to adopt UV disinfecting devices, administrators must consider how many devices to acquire and whether to purchase or lease,

as the up-front capital investment of purchasing UV devices can be substantial. Besides capital costs, our analysis also showed that using UV disinfecting devices as an adjunct to standard environmental cleaning would increase the workload of hospital EVS staff and could require the hospital to hire additional staff.

The main limitation of the analysis is our inability to estimate potential cost savings from reduced HAIs, owing to uncertainty about the clinical effectiveness of UV disinfecting devices. If UV disinfecting devices do substantially reduce HAIs, they might save hospitals money. We also did not estimate costs related to increased room turnaround time or any change in patient satisfaction before and after using UV.

Conclusion

The 5-year budget impact was estimated to be $586,023 and $634,255 in Ontario hospitals (assuming two UV devices were purchased). First-year cost was the highest because of purchasing the devices ($304,708 or $340,324). Cost in subsequent years was generated by maintenance and operation of the devices (between $55,675 and $82,387 annually). Budget impact results were sensitive to the number of devices purchased by the hospital, frequency of use during daytime, and staff time required per use.

PUBLIC AND PATIENT ENGAGEMENT

Background

Public and patient engagement explores the lived experience of a person with a health condition, including how the condition and its treatment affects the patient, the patient's family or other caregivers, and the patient's personal environment. Public and patient engagement is intended to increase awareness and build appreciation for the needs, priorities, and preferences of the person at the centre of a treatment program. Insights gained through public and patient engagement provide an in-depth picture of lived experience, through an intimate look at the values that underpin the experience.

Lived experience is a unique source of evidence about the personal impact of a health condition and how that condition is managed, including what it is like to navigate the health care system with that condition, and how technologies might or might not make a difference in people's lives. Information shared from lived experience can also identify gaps or limitations in published research (for example, outcome measures that do not reflect what is important to those with lived experience).[63-65] Additionally, lived experience can provide information or perspectives on the ethical and social value implications of technologies and treatments. Because the needs, priorities, preferences, and values of those with lived experience in Ontario are not often adequately explored by published literature, Health Quality Ontario makes an effort to reach out to, and directly speak with, people who live with the health condition, including those who have experience with the intervention in question.

Ultraviolet Disinfecting Device

For this health technology assessment, the value of pursuing patient and public engagement was determined through a needs assessment by the Public, Patient, and Caregiver Engagement team at Health Quality Ontario. The purpose of this needs assessment is threefold:

- Determine if developing a lived-experience evidence stream would be of value in the evidence-based analysis phase of the health technology assessment
- Define the goals and objective of engagement
- Scope out the type of engagement activity that would be optimal for the project

To complete the needs assessment, background reading into the topic of UV disinfection included reading the clinical review plan and consulting clinical experts in the field. A qualitative literature scan was also conducted.

The needs assessment concluded that patient engagement for this health technology assessment would be of minimal benefit and impact. A few main points were considered:

Patient Preferences and Values in Decision-Making

For a health technology assessment, patient engagement can often illuminate context surrounding patient preferences for that technology and how patients make decisions surrounding its use. However, for UV disinfecting devices, the influence of patient preference on the method of choice for disinfection was negligible. Patients in acute care settings rarely are given an opportunity to express a preference for how a room is disinfected. The process is defined by the health and safety policy in the health care facility. The choice between UV disinfection and standard disinfection would most likely not be within a patient's control.

Therefore, the effect any preferences would have on decision-making would be uncertain at best.

Patient Outcomes

A key component of health technology assessment is the clinical review, which carefully analyzes all clinical outcomes. Patient engagement can often provide context for which patient outcomes are most important and relevant to a patient population. In this health technology assessment, however, patient-relevant outcomes were expected to match outcomes deemed important by clinicians with a high degree of correlation. For this particular health technology assessment, it was thought that patients were most likely to desire a successfully disinfected room, to prevent the spread of hospital infections. We believe this desire would closely align with the outcome desired by clinicians and administrators implementing UV disinfection.

Equity

Because there is uncertainty in the clinical benefit of this technology, there is unlikely to be an equity issue concerning this technology.

Conclusion

After careful consideration of these factors within the needs assessment, the patient engagement team concluded that that direct patient engagement would provide minimal value to and impact on this health technology assessment.

CONCLUSIONS OF THIS HEALTH TECHNOLOGY ASSESSMENT

On the basis of very low to low quality of evidence, we are uncertain whether the use of portable ultraviolet light (UV) disinfecting devices as an adjunct to standard hospital cleaning and disinfection further reduces hospital-acquired infections.

The 5-year budget impact for using pulsed xenon UV devices was slightly lower than mercury-based technology if we assume that two devices would be purchased per hospital. However, this comparison is sensitive to the number of devices purchased per hospital, daytime frequency of use, and staff time required per use.

ABBREVIATIONS

CAD	Canadian dollars
CI	Confidence interval
CINAHL	Cumulative Index to Nursing & Allied Health Literature
CPE	Carbapenemase-producing *Enterobacteriaceae*
EVS	Environmental services
GRADE	Grading of Recommendations Assessment, Development, and Evaluation
HAI	Hospital-acquired infection
ICU	Intensive care unit
MRSA	Methicillin-resistant *Staphylococcus aureus*
NICE	National Institute for Health and Care Excellence
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-analyses
RCT	Randomized controlled trial
RR	Rate ratio
USD	US dollars
UV	Ultraviolet
VRE	Vancomycin-resistant *Enterococcus*

APPENDICES

Appendix 1: Literature Search Strategies

Clinical Evidence Search

Search date: Jan 23, 2017

Database: EBM Reviews - Cochrane Central Register of Controlled Trials <November 2016>, EBM Reviews - Cochrane Database of Systematic Reviews <2005 to January 18, 2017>, EBM Reviews - Database of Abstracts of Reviews of Effects <1st Quarter 2015>, EBM Reviews - Health Technology Assessment <4th Quarter 2016>, EBM Reviews - NHS Economic Evaluation Database <1st Quarter 2015>, Embase <1980 to 2017 Week 04>, Epub Ahead of Print, In-Process & Other Non-Indexed Citations, Ovid MEDLINE(R) Daily and Ovid MEDLINE(R) <1946 to Present>

Search Strategy:

---

1 Cross Infection/ (76047)
2 (((Health care* or healthcare*) adj2 (acquired or associated) adj2 (infection* or disease* or pathogen*1)) or (cross adj2 (infection* or disease* or pathogen*1)) or HAI or HAIs or HCAI or HCAIs or nosocomial*).ti,ab,kf. (89022)
3 Clostridium difficile/ (19903)
4 Clostridium Infections/ (7298)
5 (clostridium difficile or c difficile or c diff or clostridium infection* or CDI or CDIs).ti,ab,kf. (36217)
6 exp Staphylococcus aureus/ (209499)
7 (staphylococcus aureus or MRSA or MRSAs).ti,ab,kf. (203864)
8 Vancomycin-Resistant Enterococci/ (2991)
9 (vancomycin resistant enterococc* or VRE or VREs).ti,ab,kf. (10743)
10 Surgical Wound Infection/ (50090)
11 ((postoperative wound* or post-operative wound* or surgical site or surgical wound*) adj2 infect*).ti,ab,kf. (24846)
12 exp Drug Resistance, Bacterial/ (217653)
13 (((multidrug or multi-drug or antibiotic* or antimicrobial) adj (resistance or resistant)) or MDRO or MDROs or ARO or AROs).ti,ab,kf. (188047)
14 exp Health Facilities/ (2510992)
15 (((health or healthcare or care or medical) adj2 (facility or facilities or center* or centre* or setting* or institution*1)) or hospital*1 or ((healthcare or health care) adj environment*1) or (room*1 adj2 (patient* or private or semi-private or semiprivate or recovery or isolation)) or ward or wards or ((intensive or critical) adj2 unit*) or ICU or ICUs or acute care).ti,ab,kf. (2972848)
16 or/1-15 (4809416)
17 Ultraviolet Rays/ (160863)
18 (ultraviolet or ultra-violet or uv or uvc or uv-c).ti,ab,kf. (376269)
19 Xenon/ (12327)
20 xenon.ti,ab,kf. (14758)
21 Mercury/ (67269)
22 mercury.ti,ab,kf. (74381)
23 or/17-22 (538279)
24 Infection Control/ (103445)

25 (infection adj (control or prevention)).ti,ab,kf. (46649)
26 Disinfection/ (36681)
27 (cleaning or decontamin* or disinfect* or dis-infect* or terminal or no-touch or non-manual or germicid* or bactericid* or fungicid* or virucid* or bacteriostat*).ti,ab,kf. (1041655)
28 or/24-27 (1169839)
29 23 and 28 (20038)
30 (((ultraviolet or ultra-violet or xenon or mercury or uv or uvc or uv-c) adj3 (irradia* or pulse* or emitting or lamp* or bulb* or system* or device* or robot*1)) or uvgi or px-uv or pxuv).ti,ab,kf. (66816)
31 29 or 30 (82468)
32 16 and 31 (3306)
33 exp Animals/ not Humans/ (16218867)
34 32 not 33 (2533)
35 Case Reports/ or Comment.pt. or Editorial.pt. or Letter.pt. or Congresses.pt. (5047217)
36 34 not 35 (2494)
37 limit 36 to english language [Limit not valid in CDSR,DARE; records were retained] (2202)
38 37 use ppez,coch,cctr,dare,clhta,cleed (1081)
39 hospital infection/ (96843)
40 (((Health care* or healthcare*) adj2 (acquired or associated) adj2 (infection* or disease* or pathogen*1)) or (cross adj2 (infection* or disease* or pathogen*1)) or HAI or HAIs or HCAI or HCAIs or nosocomial*).tw,kw. (91671)
41 peptoclostridium difficile/ (2807)
42 Clostridium difficile infection/ (10218)
43 (clostridium difficile or c difficile or c diff or clostridium infection* or CDI or CDIs).tw,kw. (36580)
44 exp Staphylococcus aureus/ (209499)
45 (staphylococcus aureus or MRSA or MRSAs).tw,kw. (205503)
46 vancomycin resistant enterococcus/ (4907)
47 (vancomycin resistant enterococc* or VRE or VREs).tw,kw. (10963)
48 surgical infection/ (35154)
49 ((postoperative wound* or post-operative wound* or surgical site or surgical wound*) adj2 infect*).tw,kw. (25272)
50 antibiotic resistance/ (199129)
51 (((multidrug or multi-drug or antibiotic* or antimicrobial) adj (resistance or resistant)) or MDRO or MDROs or ARO or AROs).tw,kw. (192950)
52 exp health care facility/ (1747030)
53 (((health or healthcare or care or medical) adj2 (facility or facilities or center* or centre* or setting* or institution*1)) or hospital*1 or ((healthcare or health care) adj environment*1) or (room*1 adj2 (patient* or private or semi-private or semiprivate or recovery or isolation)) or ward or wards or ((intensive or critical) adj2 unit*) or ICU or ICUs or acute care).tw,kw. (2988778)
54 or/39-53 (4403522)
55 exp ultraviolet radiation/ (108700)
56 (ultraviolet or ultra-violet or uv or uvc or uv-c).tw,kw,dv. (377881)
57 xenon/ (12327)
58 xenon.tw,kw,dv. (14981)
59 mercury/ (67269)
60 mercury.tw,kw,dv. (74979)
61 or/55-60 (524207)
62 infection control/ (103445)
63 (infection adj (control or prevention)).tw,kw,dv. (48371)
64 disinfection/ (36681)

65 (cleaning or decontamin* or disinfect* or dis-infect* or terminal or no-touch or non-manual or germicid* or bactericid* or fungicid* or virucid* or bacteriostat*).tw,kw,dv. (1046993)
66 or/62-65 (1175405)
67 61 and 66 (19759)
68 disinfection system/ (176)
69 (((ultraviolet or ultra-violet or xenon or mercury or uv or uvc or uv-c) adj3 (irradia* or pulse* or emitting or lamp* or bulb* or system* or device* or robot*1)) or uvgi or px-uv or pxuv).tw,kw,dv. (67193)
70 or/67-69 (82636)
71 54 and 70 (3421)
72 (exp animal/ or nonhuman/) not exp human/ (10585289)
73 71 not 72 (2749)
74 Case Report/ or Comment/ or Editorial/ or Letter/ or conference abstract.pt. (9318850)
75 73 not 74 (2416)
76 limit 75 to english language [Limit not valid in CDSR,DARE; records were retained] (2132)
77 76 use emez (1037)
78 38 or 77 (2118)
79 78 use ppez (1041)
80 78 use emez (1037)
81 78 use coch (0)
82 78 use cctr (38)
83 78 use clhta (2)
84 78 use cleed (0)
85 78 use dare (0)
86 remove duplicates from 78 (1454)

CINAHL EBSCOhost interface

#	Query	Results
S1	(MH "Cross Infection")	20,655
S2	(((Health care* or healthcare*) N2 (acquired or associated) N2 (infection* or disease* or pathogen*1)) or (cross N2 (infection* or disease* or pathogen*)) or HAI or HAIs or HCAI or HCAIs or nosocomial*)	24,470
S3	(MH "Clostridium Difficile")	2,190
S4	(MH "Clostridium Infections")	2,718
S5	(clostridium difficile or c difficile or c diff or clostridium infection* or CDI or CDIs)	4,787
S6	(MH "Staphylococcus Aureus+")	8,102
S7	(staphylococcus aureus or MRSA or MRSAs)	13,286
S8	(MH "Vancomycin Resistant Enterococci")	105
S9	(vancomycin resistant enterococc* or VRE or VREs)	1,165
S10	(MH "Surgical Wound Infection")	7,149
S11	((postoperative wound* or post-operative wound* or surgical site or surgical wound*) N2 infect*)	8,392
S12	(MH "Drug Resistance, Microbial+")	18,909
S13	(((multidrug or multi-drug or antibiotic* or antimicrobial) N1 (resistance or resistant)) or MDRO or MDROs or ARO or AROs)	9,512

S14	(MH "Health Facilities+")	332,145
S15	(((health or healthcare or care or medical) N2 (facility or facilities or center* or centre* or setting* or institution or institutions)) or hospital or hospitals or ((healthcare or health care) N1 environment*) or (room* N2 (patient* or private or semi-private or semiprivate or recovery or isolation)) or ward or wards or ((intensive or critical) N2 unit*) or ICU or ICUs or acute care)	489,002
S16	S1 OR S2 OR S3 OR S4 OR S5 OR S6 OR S7 OR S8 OR S9 OR S10 OR S11 OR S12 OR S13 OR S14 OR S15	635,744
S17	(MH "Ultraviolet Rays")	2,785
S18	(ultraviolet or ultra-violet or uv or uvc or uv-c)	4,990
S19	xenon	537
S20	(MH "Mercury")	1,628
S21	mercury	2,833
S22	S17 OR S18 OR S19 OR S20 OR S21	8,321
S23	(MH "Infection Control")	21,378
S24	(infection N1 (control or prevention))	64,862
S25	(MH "Sterilization and Disinfection")	8,216
S26	(cleaning or decontamin* or disinfect* or dis-infect* or terminal or no-touch or non-manual or germicid* or bactericid* or fungicid* or virucid* or bacteriostat*)	40,434
S27	S23 OR S24 OR S25 OR S26	100,691
S28	S22 AND S27	503
S29	(((ultraviolet or ultra-violet or xenon or mercury or uv or uvc or uv-c) N3 (irradia* or pulse* or emitting or lamp* or bulb* or system* or device or robot or robots)) or uvgi or px-uv or pxuv)	594
S30	S28 OR S29	938
S31	S16 AND S30	317
S32	(MH "Animals+") OR (MH "Rodents+")	123,561
S33	S31 not S32	309
S34	PT Case Study or Commentary or Editorial or Letter or Proceedings	388,985
S35	S33 not S34	303
S36	S35 Narrow by Language: - English	294

Economic Evidence Search

Search date: Jan 24, 2017

Databases searched: EBM Reviews - Cochrane Central Register of Controlled Trials <November 2016>, EBM Reviews - Cochrane Database of Systematic Reviews <2005 to January 18, 2017>, EBM Reviews - Database of Abstracts of Reviews of Effects <1st Quarter 2015>, EBM Reviews - Health Technology Assessment <4th Quarter 2016>, EBM Reviews - NHS Economic Evaluation Database <1st Quarter 2015>, Embase <1980 to 2017 Week 04>, Epub Ahead of Print, In-Process & Other Non-Indexed Citations, Ovid MEDLINE(R) Daily and Ovid MEDLINE(R) <1946 to Present>
Search Strategy:
---
1 Cross Infection/ (76052)
2 (((Health care* or healthcare*) adj2 (acquired or associated) adj2 (infection* or disease* or pathogen*1)) or (cross adj2 (infection* or disease* or pathogen*1)) or HAI or HAIs or HCAI or HCAIs or nosocomial*).ti,ab,kf. (89022)
3 Clostridium difficile/ (19904)
4 Clostridium Infections/ (7301)
5 (clostridium difficile or c difficile or c diff or clostridium infection* or CDI or CDIs).ti,ab,kf. (36219)
6 exp Staphylococcus aureus/ (209504)
7 (staphylococcus aureus or MRSA or MRSAs).ti,ab,kf. (203879)
8 Vancomycin-Resistant Enterococci/ (2991)
9 (vancomycin resistant enterococc* or VRE or VREs).ti,ab,kf. (10746)
10 Surgical Wound Infection/ (50091)
11 ((postoperative wound* or post-operative wound* or surgical site or surgical wound*) adj2 infect*).ti,ab,kf. (24850)
12 exp Drug Resistance, Bacterial/ (217657)
13 (((multidrug or multi-drug or antibiotic* or antimicrobial) adj (resistance or resistant)) or MDRO or MDROs or ARO or AROs).ti,ab,kf. (188059)
14 exp Health Facilities/ (2511063)
15 (((health or healthcare or care or medical) adj2 (facility or facilities or center* or centre* or setting* or institution*1)) or hospital*1 or ((healthcare or health care) adj environment*1) or (room*1 adj2 (patient* or private or semi-private or semiprivate or recovery or isolation)) or ward or wards or ((intensive or critical) adj2 unit*) or ICU or ICUs or acute care).ti,ab,kf. (2972961)
16 or/1-15 (4809600)
17 Ultraviolet Rays/ (160865)
18 (ultraviolet or ultra-violet or uv or uvc or uv-c).ti,ab,kf. (376301)
19 Xenon/ (12327)
20 xenon.ti,ab,kf. (14758)
21 Mercury/ (67272)
22 mercury.ti,ab,kf. (74380)
23 or/17-22 (538311)
24 Infection Control/ (103447)
25 (infection adj (control or prevention)).ti,ab,kf. (46649)
26 Disinfection/ (36683)
27 (cleaning or decontamin* or disinfect* or dis-infect* or terminal or no-touch or non-manual or germicid* or bactericid* or fungicid* or virucid* or bacteriostat*).ti,ab,kf. (1041690)
28 or/24-27 (1169876)
29 23 and 28 (20039)

30 (((ultraviolet or ultra-violet or xenon or mercury or uv or uvc or uv-c) adj3 (irradia* or pulse* or emitting or lamp* or bulb* or system* or device* or robot*1)) or uvgi or px-uv or pxuv).ti,ab,kf. (66817)
31 29 or 30 (82470)
32 16 and 31 (3308)
33 economics/ (255644)
34 economics, medical/ or economics, pharmaceutical/ or exp economics, hospital/ or economics, nursing/ or economics, dental/ (787305)
35 economics.fs. (426360)
36 (econom* or price or prices or pricing or priced or discount* or expenditure* or budget* or pharmacoeconomic* or pharmaco-economic*).tw. (761935)
37 exp "costs and cost analysis"/ (555513)
38 cost*.ti. (255673)
39 cost effective*.tw. (277175)
40 (cost* adj2 (util* or efficacy* or benefit* or minimi* or analy* or saving* or estimate* or allocation or control or sharing or instrument* or technolog*)).ab. (174564)
41 models, economic/ (167650)
42 markov chains/ or monte carlo method/ (72303)
43 (decision adj1 (tree* or analy* or model*)).tw. (37660)
44 (markov or markow or monte carlo).tw. (113089)
45 quality-adjusted life years/ (34238)
46 (QOLY or QOLYs or HRQOL or HRQOLs or QALY or QALYs or QALE or QALEs).tw. (58768)
47 ((adjusted adj (quality or life)) or (willing* adj2 pay) or sensitivity analys*s).tw. (111238)
48 or/33-47 (2463327)
49 32 and 48 (185)
50 49 use ppez,coch,cctr,dare,clhta (67)
51 32 use cleed (0)
52 50 or 51 (67)
53 limit 52 to english language [Limit not valid in CDSR,DARE; records were retained] (65)
54 hospital infection/ (96848)
55 (((Health care* or healthcare*) adj2 (acquired or associated) adj2 (infection* or disease* or pathogen*1)) or (cross adj2 (infection* or disease* or pathogen*1)) or HAI or HAIs or HCAI or HCAIs or nosocomial*).tw,kw. (91671)
56 peptoclostridium difficile/ (2807)
57 Clostridium difficile infection/ (10218)
58 (clostridium difficile or c difficile or c diff or clostridium infection* or CDI or CDIs).tw,kw. (36582)
59 exp Staphylococcus aureus/ (209504)
60 (staphylococcus aureus or MRSA or MRSAs).tw,kw. (205518)
61 vancomycin resistant enterococcus/ (4907)
62 (vancomycin resistant enterococc* or VRE or VREs).tw,kw. (10966)
63 surgical infection/ (35154)
64 ((postoperative wound* or post-operative wound* or surgical site or surgical wound*) adj2 infect*).tw,kw. (25276)
65 antibiotic resistance/ (199129)
66 (((multidrug or multi-drug or antibiotic* or antimicrobial) adj (resistance or resistant)) or MDRO or MDROs or ARO or AROs).tw,kw. (192960)
67 exp health care facility/ (1747030)

68 (((health or healthcare or care or medical) adj2 (facility or facilities or center* or centre* or setting* or institution*1)) or hospital*1 or ((healthcare or health care) adj environment*1) or (room*1 adj2 (patient* or private or semi-private or semiprivate or recovery or isolation)) or ward or wards or ((intensive or critical) adj2 unit*) or ICU or ICUs or acute care).tw,kw. (2988891)
69 or/54-68 (4403661)
70 exp ultraviolet radiation/ (108700)
71 (ultraviolet or ultra-violet or uv or uvc or uv-c).tw,kw,dv. (377912)
72 xenon/ (12327)
73 xenon.tw,kw,dv. (14982)
74 mercury/ (67272)
75 mercury.tw,kw,dv. (74978)
76 or/70-75 (524238)
77 infection control/ (103447)
78 (infection adj (control or prevention)).tw,kw,dv. (48372)
79 disinfection/ (36683)
80 (cleaning or decontamin* or disinfect* or dis-infect* or terminal or no-touch or non-manual or germicid* or bactericid* or fungicid* or virucid* or bacteriostat*).tw,kw,dv. (1047027)
81 or/77-80 (1175442)
82 76 and 81 (19760)
83 disinfection system/ (176)
84 (((ultraviolet or ultra-violet or xenon or mercury or uv or uvc or uv-c) adj3 (irradia* or pulse* or emitting or lamp* or bulb* or system* or device* or robot*1)) or uvgi or px-uv or pxuv).tw,kw,dv. (67194)
85 or/82-84 (82638)
86 69 and 85 (3423)
87 Economics/ (255644)
88 Health Economics/ or exp Pharmacoeconomics/ (223135)
89 Economic Aspect/ or exp Economic Evaluation/ (436063)
90 (econom* or price or prices or pricing or priced or discount* or expenditure* or budget* or pharmacoeconomic* or pharmaco-economic*).tw. (761935)
91 exp "Cost"/ (555513)
92 cost*.ti. (255673)
93 cost effective*.tw. (277175)
94 (cost* adj2 (util* or efficacy* or benefit* or minimi* or analy* or saving* or estimate* or allocation or control or sharing or instrument* or technolog*)).ab. (174564)
95 Monte Carlo Method/ (58378)
96 (decision adj1 (tree* or analy* or model*)).tw. (37660)
97 (markov or markow or monte carlo).tw. (113089)
98 Quality-Adjusted Life Years/ (34238)
99 (QOLY or QOLYs or HRQOL or HRQOLs or QALY or QALYs or QALE or QALEs).tw. (58768)
100 ((adjusted adj (quality or life)) or (willing* adj2 pay) or sensitivity analys*s).tw. (111238)
101 or/87-100 (2038943)
102 86 and 101 (217)
103 limit 102 to english language [Limit not valid in CDSR,DARE; records were retained] (215)
104 103 use emez (126)
105 53 or 104 (191)
106 105 use ppez (62)
107 105 use emez (126)
108 105 use coch (0)

109 105 use cctr (3)
110 105 use dare (0)
111 105 use clhta (0)
112 105 use cleed (0)
113 remove duplicates from 105 (140)

CINAHL EBSCOhost interface

#	Query	Results
S1	(MH "Cross Infection")	20,655
S2	(((Health care* or healthcare*) N2 (acquired or associated) N2 (infection* or disease* or pathogen*1)) or (cross N2 (infection* or disease* or pathogen*)) or HAI or HAIs or HCAI or HCAIs or nosocomial*)	24,470
S3	(MH "Clostridium Difficile")	2,193
S4	(MH "Clostridium Infections")	2,721
S5	(clostridium difficile or c difficile or c diff or clostridium infection* or CDI or CDIs)	4,787
S6	(MH "Staphylococcus Aureus+")	8,102
S7	(staphylococcus aureus or MRSA or MRSAs)	13,287
S8	(MH "Vancomycin Resistant Enterococci")	105
S9	(vancomycin resistant enterococc* or VRE or VREs)	1,165
S10	(MH "Surgical Wound Infection")	7,149
S11	((postoperative wound* or post-operative wound* or surgical site or surgical wound*) N2 infect*)	8,393
S12	(MH "Drug Resistance, Microbial+")	18,909
S13	(((multidrug or multi-drug or antibiotic* or antimicrobial) N1 (resistance or resistant)) or MDRO or MDROs or ARO or AROs)	9,516
S14	(MH "Health Facilities+")	332,183
S15	(((health or healthcare or care or medical) N2 (facility or facilities or center* or centre* or setting* or institution or institutions)) or hospital or hospitals or ((healthcare or health care) N1 environment*) or (room* N2 (patient* or private or semi-private or semiprivate or recovery or isolation)) or ward or wards or ((intensive or critical) N2 unit*) or ICU or ICUs or acute care)	489,066
S16	S1 OR S2 OR S3 OR S4 OR S5 OR S6 OR S7 OR S8 OR S9 OR S10 OR S11 OR S12 OR S13 OR S14 OR S15	635,822
S17	(MH "Ultraviolet Rays")	2,785
S18	(ultraviolet or ultra-violet or uv or uvc or uv-c)	4,990
S19	xenon	537

S20	(MH "Mercury")	1,628
S21	mercury	2,833
S22	S17 OR S18 OR S19 OR S20 OR S21	8,321
S23	(MH "Infection Control")	21,378
S24	(infection N1 (control or prevention))	64,865
S25	(MH "Sterilization and Disinfection")	8,216
S26	(cleaning or decontamin* or disinfect* or dis-infect* or terminal or no-touch or non-manual or germicid* or bactericid* or fungicid* or virucid* or bacteriostat*)	40,438
S27	S23 OR S24 OR S25 OR S26	100,698
S28	S22 AND S27	503
S29	(((ultraviolet or ultra-violet or xenon or mercury or uv or uvc or uv-c) N3 (irradia* or pulse* or emitting or lamp* or bulb* or system* or device or robot or robots)) or uvgi or px-uv or pxuv)	594
S30	S28 OR S29	938
S31	S16 AND S30	317
S32	(MH "Economics")	10,992
S33	(MH "Economic Aspects of Illness")	6,584
S34	(MH "Economic Value of Life")	518
S35	MH "Economics, Dental"	104
S36	MH "Economics, Pharmaceutical"	1,758
S37	MW "ec"	140,415
S38	(econom* or price or prices or pricing or priced or discount* or expenditure* or budget* or pharmacoeconomic* or pharmaco-economic*)	210,019
S39	(MH "Costs and Cost Analysis+")	83,873
S40	TI cost*	39,321
S41	(cost effective*)	26,684
S42	AB (cost* N2 (util* or efficacy* or benefit* or minimi* or analy* or saving* or estimate* or allocation or control or sharing or instrument* or technolog*))	17,564
S43	(decision N1 (tree* or analy* or model*))	4,860
S44	(markov or markow or monte carlo)	3,000
S45	(MH "Quality-Adjusted Life Years")	2,571

S46	(QOLY or QOLYs or HRQOL or HRQOLs or QALY or QALYs or QALE or QALEs)	5,647
S47	((adjusted N1 (quality or life)) or (willing* N2 pay) or sensitivity analys?s)	10,807
S48	S32 OR S33 OR S34 OR S35 OR S36 OR S37 OR S38 OR S39 OR S40 OR S41 OR S42 OR S43 OR S44 OR S45 OR S46 OR S47	279,330
S49	S31 AND S48	22
S50	S31 AND S48 Narrow by Language: - english	22

Grey Literature Search

Performed on:
January 11, 2017-January 13, 2017

Websites searched:
HTA Database Canadian Repository, Alberta Health Technologies Decision Process reviews, Canadian Agency for Drugs and Technologies in Health (CADTH), Institut national d'excellence en santé et en services sociaux (INESSS), Institute of Health Economics (IHE), McGill University Health Centre Health Technology Assessment Unit, National Institute for Health and Care Excellence (NICE), Agency for Healthcare Research and Quality (AHRQ) Evidence-based Practice Centers, Australian Government Medical Services Advisory Committee, Centers for Medicare & Medicaid Services Technology Assessments, Institute for Clinical and Economic Review, Ireland Health Information and Quality Authority Health Technology Assessments, Washington State Health Care Authority Health Technology Reviews, Tufts Cost-Effectiveness Analysis Registry, ClinicalTrials.gov

Keywords used: ultraviolet or ultra violet or uv or uvc or uv-c or uvgi or xenon or mercury or mercure, cleaning or disinfect or disinfecting or disinfection or decontamination or terminal

Results: 5 HTA Reports
5 clinical trials not counted in PRISMA

Appendix 2: Risk of Bias

Table A1: Risk of Bias[a] Among Randomized Controlled Trials for Comparison of UV-C Disinfection as Adjunct to Manual Cleaning and Disinfection Versus Manual Cleaning and Disinfection

Author, Date	Random Sequence Generation (Selection Bias)	Allocation Concealment (Selection Bias)	Blinding of Participants and Personnel (Performance Bias)	Blinding of Outcome assessment (Detection Bias)	Incomplete Outcome Data (Attrition Bias)	Selective Reporting (Reporting Bias)	Free of Other Biases
Anderson et al, 2017[43]	Y	N	N	N	Y	Y	N

Abbreviations: Y, Yes; N, No.
Risk of bias assessed using Cochrane Risk of Bias tool.[32]

Table A2: Risk of Bias[a] Among Uncontrolled Before-After Studies for Comparison of UV-C Disinfection as Adjunct to Manual Cleaning and Disinfection Versus Manual Cleaning and Disinfection

Author, Date	Clearly Stated Objective	Pre-specified Eligibility Criteria	Representative Patients	All Eligible Patients Enrolled	Calculated Adequate Sample Size	Intervention Described and Delivered	Pre-specified, Valid Outcome Measures	Blind Outcome Assessment	Loss to Follow-Up Accounted for	Statistical Methods Appropriate	Multiple Outcome Measurement Times	Appropriate Group-Level Analysis	Free of Other Biases
Napolitano et al, 2015[41]	Y	Y	Y	N	N	Y	Y	N	?	Y	N	Y	N
Catalanotti et al, 2016[38]	N	Y	Y	?	N	Y	Y	N	?	Y	N	Y	N
Green et al, 2017[39]	Y	Y	Y	?	N	Y	Y	N	?	Y	N	Y	N
Haas et al, 2014[35]	Y	N	Y	N	N	Y	Y	N	?	Y	N	Y	N
Nagaraja et al, 2015[36]	Y	N	Y	N	N	Y	Y	N	?	Y	N	Y	N
Miller et al, 2015[40]	Y	N	Y	?	N	N	Y	N	?	Y	N	Y	N
Vianna et al, 2016[42]	Y	Y	Y	?	N	Y	Y	N	?	Y	N	Y	N
Levin et al, 2013[45]	N	N	Y	N	N	Y	Y	N	?	Y	N	Y	N

Abbreviations: Y, Yes; N, No; UV, ultraviolet; ?, unsure or unclear.
[a]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.[33]

Table A3: Risk of Bias Among Interrupted Time Series Studies for Comparison of UV-C Disinfection as Adjunct to Manual Cleaning and Disinfection Versus Manual Cleaning and Disinfection

Author, Date	Intervention Independent of Other Changes	Shape of Intervention Pre-specified	Intervention Unlikely to Affect Data Collection	Knowledge of Allocated Interventions Adequately Prevented	Incomplete Outcome Data Adequately Addressed	Free From Selective Outcome Reporting	Free of Other Biases
Pegues et al, 2017[44]	N	Y	Y	N	N	Y	N

Abbreviations: Y, Yes; N, No; UV, ultraviolet.
Risk of bias assessed using Effective Practice and Organisation of Care (EPOC) criteria for interrupted time-series studies.[31]

Appendix 3: Summary of Study Outcomes and Hospital-Acquired Infection Definitions

Table A4: Outcomes Assessed and Definitions of Hospital-Acquired Infections

Author, Year	HAI Outcomes Assessed	HAI Determination/Definition
Mercury UV Devices		
Anderson et al, 2017[43]	Infection OR colonization with MRSA, VRE, *Clostridium difficile*, or multidrug-resistant *Acinetobacter* Primary Outcomes • Incidence of all target organisms among patients exposed to seed rooms • Incidence of *C. difficile* infection among patients exposed to seed rooms Secondary Outcomes • Incidence of MRSA, VRE, MDR *Acinetobacter* among exposed patients • Incidence in whole hospital of all target organisms • Adverse events	Hospital acquired: isolation of target organism after 48 h of hospital admission Incident cases: in seed room for 24 h or more AND positive clinical culture or test with one of the target organisms AND organism identified in clinical culture or test was the same target organism isolated from preceding patient in seed room AND positive culture or test was obtained during index admission (either during exposure to seed room OR positive culture or test was obtained after exposure to seed room during index admission or readmission within 90 days of discharge from a room) for MRSA, VRE, or MDR *Acinetobacter* or within 28 days of discharge from room for *C. difficile*
Pegues et al, 2017[44]	*C. difficile* infection rate	Cases documented in surveillance program and NHSN databases For patients with positive assays sent > 48 h after admission and from patients readmitted within 14 d of a previous discharge, NHSN criteria for GI event were determined
Napolitano et al, 2015[41]	HAIs stratified by *Acinetobacter baumannii*, *C. difficile*, *Klebsiella pneumoniae*, MRSA, and VRE	Hospital-associated infection: culture within 48 h of admission AND diagnosis at admission different from HAI diagnosis AND colonization or infection contributing to increased length of hospital stay
Pulsed Xenon UV Devices		
Green et al, 2016[39]	• HAI rates Device-associated infections: CLABSI, CAUTI, VAP • MDR organism acquisition Includes both incident colonization and infection	NHSN-defined HAI rates and MDR organism acquisition
Catalanotti et al, 2016[38]	Class I (clean) and Class II (clean-contaminated) surgical site infections	Defined using NHSN's infection surveillance reporting criteria rained infection preventionists tracked patients for signs and symptoms during stay and after discharge
Vianna et al, 2016[42]	*C. difficile* infection rate	Defined using NHSN's infection surveillance reporting criteria
Miller et al, 2015[40]	*C. difficile* infection rate	Defined using NHSN's infection surveillance reporting criteria
Nagaraja et al 2015[66]	*C. difficile* infection rate	*C. difficile* infection: patient with diarrhea and positive stool test results Hospital acquired: diagnosed at least 72 h after admission and infection was not incubating at admission and without previously positive test in prior 8 wk
Haas et al, 2014[35]	MDR organisms: MRSA, VRE, gram-negative bacteria, and *C. difficile* infection rates	MDR definition: MRSA, VRE, gram-negative bacteria from clinical cultures that are susceptible to 2 or fewer classes of antibiotics *C. difficile* infection: defined with positive stool diagnostic test Hospital acquired: no history of organism and onset of symptoms that led to recovery of organism. Organism presents within 3 d after admission and was not incubating at admission nor recovered within 48 h after discharge
Levin et al, 2013[4545]	Hospital-associated *C. difficile* infection rates • Attributable deaths • Attributable colectomies	Followed guidelines published by SHEA

Abbreviations: CLABSI, central line–associated bloodstream infection; CLAUTI, catheter-associated urinary tract infection; GI, gastrointestinal; HAI, hospital-associated infection; MDR, multidrug-resistant; MRSA, methicillin-resistant *Staphylococcus aureus*; NHSN, National Healthcare Safety Network; SHEA, Society for Healthcare Epidemiology of America; VAP, ventilator-associated pneumonia; VRE, vancomycin-resistant *Enterococcus*.

Appendix 4: Modified Methodologic Checklist for Economic Evaluations

Table A5: Study Applicability Appraisal Checklist

Question	Possible Responses
Is the study population similar to the question?	Yes/Partly/No/Unclear
Are the interventions similar to the question?	Yes/Partly/No/Unclear
Is the health care system in which the study was conducted similar to the current Ontario context?	Yes/No/Unclear
Was/were the perspective(s) clearly stated and what were they?	Yes/No/Unclear
Are estimates of treatment effect from the best available source?	Yes/No/Unclear
Are all future costs and outcomes discounted?	Yes/No
Is the value of health effects expressed in terms of quality-adjusted life years?	Yes/No
Are costs and outcomes from other sectors fully and appropriately measured and valued?	Yes/No
Overall judgment	Directly applicable/partially applicable/not applicable

REFERENCES

(1) Ontario Agency for Health Protection and Promotion (Public Health Ontario), Provincial Infectious Diseases Advisory Committee. Best practices for surveillance of health care-associated infections in patient and resident populations. Toronto [ON]: Queen's Printer for Ontario; 2014.

(2) World Health Organization. Prevention of hospital-acquired infections. A practical guide. Geneva, Switzerland: World Health Organization; 2002.

(3) 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 [Internet]. Ottawa [ON]: Public Health Agency of Canada; 2013 [Dec 2016]. Available from: http://www.phac-aspc.gc.ca/cphorsphc-respcacsp/2013/infections-eng.php

(4) Health Quality Ontario. Hospital care sector performance [Internet]. Toronto [ON]: Queen's Printer for Ontario; 2015 [Available from: http://www.hqontario.ca/System-Performance/Hospital-Care-Sector-Performance

(5) Public Health Ontario. Carbapenemase-producing *Enterobacteriaceae* (CPE) surveillance report. [Internet]. Ottawa [ON]: Public Health Ontario; 2016 [cited 2017 March]. Available from: https://www.publichealthontario.ca/en/DataAndAnalytics/Documents/Carbapenemase_Producing_Enterobacteriaceae_(CPE)_Surveillance_Report_October_2016.pdf

(6) 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.

(7) Health Quality Ontario. Measuring up 2016: a yearly report on how Ontario's health system is performing [Internet]. Toronto [ON]: Queen's Printer for Ontario; 2016.

(8) Public Health Agency of Canada. Antimicrobial resistant organisms (ARO) surveillance. Summary report for data from January 1, 2009 to December 31, 2015. Ottawa [ON]: Public Health Agency of Canada; 2015.

(9) 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.

(10) 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):76.

(11) 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.

(12) Infection prevention and control [Internet]. In: Health information [Internet]. Edmonton: Alberta Health; 2012 [cited 2015 Jan 22]. Available from: http://www.health.alberta.ca/health-info/preventinfections.html

(13) 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.

(14) Boyce JM. Environmental contamination makes an important contribution to hospital infection. J Hosp Infect. 2007;65(Suppl 2):50-4.

(15) 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.

(16) Kramer A, Schwebke I, Kampf G. How long do nosocomial pathogens persist on inanimate surfaces? A systematic review. BMC Infect Dis. 2006;6(130):8.

(17) Mitchell BG, Dancer SJ, Anderson M, Dehn E. Risk of organism acquisition from prior room occupants: a systematic review and meta-analysis. J Hosp Infect. 2015;91(3):211-7.
(18) Ontario Agency for Health Protection and Promotion, Provincial Infectious Diseases Advisory Committee. Best practices for environmental cleaning for prevention and control of infections in all health care settings. Toronto [ON]: Queen's Printer for Ontario; 2012.
(19) Ontario Agency For Health Protection and Promotion. Provincial Infectious Diseases Advisory Committee. Best Practices for Infection Prevention and Control Programs in All Health Care Settings, 3rd edition. Toronto, ON: Queen's Printer for Ontario; May 2012.
(20) 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.
(21) Carling CP, Briggs JL, Perkins J, Highlander D. Improved cleaning of patient rooms using a new targeting method. Clin Infect Dis. 2006;42(3):385-8.
(22) Leas BF, Sullivan N, Han JH, Pegues DA, Kaczmarek JL, Umscheid CA. Environmental cleaning for the prevention of healthcare-associated infections. Technical brief No. 22. AHRQ publication No. 15-EHC020-EF. Rockville (MD): Agency for Healthcare Research and Quality; 2015.
(23) Boyce JM. Modern technologies for improving cleaning and disinfection of environmental surfaces in hospitals. Antimicrob Resist Infect Control. 2016;5:10.
(24) Otter JA, Yezli S, Salkeld JA, French GL. Evidence that contaminated surfaces contribute to the transmission of hospital pathogens and an overview of strategies to address contaminated surfaces in hospital settings. Am J Infect Control. 2013;41:S6-11.
(25) 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.
(26) 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.
(27) Xenex Disinfection Services. How UV disinfection works [Internet]. 2016 [cited 2016 3 Aug]. Available from: http://xenex.com/how-uv-disinfection-works
(28) Weber DJ, Rutala WA, Anderson DJ, Chen LF, Sickbert-Bennett EE, Boyce JM. Effectiveness of ultraviolet devices and hydrogen peroxide systems for terminal room decontamination: focus on clinical trials. Am J Infect Control. 2016;44(5 Suppl):e77-84.
(29) Tru-D SmartUVC [Internet]. Memphis (TN): Tru-D SmartUVC; 2017 [cited 2017 Jan]. Available from: http://tru-d.com/why-tru-d/smart-uvc-sensor-360/
(30) McGowan J, Sampson M, Salzwedel D, Cogo E, Foerster V, Lefebvre C. PRESS peer review of electronic search strategies: 2015 guideline statement. J Clin Epidemiol. 2016;75:40-6.
(31) Effective Practice and Organisation of Care. EPOC resources for review authors [Internet]. Oslo: Norwegian Knowledge Centre for the Health Services; 2015 [cited 2016 Dec]. Available from: http://epoc.cochrane.org/resources/epoc-resources-review-authors.
(32) Higgins JPT, Altman DG, Sterne JAC, editors. Chapter 8: Assessing the risk of bias in included studies. In: Higgins JPT, Green S, editors. Cochrane handbook for systematic reviews of interventions, version 5.1.0 [Internet]. London: The Cochrane Collaboration; 2011 [cited Dec 2017]. Available from: http://handbook.cochrane.org/chapter_8/8_assessing_risk_of_bias_in_included_studies.htm.
(33) National Heart, Lung, and Blood Institute. Quality assessment tool for before-after (pre-post) studies with no control group [Internet]. Bethesda (MD): National Institutes of Health; 2014 [Available from: https://www.nhlbi.nih.gov/health-pro/guidelines/in-develop/cardiovascular-risk-reduction/tools/before-after

(34) Schünemann H, Brozek J, Guyatt G, Oxman A, editors. GRADE handbook: handbook for grading the quality of evidence and strength of recommendations using the GRADE approach. Updated March 2013. The GRADE Working Group, 2013. Available from http://gdt.guidelinedevelopment.org/app/handbook/handbook.html.
(35) 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.
(36) Nagaraja A, Visintainer P, Haas JP, Menz J, Wormser GP, Montecalvo MA. *Clostridium difficile* infections before and during use of ultraviolet disinfection. Am J Infect Control. 2015;43(9):940-5.
(37) Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Int J Surg. 2010;8(5):336-41.
(38) Catalanotti A, Abbe D, Simmons S, Stibich M. Influence of pulsed-xenon ultraviolet light-based environmental disinfection on surgical site infections. Am J Infect Control. 2016;44(6):e99-e101.
(39) Green C, Pamplin JC, Chafin KN, Murray CK, Yun HC. Pulsed-xenon ultraviolet light disinfection in a burn unit: Impact on environmental bioburden, multidrug-resistant organism acquisition and healthcare associated infections. Burns. 2017;43(2):388-96.
(40) Miller R, Simmons S, Dale C, Stachowiak J, Stibich M. Utilization and impact of a pulsed-xenon ultraviolet room disinfection system and multidisciplinary care team on *Clostridium difficile* in a long-term acute care facility. Am J Infect Control. 2015;43(12):1350-3.
(41) Napolitano NA, Mahapatra T, Tang W. The effectiveness of UV-C radiation for facility-wide environmental disinfection to reduce health care-acquired infections. Am J Infect Control. 2015;43(12):1342-6.
(42) Vianna PG, Dale CR, Jr., Simmons S, Stibich M, Licitra CM. Impact of pulsed xenon ultraviolet light on hospital-acquired infection rates in a community hospital. Am J Infect Control. 2016;44(3):299-303.
(43) 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.
(44) 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.
(45) Levin J, Riley LS, Parrish C, English D, Ahn S. The effect of portable pulsed xenon ultraviolet light after terminal cleaning on hospital-associated *Clostridium difficile* infection in a community hospital. Am J Infect Control. 2013;41(8):746-8.
(46) 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.
(47) Huang SS, Platt R. Risk of methicillin-resistant *Staphylococcus aureus* infection after previous infection or colonization. Clin Infect Dis. 2003;36(3):281-5.
(48) 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.
(49) Zirakzadeh A, Patel R. Vancomycin-resistant enterococci: colonization, infection, detection, and treatment. Mayo Clin Proc. 2006;81(4):529-36.

(50) Canadian Agency for Drugs and Technologies in Health. Non-manual techniques for room disinfection in healthcare facilities: a review of clinical effectiveness and guidelines. CADTH Rapid Response Reports. Ottawa [ON]: The Agency; 2014.
(51) Loveday HP, Wilson JA, Pratt RJ, Golsorkhi M, Tingle A, Bak A, et al. EPIC3: national evidence-based guidelines for preventing healthcare-associated infections in NHS hospitals in England. J Hosp Infect. 2014;86 Suppl 1:S1-70.
(52) MacCannell T, Umscheid CA, Agarwal RK, Lee I, Kuntz G, Stevenson KB, et al. Guideline for the prevention and control of norovirus gastroenteritis outbreaks in healthcare settings. Infect Control Hosp Epidemiol. 2011;32(10):939-69.
(53) Emond Y, Deans I, O'Neill C, Mertz D. Feasibility of UV-C light disinfection in a Canadian hospital. Can J Infect Dis Med Microbio. 2015;26(2):73-6.
(54) National Institute for Health and Care Excellence. Process and methods guides. The guidelines manual: appendix G: methodology checklist: economic evaluations [Internet]. London (UK): National Institute for Health and Care Excellence; 2013 [updated November 2012. Available from: https://www.nice.org.uk/process/pmg6/resources/the-guidelines-manual-appendices-bi-1967364/chapter/appendix-g-methodology-checklist-economic-evaluations
(55) Fornwalt L, Ennis D, Stibich M. Influence of a total joint infection control bundle on surgical site infection rates. Am J Infect Control. 2016;44(2):239-41.
(56) Haas JP, Menz J, Dusza S, Montecalvo MA. Implementation and impact of ultraviolet environmental disinfection in an acute care setting. American journal of infection control.42(6):586-90.
(57) Emergency Care Research Institute. 2015 top 10 hospital C-suite watch list. Plymouth Meeting [PA]: ECRI Institute; 2015.
(58) Year average of exchange rates [Internet]: Bank of Canada; 2016 [cited 2017 Apr 7]. Available from: http://www.bankofcanada.ca/stats/assets/pdf/nraa-2016-en.pdf
(59) Humber River Hospital. Careers center, Environmental services attendant [Internet]. Toronto [ON]: Humber River Hospital; 2016 [cited 2017 Feb 1]. Available from: https://careersen-hrrh.icims.com/jobs/2919/environmental-services-attendant
(60) What is the cost of labor? [Internet]. AccountingTools; 2016 [cited 2017 Feb 1]. Available from: http://www.accountingtools.com/questions-and-answers/what-is-the-cost-of-labor.html
(61) 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.
(62) Jinadatha C, Quezada R, Huber TW, Williams JB, Zeber JE, Copeland LA. Evaluation of a pulsed-xenon ultraviolet room disinfection device for impact on contamination levels of methicillin-resistant *Staphylococcus aureus*. BMC Infect Dis. 2014;14(1):187.
(63) Barham L. Public and patient involvement at the UK National Institute for Health and Clinical Excellence. Patient. 2011;4(1):1-10.
(64) Messina J, Grainger DL. A pilot study to identify areas for further improvements in patient and public involvement in health technology assessments for medicines. Patient. 2012;5(3):199-211.
(65) OHTAC Public Engagement Subcommittee. Public engagement for health technology assessment at Health Quality Ontario—Final report from the Ontario Health Technology Advisory Committee Public Engagement Subcommittee. Toronto [ON]: Queen's Printer for Ontario; 2015.
(66) Jinadatha C, Villamaria FC, Restrepo MI, Ganachari-Mallappa N, Liao IC, Stock EM, et al. Is the pulsed xenon ultraviolet light no-touch disinfection system effective on methicillin-resistant *Staphylococcus aureus* in the absence of manual cleaning? Am J Infect Control. 2015;43(8):878-81.

About Health Quality Ontario

Health Quality Ontario is the provincial advisor on the quality of health care. We are motivated by a single-minded purpose: **Better health for all Ontarians.**

Who We Are.

We are a scientifically rigorous group with diverse areas of expertise. We strive for complete objectivity, and look at things from a vantage point that allows us to see the forest and the trees. We work in partnership with health care providers and organizations across the system, and engage with patients themselves, to help initiate substantial and sustainable change to the province's complex health system.

What We Do.

We define the meaning of quality as it pertains to health care, and provide strategic advice so all the parts of the system can improve. We also analyze virtually all aspects of Ontario's health care. This includes looking at the overall health of Ontarians, how well different areas of the system are working together, and most importantly, patient experience. We then produce comprehensive, objective reports based on data, facts and the voice of patients, caregivers and those who work each day in the health system. As well, we make recommendations on how to improve care using the best evidence. Finally, we support large scale quality improvements by working with our partners to facilitate ways for health care providers to learn from each other and share innovative approaches.

Why It Matters.

We recognize that, as a system, we have much to be proud of, but also that it often falls short of being the best it can be. Plus certain vulnerable segments of the population are not receiving acceptable levels of attention. Our intent at Health Quality Ontario is to continuously improve the quality of health care in this province regardless of who you are or where you live. We are driven by the desire to make the system better, and by the inarguable fact that better has no limit.

About the Ontario Health Technology Advisory Committee (OHTAC)

About OHTAS

How to Obtain OHTAS Reports

Disclaimer

Health Quality Ontario
130 Bloor Street West, 10th Floor
Toronto, Ontario
M5S 1N5
Tel: 416-323-6868
Toll Free: 1-866-623-6868
Fax: 416-323-9261
Email: EvidenceInfo@hqontario.ca
www.hqontario.ca

ISSN 1915-7398 (online)
ISBN 978-1-4868-1394-0 (PDF)